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**WORLD MARITIME UNIVERSITY**  
Malmö, Sweden

**A STUDY OF TEACHING AUTOMATION FOR  
MARINE ENGINEERS**

By

**MYAT MOE**  
Union of Myanmar

A dissertation submitted to the World Maritime University in partial  
fulfilment of the requirements for the award of the degree of

**MASTER OF SCIENCE**

in

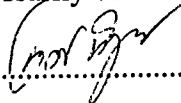
**MARITIME EDUCATION AND TRAINING**  
(Engineering)

1997

## THE DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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## ABSTRACT

This dissertation is a research into a study of teaching automation for marine engineers which is conducted at the Institute of Marine Technology (IMT) of the Union of Myanmar as related to the Fundamentals of Automation, Instrumentation and Control systems, module 9 of IMO model course 7.02 . This course is now included in the mandatory part of STCW Code A of the revised STCW Convention.

An examination is made of the fundamentals of ship automation and a brief overview is given of the modern developments in ship automation system. This includes modern developments in main engine automation , navigation/ bridge control, integrated control ship, condition monitoring systems and programmable controller.

The author has attempted to analyse the present syllabus on Automation, Instrumentation and Control Systems ( AICS ) course conducted at IMT and related subjects conducted in recent education and training schemes for marine engineers in Myanmar. Comparisons of the IMO model course and IMT's AICS course are presented emphasising entry standards, subject outline and detailed teaching syllabus. Then the author proposes ways and means to improve the course to meet the requirements of the IMO model course. The author also suggests the promotion of some related subjects to support the AICS course by using teaching aids and some courses which are recently available in IMT.

The modern developments in ship automation are very rapid and dramatic. In this regard, a brief syllabus for the near future is also proposed to cope with modern developments. A number of recommendations are also made to harmonise with the course to be promoted.

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## List of Abbreviations

AICS	- Automation, Instrumentation and Control System
ARPA	- Automatic Radar Plotting Aids
CAPA	- Computer Aided Performance Analysis
CCS	- Centralised Control Station
CSC	- Computer Supervisory Control
DDC	- Direct Digital Control
GPS	- Global Positioning System
ICC	- Integrated Computer Control
IMO	- International Maritime Organisation
IMT	- Institute of Marine Technology
IP	- Integrated Propulsion
LAN	- Local Area Network
LNC	- Lloyd's Navigation Certificate
LSCU	- Local Scanner and Control Units
MET	- Maritime Education and Training
MIP	- Mean Indicated Pressure
MOT	- Ministry Of Transport
PC	- Personal Computer
STCW	- International Convention on Standards of Training, Certification and Watchkeeping for seafarers
UMS	- Unattended Machinery Space
USA	- United States of America
WMU	World Maritime University

# Chapter 1

## Introduction

### 1.1 General overview of historical developments in ship automation

Significant developments in ship automation began in the early 1960s. The first major milestone in the field of ship automation occurred in 1969. It was Unattended Machinery Space ( UMS ) notation to assign a new ship in which the machinery space had been fitted with suitable automation, alarms and safety systems so that it could be operated periodically unattended.

Lloyd's register produced classification rules to identify UMS notation by specifying the basic requirements for the safe operation of an UMS. These requirements called for the fitting of :

- A bridge control system for propulsion
- A machinery alarm system to engineer's accommodation
- A fire detection system
- A bilge level detection system
- A machinery control station
- An emergency lighting system
- Local control of machinery.

Since that time, these basic requirements have been developed and expanded. Today, there are in order of 150 rules and 250 specific alarms and safety systems for the same operational mode.

During the 1970's , two other class notations had to be added to UMS. The first was Centralised Control Station ( CCS ) which defined requirements for operating the machinery space from the centralised control station from where all control, monitoring and corrective actions can be carried out to enable continuous supervision to be as effective as conventional watchkeeping.

The second development in the 1970s was the introduction of the IP notation which provides standards for an Integrated Propulsion system. IP systems are a combination of machinery automation and machinery configuration to give a very reliable and redundant propulsion system. The concept is redundancy by association which gets round the more expensive method of providing redundancy by duplication to give the equivalent control system and machinery availability.

By 1985, the installation of computer based systems on board ships had become very widespread. Originally, the computers were installed in the traditional , highly compartmental approach with the computers for machinery control in the machinery space, those for navigation on the bridge and those for cargo handling in the cargo control room. But now, it is possible to arrange for all computers to communicate with each other via a Local Area Network ( LAN ) to form an Integrated Computer Control system. This had led to the introduction of the new class notation ICC which became effective in July 1990 in Lloyd's Register.

Tremendous changes have also been developed in the field of navigation. With the satellite navigation systems, collision avoidance systems and computer control now being installed, it is possible to sail a ship from one port to another with the minimal manual intervention. In 1989, Lloyd's Register introduced the LNC ( AA ) class notation for Lloyd's Navigation Certificate for periodical one-man bridge operations. Artificial Intelligence will be introduced in ship automation in the future.

## 1.2 Nature of crew manning in the modern world

Reducing crew sizes was prompted just after the Second World War because of the significant shortage of trained and qualified personnel and many reductions were possible due to technical development. The introduction of advance ship automation has an important impact on the size of ship's crew. A crew size of 18 men is quiet normal nowadays and a further reduction to 12 in the near future is not so much a matter of technical possibility.

Moreover, crewing cannot be considered just as a national issue nowadays. Because of the growth of open registers, second registers and special national and union agreements, ship managers can now, to a large extent, hire multinational crews in the international markets. Because of these matters, shipping became the most international industry in the world. In 1990, there were 403,000 merchant marine officers in the world and 838,000 ratings, giving a total of 1,241,000 seafarers world-wide. The percentage of the world's total supply of seafarers by the different countries is shown in Table 1.1- Percentage of supply of seafarers in 1990

**Table 1.1- Percentage of supply of seafarers in 1990**

Country	Percentage of seafarers supplied
UK	1.5
Philippines	15.0
South Korea	3.7
China	8.5
Greece	3.0
Africa	3.0
North America	4.0
South America	7.0

Source: Sea Transport( 1995 )

Although the amount of Myanmar seafarers is still not big enough to express in the above table, the Sea (September/October, 1996) expressed the following regarding r seafarers from Myanmar:

“The number of Myanmar crews employed in international shipping has risen significantly over the last year, according to a report in the shipping newspaper, Lloyd’s List. They are becoming increasingly popular...This is because they are gaining a reputation for good English language skills and a relatively high standard of training.”

### **1.3 The maritime education and training ( MET ) system in Myanmar**

During the period under British colonial administration, all Myanmar seagoing personnel had to obtain their maritime education and training abroad, mostly in the United Kingdoms and India. After the independence in 1948, with the acquisition of national flag vessels in the fifties, some seafarers obtained their training on them although examinations still had to be taken elsewhere as there were no local examination facilities. During the period of 1968 to 1974, Myanmar introduced her own certificate of competency examination rules and today the department of marine administration under the Ministry of Transport conducts regular certificate of competency examinations.

The existing Myanmar MET system is a sandwich system, commencing with pre-sea training, followed by post-sea training, after requisite sea-service at the prescribed appropriate levels and prior to the examination for each grade of certificate.

The number of Myanmar seafarers who are serving in national shipping as well as in international shipping has increased in recent years. This can be seen in the table 1.2 .

**Table 1.2 The statistic of Myanmar marine engineers**

Ranks	1988	1996 ( estimated )
1. Chief Engineer	70	120
2. Second Engineer	100	130
3. Third Engineer	220	316
4. Fourth Engineer	180	270
5. Fifth Engineer	116	205
6. Junior Engineer	828	1215
7. Engine Cadet	171	286
8. Electrical Officer	405	520
<b>Total</b>	<b>2090</b>	<b>3062</b>

Source: Seamen Employment Control Division ( Myanmar )

#### **1.4 The Institute of Marine Technology ( I M T )**

Under the auspices of the Ministry of Transport , the IMT was established on 1 October 1971. It is the one and only maritime institute in Myanmar. It educates and trains its students to become certificated officers of appropriate international standards in accordance with the STCW Convention. Concerning the various aspects of training, there are two main departments, namely the Nautical Department and the Engineering department in the faculty of IMT.

Courses for Certificate of Competency conducted by the Nautical department are

- |                                     |          |
|-------------------------------------|----------|
| ( a ) Master ( Foreign-going )      | 6 months |
| ( b ) First Mate ( Foreign-going )  | 6 months |
| ( c ) Second Mate ( Foreign-going ) | 6 months |
| ( d ) Third Mate ( Foreign-going )  | 2 months |
| ( e ) Master ( Home-Trade )         | 6 months |



( f ) First Mate ( Home- Trade ) 6 months

Courses for Certificate of Competence conducted by the Engineering department are

- (a) Refresher course for MOT First class engineer ( Foreign-going ) 6 months
- (b) Refresher course for MOT Second class engineer (Foreign-going) 6 months
- (c) Third engineer ( Foreign-going ) 1 months
- (d) Marine Diesel Training Course ( only for government services ) 1 year

With regards to the IMO model courses ( short courses ), the IMT has special courses as well as tutorial courses. Those are

- ( a ) Automation, Instrumentation and Control system course 1 week
- ( b ) Computer introductory course 5 weeks
- ( c ) Radar Simulator Course 1 week
- ( d ) Radar Observer Course 2 weeks
- ( e ) Automatic Radar Plotting Aids 1 week
- ( f ) Electronic Navigation Aids 3 weeks
- ( e ) Survival at sea course 2 weeks
- ( f ) Ship's Captain Medical Course 1 month
- ( g ) Tanker Familiarisation Course 1 week
- ( h ) Advanced Training Programme on Oil Tanker Operation 2 weeks
- ( I ) Advanced Training Programme on Chemical Tanker Operation 2 weeks
- ( j ) Maritime English Course 1 week
- ( k ) Computer Introductory Course 5 weeks

Other main courses conducted by the Institute are

- ( a ) Mercantile Marine Cadet Courses ( Nautical & Engineering ) 1 year
- ( b ) Seagoing Basic Seaman ( Deck ) Course 3 months
- ( c ) Inland Rating ( Deck ) Course 3 months

The IMT often needs modern teaching aids, adequate training equipment and qualified lecturers for some of the courses. For such cases, the IMT has to seek these requirements through other ministries, such as the Ministry of Education, the Ministry of Health and the Ministry of Agriculture.

### **1.5 STCW 95**

To omit the weaknesses of STCW78, it was revised in 1995. One of the most important aspects of the revised Convention is that it introduces significant measures designed to ensure that the new standards of competence and other requirements contained in the revised Convention, will be uniformly implemented on a global basis when they enter into force.

One of the major features of the revision is the adoption of a new STCW Code annexed to the Convention, to which many technical regulations have been transferred. Part A of the Code is mandatory and the minimum standards of competence required for seagoing personnel are given in detail in a series of tables. Part B of the Code contains recommended guidance which is intended to help Parties to implement the Convention.

The minimum standards of competence required for chief engineer officers and second engineer officers related to the fundamentals of automation, instrumentation and control system course, which is Module 9 of IMO Model Course 7.02- Chief and Second engineer officer ( Motorship ) is expressed in Table A III / 2 of STCW Code A.

## **Chapter- 2**

### **The Fundamentals of Ship Automation**

#### **2.1 Ship automation**

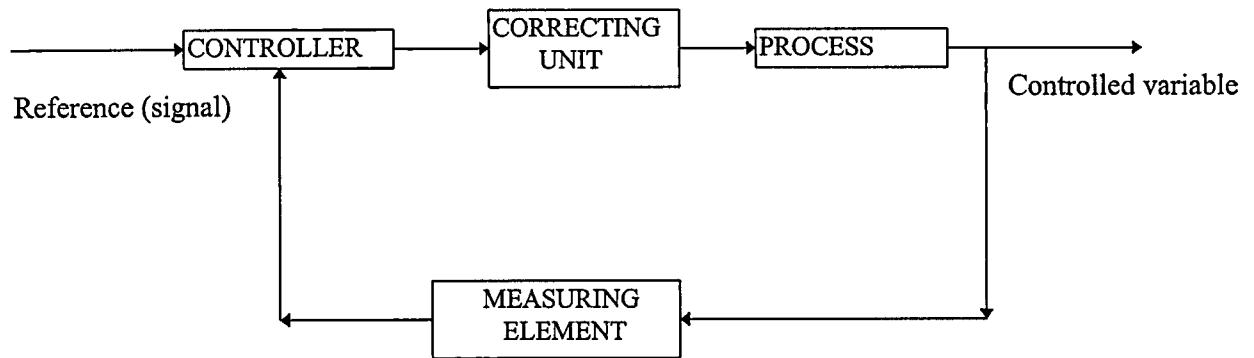
Ship automation can not be discussed separately from other kinds of automation such as in industrial and aeroplane automation etc.. Of course, automated ship control automation is not as highly accurate and complicated as in space-ship control. But some modern developments such as the Condition Monitoring System in ship automation and Integrated Bridge Control Systems prove that almost all the fundamentals of ship automation are generally the same as those of other kinds of automation.

#### **2.2 Elements of an automatic control system**

Inherently, all automatic control systems are closed-loop control systems.

An Automatic Control System can be described as shown in Fig.( 2.1 ) having four major elements, measuring element, controller, correcting unit and process.

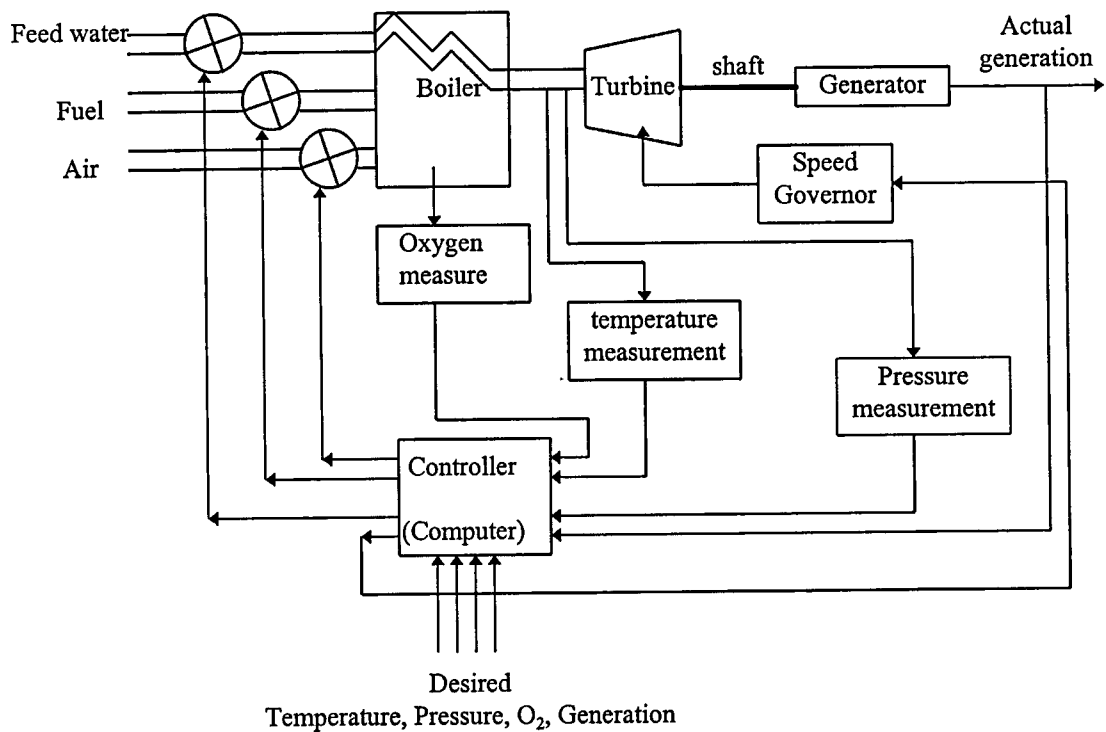
The control actions of an automatic closed-loop control system are dependent upon its output. All elements can connect one after another only by means of transferring signals which represent the controlled variables.



**Figure 2.1 Elements of an Automatic Control System**  
 Adapted from: *Instrumentation and Control Systems* ( L.Jackson, 1979, page 131 )

A measuring element will get a represented signal of output of the system. Then the signal is transmitted to the comparing element of the controller, and compared with some set or desired value (signal) of the controlled condition which is already supplied to the comparator. If there is no difference between these two values, everything will remain unchanged. Otherwise, the difference between two values (deviation) will result in an output signal being sent to the controlling element of the controller and the controller will compute based on that deviation and provide a signal to the correcting unit. According to that signal, the correcting unit will then control the process properly to reach the desired value of the system by eliminating the occurring deviation.

Although it can not be expressed here for clarity, there are two types of disturbances which can occur in the control system. One occurs within the system and other occurs outside the system. Furthermore, as the systems become complex, the interrelationship of many controlled variables must be controlled in the control system and hence multi-loop closed-loop systems are introduced as shown in figure ( 2.2 ) instead of single loop control systems.



**Figure 2.2 Co-ordinated Control System for a Boiler-generator**

Source: R.C. Dorf ( 1980, page 10 )

### 2.2.1 Measuring elements

The first requirement for the various parameters in a control system is accurate measurement to get the information which is the basic requirement of all control. The actual measuring instruments can be divided into two groups; the indicating instrument which displays the measured value visually only and the recording instrument which gives some forms of permanent record of measurement taken over a period of time.

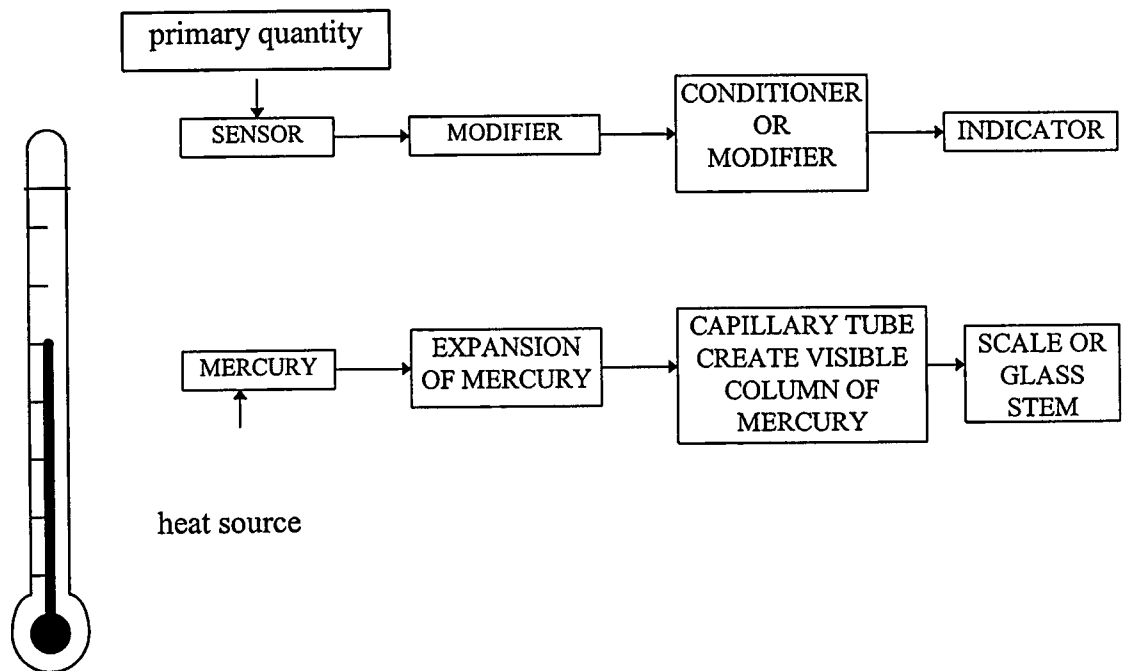
All functions of the automatic control system are performed sequentially based upon the measurement. There is no way to control a condition with a control system without getting the correct measurement. So it can be said that the measurement is

the most important part in an automatic control system. But, there are many problems with measuring which are as follows.

All measuring systems are made up of three basic functional elements- a transducer, a signal modifier or conditioner, and an indicator or recorder. The functions of the transducer are to detect and measure a particular variable(measurand) and then to convert the signal received into the useable signals which are usually either mechanical or electrical. Most of the transducer are made up of a sensing element and some form of conversion element. Consider as an example, a liquid which senses a temperature change by expanding itself and converting the temperature into a height of the liquid column. The sensor in a transducer usually extracts some energy from the measured medium and thus changes it in some way. Such an effect is called a modifying or a loading effect and because of this effect, it is virtually impossible to make a perfect measurement. So careful design and installation of the transducer are necessary to reduce this effect to a practically useful limit for a particular job.

The function of the signal modifier or conditioner are to convert the transduced signal into a form suitable for transmission or to enable suitable recording or monitoring. This element cannot be identified in some measuring systems or might be considered a part of the transducer. Several modifications of the signal at different stages in the transmission, recording or monitoring are required in some measuring systems. The modifying of the signal, as well as changing its physical form, may result in a numerical manipulation, e.g. it may be magnified by some ratio(amplified).

The function of the indicator or the recorder is to provide a visual display of the measured variable. A temperature measuring system shown in Fig ( 2.3 ) is an example of a physical element.



**Figure 2.3 Temperature Measuring System**

Source: D.A Taylor ( 1987, page 16 )

Just as in other three elements ( controller, correcting unit and process ) of a control system, the relationship between the input and the output of the measuring system (the system's performance ) can be described partially statically ( time-independent ) and partially dynamically ( time-dependent ). Where the measured quantity is fairly constant, or varies only slowly, the measuring system can be adequately described by the use of static characteristics. Where measurement of a rapidly changing quantity is required then the dynamic characteristics of the system are important.

### Static Characteristics

The various static characteristics of a measuring system can be achieved by the static calibration process. In the static calibration process, a number of different values of the main input to the system are set while all other possible inputs are held constant. For example, if the pressure measurement of a gas is the main input, then temperature, mass, and any other variables need to be kept constant or can be

assumed to be a negligible amount. A number of different steady values of pressure ( input ) will then be applied to the measuring system and the output values for each input value will be recorded.

A graph can be drawn to show the relationship between inputs and outputs of the system by using the practical data from the static calibration process. If the graph is a straight line, the slope or gradient of the line is the static sensitivity, otherwise, the sensitivity will vary with the input value. Where several elements in a measuring system have static sensitivities and are connected in series, then the static sensitivity of the whole system is the product of the sensitivity of each element.

No measuring system is perfect and therefore no measurement is exactly correct. And hence, accuracy is just an indication of the nearness with which the true value is measured. The term precision while associated with accuracy, does not mean the same thing. Where, for the same input, applied on a number of occasions, an instrument provides readings which are very close in value, it is said to have high precision. But, if a zero error offset existed, i.e. for a zero of measured value the instrument gives a reading either above or below zero, then the instrument could not be said to be accurate, although of high precision.

Errors can occur due to incorrect observation, the incorrect position or graduation of a scale, an indication which is found to be incorrect following calibration, or a zero offset error. If a measuring system is composed of several devices, each device will introduce the own errors. So it is impossible to maximise or minimise all errors together and the errors of the whole system cannot be determined precisely.

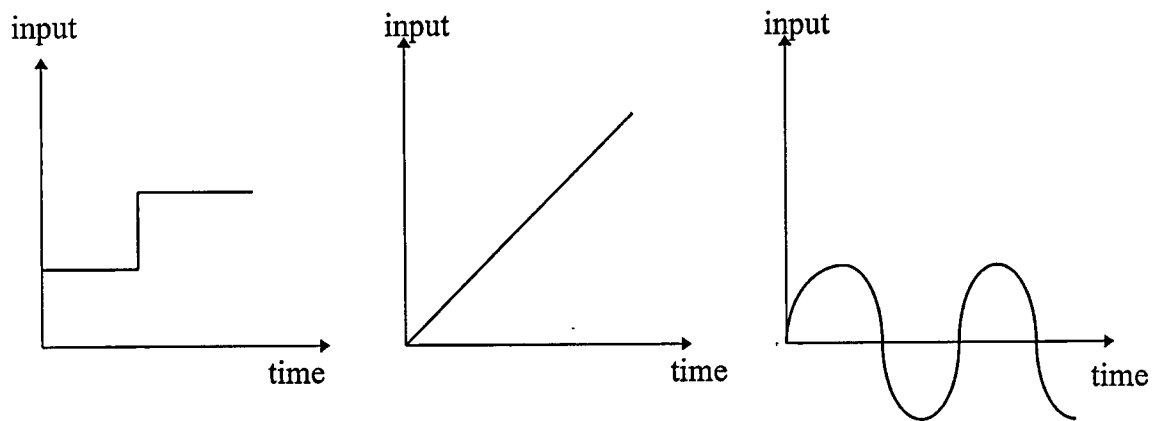
If an instrument's output readings were noted for an increase from zero to the maximum value and then back down to zero then they may appear as different values. If the instrument could read either side of zero and the exercise were continued in a negative sense back to the maximum value then the remainder of the



could be got by drawing a graph. The difference in reading for an input as a result of the direction of approach is known as hysteresis.

### Dynamic Characteristics

If a measuring system is slow to respond or not able to respond in time to input signal changes, the measurement obtained may be inaccurate or perhaps useless. The dynamic characteristics of the system can be determined by first obtaining the mathematical models. The relationships between the variable quantities in a system can be expressed as a mathematical equation which will form the mathematical model of the system. These mathematical models are usually derived from the application of the laws of physics, e.g. Newton's law and are normally ordinary linear differential equations with constant coefficients. Although many systems are different in nature, they will have mathematical equations of the same form or order. The mathematical model is then subjected to certain test inputs and the responses obtained are the dynamic characteristics. Usually three typical test inputs; the step, ramp and sine wave shown in the Figure 2.4 are used to represent the changes of the nature.

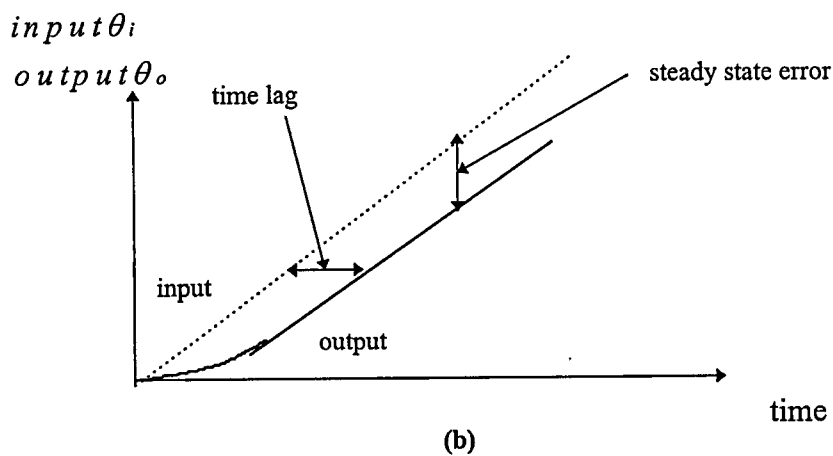
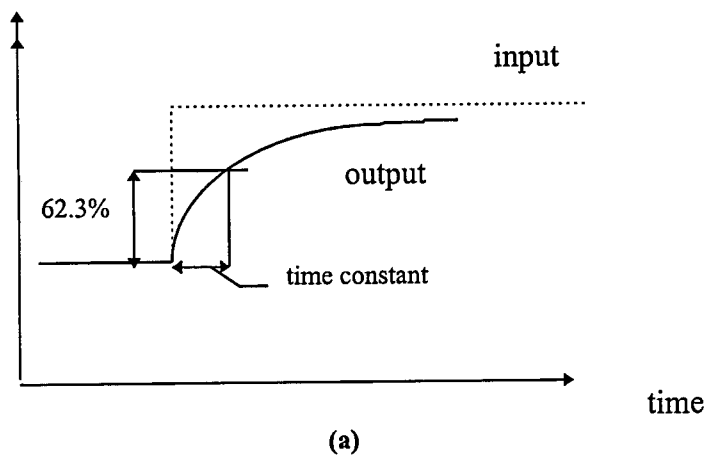


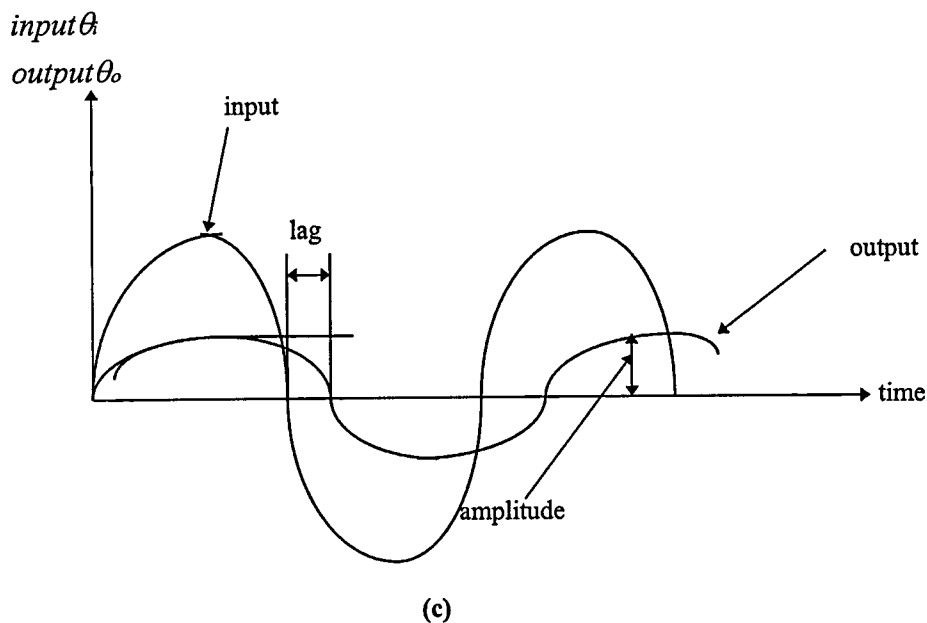
( a ) ( b ) ( c )  
**Figure 2.4 Dynamic Test Inputs ( a ) step ( b ) ramp ( c ) sine wave**

Source: D. A Taylor ( 1987, page 21 )

The step input is, in effect, a sudden or abrupt change of the input signal from one steady value to another. It is used to test the response of a system to sudden change. The result is a transient and then a steady-state response of the system. The ramp input varies linearly with time and results in a response which shows the steady-state error following the input.

*input*  $\theta_i$ ,  
*output*  $\theta_o$





**Figure 2.5 First Order System Response (a) step (b) ramp (c) frequency**

Source: D. A Taylor ( 1987, page 23 )

The sine wave input shows how the system will respond to inputs of cyclic nature as the frequency is varied. The frequency response of the system is the result. Frequency responses have considerable practical applications in the analysis and design of control systems.

Although many systems are different in their physical nature, they have identical forms of response since the dynamics of the systems are similar. If the nature of the responses of the systems are different can then the relationships between the input and output of the systems are in a different order of differential equation. It is usual to make reference to the order of the system, using numbers from zero upwards.

In a zero-order measuring system, the output is directly proportional to the input under all conditions, i.e.

$$\theta_o = K \theta_i$$

where K is the static sensitivity;

$\theta_o$  is the output variable and

$\theta_i$  is the input variable.

So the output exactly follows the input without distortion or delay. An example of zero-order measuring system is the potentiometer, which provides an output voltage proportional to the displacement of the sliding contact, if it is moving slowly.

In a first-order measuring system, the input and the output are related as follows;

$$a \frac{d \theta_o}{d t} + b \theta_o = c \theta_i$$

where a, b, c are constants.

Expressed in more usual and standard form;

$$\tau \frac{d \theta_o}{d t} + \theta_o = k \theta_i$$

where  $\tau = a/b =$  time constant in second

$c/b =$  constant

The first-order system response to a step input is exponential as shown in the figure (2.5 a). The dynamic error is the difference between the ideal response and the actual response and this can be seen to decrease with time. One specification factor found in

step input is the time constant; this is the time taken to reach 62.3% of the final value. This is a time, in seconds, independent of the size of the step input change.

The first-order system response to a ramp input is a line parallel to the input after a period of time as shown in the figure ( 2.5.b ). The steady-state error can be seen as a constant. The time lag is the time interval between equal values of input and output.

The first-order system response to a sine-wave input is the frequency which can be shown by figure ( 2.5.c ). The output lags behind the input and is reduced in amplitude. Frequency is the independent variable to time. The liquid-in-glass thermometer is an example of a first-order measuring system. The heat transfer through the sensing bulb to the liquid can be described by a first-order differential equation.

There are other higher order systems which have differential equations containing higher order derivatives.

### **2.2.2 The controller**

The controller is a main element of the control system which evaluates the deviation, i.e. the difference between the measured value and the desired value of the controlled condition ( usually the set value) and determines the output control signal, i.e. the setting of the correcting element (actuator ) at any given time. The evaluation may be performed by electronic signal processing, or by pneumatic signal processing , or by a computer.

Computer use has been growing rapidly in the field of process control because it is easily adapted to the decision making operating required in process control and because of its inherent capacity to handle control of multi-variable systems.

The controller requires an input of both a measured representation of the dynamic variables and a representation of the desired value of the variable, expressed in the

same terms as the measured value. The desired value of the dynamic variable is referred to as the set point.

Thus, the evaluation consists of (a) a comparison of the controlled variable measurement and the set point and (b) a determination of action required to bring the controlled variable to the set point value. Generally, there are two elements in every controller, the comparing element and the amplifying element. The comparing element is the essential element in every controller which produces an output signal representing the difference between the measured value of the controlled condition and the command signal. This difference is usually termed "the deviation" or "error signal"

Depending on the action of the controller, there may be a signal processing element to modify the deviation signal in order to enhance the accuracy or the speed of the response of the control system. Signal processing and the output signal to the final controlling element (correcting element) usually require more power than is available from the input and measuring device. So an "amplifying element" is necessary to boost the power. The power source is usually external but in some cases power is drawn from the process which is being controlled.

The elements of a controller are not necessarily distinct pieces of hardware. The different functions may be combined together in one amplifier circuit. In a digital controller, ( where the signals are processed as binary numbers ) the comparing and signal processing elements would be activities controlled by sections of hardware. Depending on the nature of changes in controller output when controlled variable error occurs, there may be either discontinuous control or continuous control.

Two step or on-off control is a discontinuous control, in which the controller has only two extreme positions, usually on or off. This control is suitable only for the

processes where a considerable deviation from the desired value is permissible because the controlled condition oscillates from the desired value continuously.

To eliminate such oscillation and to maintain the controlled condition very close to or at the desired value, continuous control is introduced. In continuous control, the output of the controller changes smoothly in response to the error or rate of change of error and the infinite number of positions between maximum and minimum limits of the controller. Depending on the relationship between the output signal and the input converted deviation signal of a controller there are three controller action in continuous control.

#### **In proportional control action ( P action );**

$$V = -K_1 \theta$$

where

V= output signal

$\theta$ = input converted deviation signal

$k_1$ = a constant called proportional action factor

With proportional alone the final value of the controlled condition will always have an offset ( difference ) from its desired value because this error signal is required to give the change in controller output necessary to accommodate the change in load applied. Usually the set value ( set point ) which represents the value of the controlled condition to which the comparing element is set and the desired value are the same. But to allow for offset, the set value may be adjusted to a value which is different from the desired value. The offset may be reduced by increasing the gain of the controller but too high a value of gain can lead to instability.

**In Integral control action( I action );**

$$V = -k_2 \int \theta dt$$

where

$k_2$  integral action factor

The addition of integral action to proportional action will eliminate any offset because the existence of even a small error signal would integrate up in time to produce a large correction.

**In derivative control action ( D action ) ;**

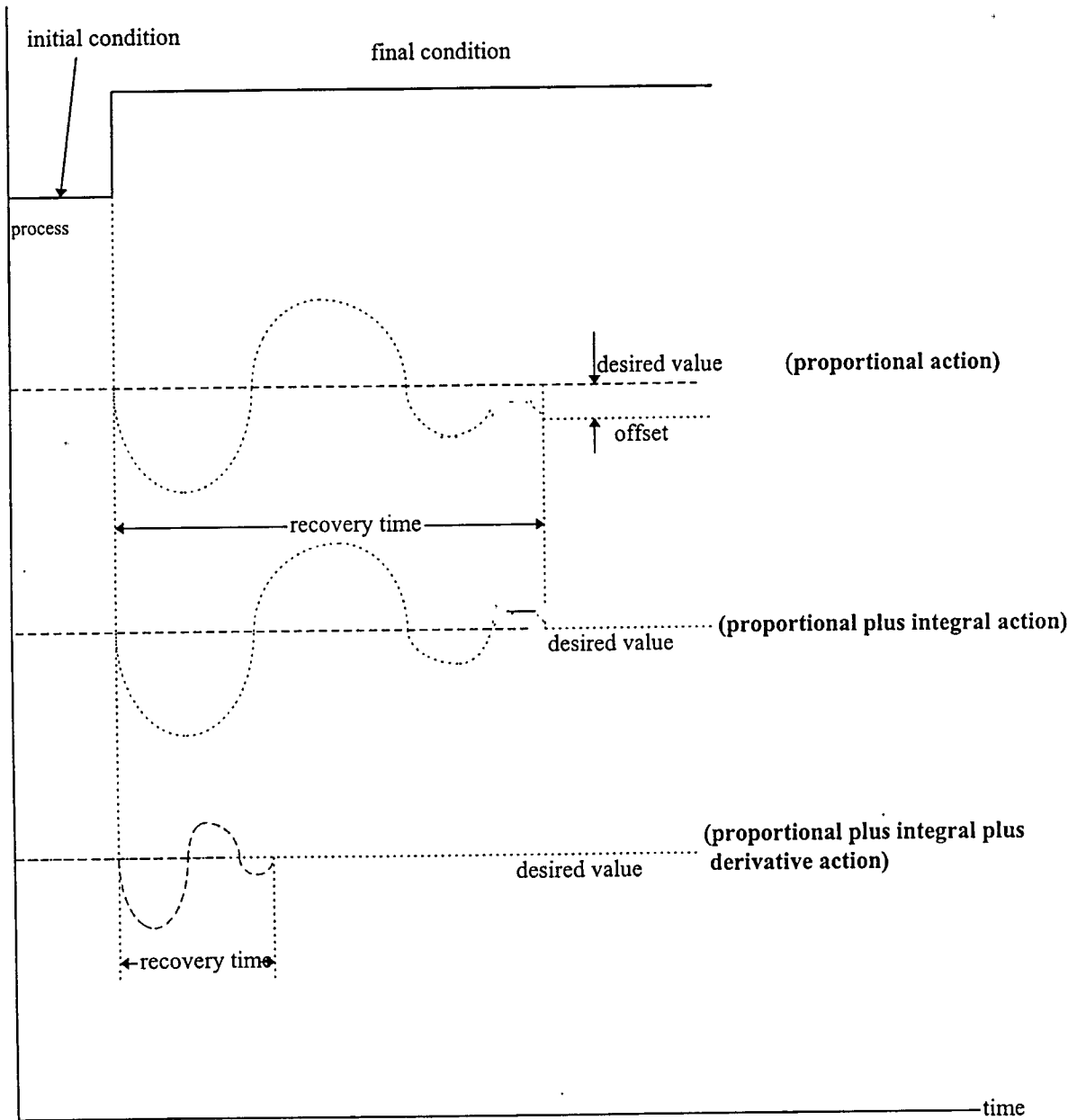
$$V = -k_3 \frac{d\theta}{dt}$$

where

$k_3$ = derivative action factor

The further addition of derivative action to proportional + integral control has the effect of reducing the time taken for the controlled condition to settle at the set point. Although the response of the controlled condition can vary greatly due to factors such as thermal or mechanical inertia, the likely forms of the systems' response of each of P action, P+I action and P+I+D action to a step change of load on the system are shown in Figure( 2.6 ).





**Figure 2.6 Controller Action Response**

Source: J. Cowley (1992, page 239)

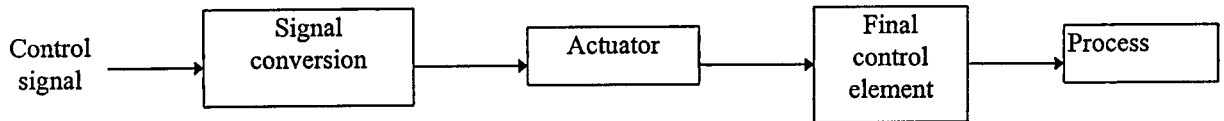
### 2.2.3 The Correcting unit

Correcting unit is in fact the final controlling unit in a closed-loop control system. It is composed of three sub-components which are

- ( 1 ) signal conversion
- ( 2 ) actuator and
- ( 3 ) control element.

Normally the measurement and evaluation of some controlled variable are carried out by a low-energy analogue or digital representation of the variable. The control signal that carries feedback information back to the process for necessary corrective action is expressed also by the same low level of representation. But the controlled process itself may involve a high-energy condition, such as several hundred thousand Newton hydraulic forces.

The function of the correcting unit is to translate low-energy control signal into a level of action proportional to the process under control. This can be considered an amplification of the control signal but in many cases, the signal is also converted into an entirely different form. So it can be said that the operation of the correcting unit involve the steps necessary to convert the control signal (generated by the controller ) into proportional action on the process itself. For example, if a typical 4 - 20 mA control signal is used to vary a large flow rate, from  $10.0 \text{ m}^3 / \text{min}$  to  $50.0 \text{ m}^3 / \text{min}$  , some intermediate operations are required certainly. The specific intermediate operations vary considerably depending on the process control design, but certain generations can be made regarding the steps leading from control signal to the final control element itself. For a typical process control application , the conversion of a process controller signal to a control function can be expressed by the steps shown in fig.(2.7 ). Here, the input control signal may take many forms, including an electrical current, digital signal or pneumatic pressure.



**Figure 2.7 Elements of the Final Control Operation**

Source: C.D Johnson ( 1977, page 246 )

### 2.2.3.1 Signal conversions

This refers to modifications that must be made to the control signal to properly interface with the next stage of control, that is, the actuator. Thus, if a valve control element is to be operated by an electric motor actuator, than a 4 to 20 mA d.c. control signal must be modified to operate the motor. The devices that perform such signal conversion are often called transducer because they convert control signals from one form to another, such as current to pressure, current to voltage, and so on.

So it can be said that the principal objective of signal conversion is to convert the low-energy control signal to a high energy signal to drive the actuator. Controller output signals are typically in one of three forms:

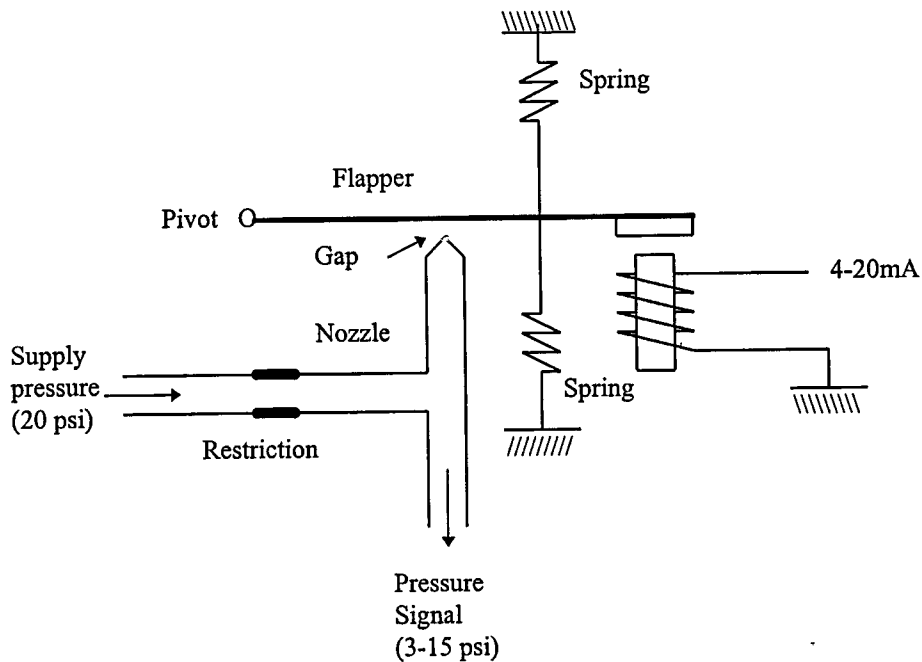
- ( 1 ) electrical current, usually 4 to 20 mA
- ( 2 ) pneumatic pressure, usually 3 to 15 psi, and
- ( 3 ) digital signals, usually TTL ( transistor-transistor-logic ) level

voltages in serial or parallel format.

There are many different schemes for conversion of these signals to other forms depending on the desired final form and on evolving technology for producing such conversions.

As an example, principles to pressure converter is expressed here.

The current to pressure converter, or simply named I / P converter, is a very important element in process control. Often, when we want to use the low-level electric current signal to do work, it is much easier to let the work be done by a pneumatic signal. The I / P converter gives us a linear way of translating the 4 to 20 mA current into a 3 to 15 psi signal. There are many designs for these converters but the basic principle almost always involves the use of a nozzle / flapper system.



**Fig. 2.8 Principles of a Current to Pressure Converter**

Adapted from: *Process and control Instrumentation Technology* ( 1977, page 254 )

Fig.2.8 illustrates a simple way to construct such a converter. Notice that the current through a coil produces a force which will tend to pull the flapper down and close off the gap. This means that a high current produces a high pressure so that the device is

direct acting. Adjustment of springs and perhaps the position relative to the pivot to which they are attached allows the unit to be calibrated so that 4 mA corresponds to 3 psi and 20 mA corresponds to 15 psi.

### **2.2.3.2 Actuators**

The results of signal conversions provides an amplified and / or converted signal which is designed to operate ( actuate ) a mechanism to change a controlling variable in the process. The direct effect is usually implemented by something in the process such as a valve or heater which must be operated by some devices. The actuator is a translation of the converted control signal into action on the control element.

So, if a valve is used to control fluid flow, some mechanism which must physically open or close, the valve is the actuator and if a heater is used to warm a system, some device which must turn the heater ON or OFF or vary its excitation is the actuator.

According to the operating medium used, there are three actuators which are ;

- ( a ) electrical actuators
- ( b ) hydraulic actuator and
- ( c ) pneumatic actuator.

Selection of an actuator depends on the type of the control element to be operated and the motion required. An actuator must be able to generate a sufficient force to overcome the reaction forces created by the control element and provide an appropriate stroke. Moreover, it must be compatible with the operating signal source, act with a suitable speed of response and in the event of supply failure, it must leave the control element in the most desirable condition.

Some common types of electrical actuator are solenoid and electrical motors. A solenoid is an elementary device which converts an electrical signal into a mechanical motion, usually rectilinear motion. Solenoids are used when a large sudden force must be applied to perform a job.

Electrical motors are devices which accept electrical input and produce a continuous rotation as a result. Types and sizes of motors can vary as demands for rotational speed, starting torque, rotational torque and other specification vary. There are many types of electric motors, each with its special set of characteristics. Three most common varieties are the D.C motor, the A.C motor and the stepping motor. The stepping motor has increased in importance in recent years in control systems because of the ease with which this rotating machine can be interfaced with digital circuit. The pneumatic actuator is most useful for translating a control signal into a large force or torque as required to operate some control element. There are many types of pneumatic actuators but the most common are those associated with control valves. The hydraulic actuator may be employed in some cases where forces required are too large to use pneumatic actuators in practice. The basic idea is the same as for pneumatic actuator but an incompressible fluid is used to provide the very high pressure.

#### **2.2.3.3 Control element**

This is the element which performs required actions on the process and is a part of the process itself. Depending on the different control problems, there are several types of control element. Generally, there are three types of control element which are;

- ( a ) mechanical control element
- ( b ) electrical control element and
- ( c ) fluid valves.

#### **2.2.4 Process**

Process is the act of physically or chemically changing ( including combining ) alter or converting energy. The Merriam-Webster Dictionary defines more precisely a process to be a natural, progressively continuing operation or development marked by a series of gradual changes that succeed one another in a relatively fixed way and

lead toward a particular result or end; or an artificial voluntary, progressively continuing operation that consists of a series of controlled actions or movements systematically directed toward a particular result or end.

Ogata defines clearly a process any operation to be controlled.

Although process is controlled by other successive components, it determines the other components in designing the control system.

### **2.3 Classification of control systems**

Automatic control systems can be classified in many different ways from different perspectives. Every system may have some relation to another one or two or various systems.

#### **2.3.1 Classification by feedback**

Feedback is the transmission of a signal representing the controlled condition for comparison with a signal pre-set by the operator and which is intended to determine the value of the controlled condition. A system which controls a variable conditions without applying feedback is classified as an open-loop control system.

In an open-loop control system, a process is controlled by inputting to the controller the conditions believed necessary to achieve the desired result and accepting whatever output results. Generally, the advantages of an open-loop control system are; relative simplicity, resulting in cost, reliability and maintainability advantages and inherent stability. Disadvantages are; relative slowness in response to demanded changes and inaccuracy, due to lack of corrective action for errors.

A system which controls a variable conditions by using feedback is classified as closed-loop control system. In a closed-loop control system, actual output of the process is measured and compared to the desired output. And then, adjustments are

made by the control system until the difference between the desired and actual output is as small as required. Generally, the advantages of closed-loop control system are; relative speed in response to demanded changes and relative accuracy in matching actual to desired value. Disadvantages are; relative complexity and potential instability, under fault conditions.

All automatic control systems are closed-loop control systems. A closed-loop control system can be classified as a kinetic and a process system. These systems can, in addition, be continuous or discontinuous.

In a kinetic Control system, servomechanisms or position controllers are used and the system can be used to control the motion parameters such as displacement, velocity and acceleration to follow a continually changing desired value or input. And hence, the system has to be designed to be fast acting, with very small time lags and response times and electric or hydraulic actuation will have to be utilised.

Process control can be used to maintain parameters such as pressure, temperature, flow and level without regard for the changes in external process conditions. Usually, these systems are designed to be slow-acting , with large time lags in the measuring system and process.

In discontinuous or on-off control, operation is simple but this system can be used only when load changes are slow to occur

Continuous control can be used when the controlling signal is continuous to provide a smooth controlling action to obtain close control at, or near, the desired value.

### **2.3.2 Classification by type of plant being controlled**

Plant is the installation in which a process is carried out. Some examples in ship automation are main engine control, boiler control, generator control and so on.



### **2.3.3 Classification by type of process variable being controlled**

Some examples of process variables are displacement, velocity, acceleration, force, torque, tension, temperature, pressure, mass, liquid and gas flow rate, humidity, liquid level, chemical composition, pH, voltage, current, frequency, altitude, air speed, and etc.

### **2.3.4 Servomechanism versus Regulator**

Both are closed-loop continuous systems.

In a servomechanism, the plant output is mechanical in its nature. The function of servomechanism is to cause the actual value to track as accurately as possible changes(which may be rapid) in the desired value, e.g., position control system for rudder. The function of a regulator is to hold the actual value at a constant level, determined by a pre-set desired value in the presence of fluctuating operational conditions, e.g., a pressure control system in a steam generating plant.

The distinction between a servomechanism and a regulator can not be made clearly in practice because the principles involved in the construction, analysis and design of the two systems are identical.

### **2.3.5 Classification by type of control signals being employed**

In this context, the systems are classified by the nature of the signals involved. The nature of the signals may be electrical/electronic or mechanical or pneumatic or hydraulic or combinations of the above. Although each type has its own particular usefulness according to its specific characteristic, the usefulness of a combination of electrical/electronic measure-record instrumentation and a pneumatic final power control element is increasing continuously due to the developments of electronic devices over the last five decades.

### 2.3.6 Analogue, Digital and Hybrid control Elements

An analogue signal is a signal continuously varying with respect to time which can provide an infinite variety of values. Most electrical elements and virtually all non-electrical elements are inherently analogue.

The majority of transducers used in measuring systems produce analogue output signals. Where these are to be input to a digital controller or computer, the conversion from analogue to digital must be made by means of an analogue-to-digital converter.

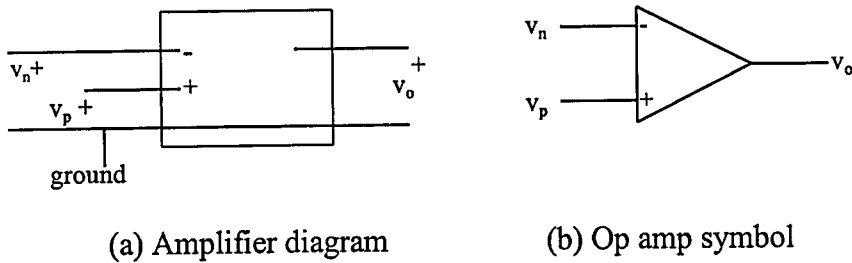
A digital signal is a discrete signal which is a form of pulse train with varying characteristics. In binary digital signal transmission the pulse will have two distinct values, usually a high and low value. A code must then be employed for this two-state pulse to be able to carry information. A typical example of such a code is the Morse code used for telegraphy where the length of pulse i.e. dash or dot, provides a code which can be interpreted as letters or numbers. A binary number code is used in electronic signal transmission.

Hybrid systems, usually referred as sampled data control systems contain some analogue and some digital elements. Since almost all plant processes are inherently analogue, it follows that any continuous control system using a digital control element is a sampled data system.

## 2.4 Electronic control principles

### The Operational Amplifiers

An *op amp* is a direct-coupled, high-gain voltage amplifier designed to amplify signals over a wide frequency range. Typically, it has two input terminals and one output terminal and a gain of at least  $10^5$  and is represented by the symbol in fig.2.9 (b)



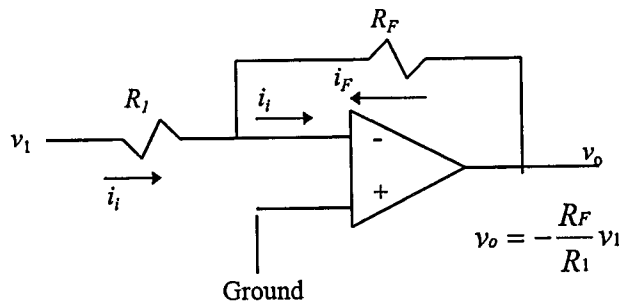
**Figure 2.9 Operational Amplifier Diagram and Symbol**

**Source: Ralph J. Smith (1980, page 73)**

It is basically a differential amplifier responding to the difference in the voltages applied to the positive and negative input terminals ( single-input *op amps* correspond to the special case where the + input is grounded.) It is normally used with external feedback networks that determine the function performed. The characteristics of the ideal *op amp* are as follows:

- Voltage gain  $A = \infty$
- Output voltage  $v_o = 0$  when  $v_n = v_p$
- Bandwidth  $BW = \infty$
- Input impedance  $Z_i = \infty$
- Output impedance  $Z_o = 0$

Figure (2.10) illustrates an operational amplifier circuit where the input signal is applied to the negative terminal and the positive terminal is grounded. The input voltage  $v_i$  is applied in series with resistance  $R_i$ , and the output voltage  $v_o$  is fed back through resistance  $R_F$ . Because the amplifier gain  $A$  is very large,  $v_i = -v_o/A \cong 0$ . Because  $R_i$  is very large,  $i_i = v_i/R_i \cong 0$ .



**Figure 2.10 Symbolic Circuit and Representation**

**Source: Ralph, J. Smith (1980, page 75)**

For an ideal amplifier, closely approximated by a practical amplifier,  $v_i = 0$  and  $i_i = 0$ ; therefore

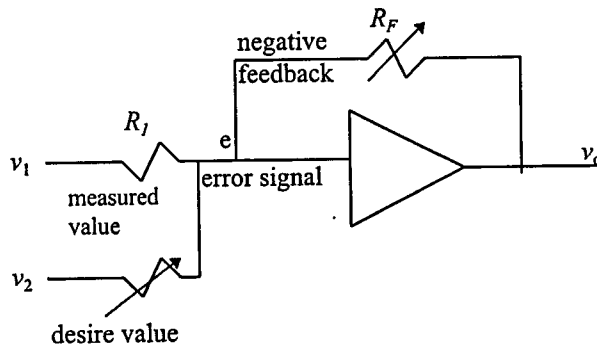
$$i_1 + i_F = \frac{v_1}{R_1} + \frac{v_o}{R_F} = 0$$

and

$$v_o = -\frac{R_F}{R_1} v_1 \quad \text{or} \quad A_F = \frac{v_o}{v_1} = -\frac{R_F}{R_1}$$

The action is scalar multiplication ( $V_o$  proportional to  $V_1$ ) with the multiplying factor  $R_F/R_1$  and the negative sign indicating inversion. Removal of the minus sign can be achieved by using two amplifiers in series.

### 2.4.1 Electronic proportional control



**Figure 2.11 Electronic Proportional Control**

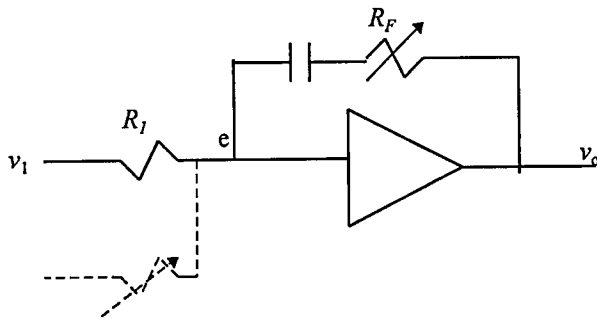
Source: L. Jackson (1979, page 173)

$$V_o = -R_F \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$$

Consider two inputs as shown in fig.(2.11).  $v_1$  and  $v_2$  are negative inputs. This is essentially a summer (and scalar) action which can be extended to further inputs as required. If  $R_1 = R_2 = R_3 = \text{etc.} = R_F$  then  $V_o = -(v_1 + V_2 + V_3 + \text{etc.})$ , i.e. summation only. Ratio control of inputs can be achieved by adjustment of the respective input resistance. A controller must produce and output signal proportional to the deviation between desired and measured values. The two signals can be compared (comparing element), perhaps elsewhere, by opposition flow through a common resistor the

voltage across which now represents a deviation (error) signal, for transmission to the amplifier input. If one input voltage is applied as negative to a summer the result is effectively subtraction. For Fig (2.11) if  $V_1$  and  $V_2$  are regarded as measured value and desired value (in opposition) this give error input and proportional to deviation control action, bandwidth adjustment at  $R_F$ . Amplifier power supplies and earth lines are omitted for simplicity.

### 2.4.2 Electronic integral control



**Figure. 2.12 Electronic Integral ( reset ) Control**

Source: L. Jackson ( 1979, page 175 )

By placing a capacitor  $C_F$  in the feedback circuit a limit is placed on the amplifier response rate to change of input signal

For a capacitor

$$C = Q/V$$

$$Q_F = C_F V_O$$

$$I_F = \frac{dQ_F}{dt} = C_F \frac{dV_O}{dt}$$

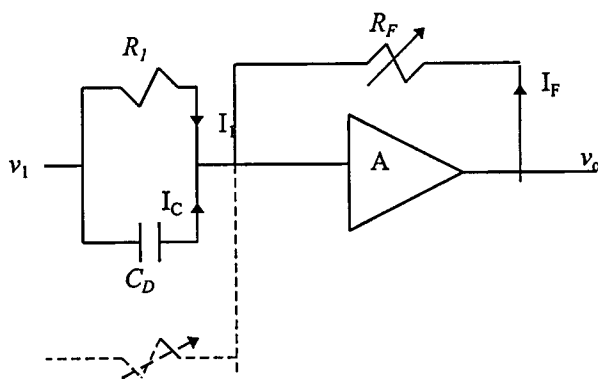
$$\int dV_O = \frac{1}{C_F} \int I_F dt$$

But,  $I_1 = - I_F$  and  $I_1 = V_1 / R_1$  ;

$$\text{Then } V_O = -\frac{1}{C_F R_1} \int V_1 dt$$

That is to say output voltage is the integral of input voltage with the time constant (reset rate) dependent on  $C_F$  and  $R_1$ . If, as for the two previous sketches, there is a modification to two inputs, via resistors representing measured and desired values, then amplifier input voltage corresponds to error input voltage. A feedback resistor  $R_F$  is necessary to give proportional addition and make adjustment easier, with a fixed capacitor. Alternatively potentiometer adjustment could be provided. Integral action is essentially rate control in the feedback network of the circuit by capacitance.  $R_F$  and  $R_2$  additions shown dotted.

### 2.4.3 Electronic proportional plus derivative controller



**Figure 2.13 Electronic Proportional plus Derivative Control**

Source: L. Jackson (1979, page 176)

Consider the circuit of Figure 2.13 which is P + D combination. A capacitor  $C_D$  is in the input circuit, together with a resistor  $R_1$ , to produce a rate of change component. In the steady state there is no current through  $C_D$

$$I_1 = I_F$$

$$V_0 = -\frac{R_F}{R_1} V_1$$

In the transient (changing ) state:

$$I_1 = \frac{V_1}{R_1}$$

$$I_C = C_D \frac{dV_1}{dt}$$

$$I_1 + I_C = -I_F$$

$$I_1 + I_C = -\frac{V_0}{R_F}$$

$$V_0 = -R_F(I_1 + I_C)$$

$$V_0 = -R_F\left(\frac{V_1}{R_1} + C_D \frac{dV_1}{dt}\right)$$

The output voltage therefore has the two desired components (proportional to input and proportional to the rate of change of input). The feedback resistor is necessary to give proportional addition and adjustment. If, as before, measured value and desired value inputs through resistors are applied then input voltage is the deviation error signal and output voltage is the signal to final control element. The phase advance network ahead of the amplifier gives attenuation across the CR circuit which requires compensation with increased gain at the amplifier. The R2 desired value resistor is shown dotted.

#### 2.4.4. Electronic compound controller ( P + I + D )

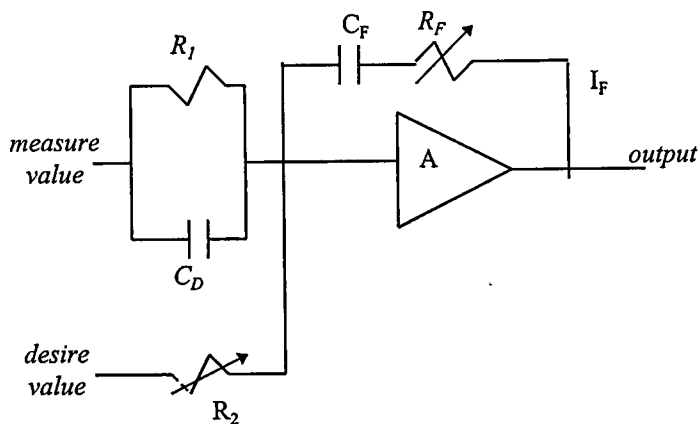


Figure 2.14 Compound ( P+I+D ) Electronic Controller

Source: L. Jackson (1979, page 177)

Fig.(2.14) shows the compound electronic controller, proportional, integral and derivative factors. The equations are shown as follows:

$$V_0 = -R_F \left( \frac{V_1}{R_1} + \frac{1}{C_F R_1} \int V_1 dt + C_D \frac{dV_1}{dt} \right)$$

## 2.6 Computer control system

Nowadays in marine automation, attempts are being made to try to design systems to perform and monitor every possible operation from a centralised control room. Such a vast amount of information coming into the control room is more than the engineer supervisor can continuously observe and hence, integrated monitoring and recording systems are being used increasingly. Such complicated systems mean that it is necessary to incorporate the computer as an essential device in the control system.

Depending on the type of control signal, there are basically two types of computers: analogue and digital computers. Analogue computers can be used to solve differential equations both linear and non-linear but are particularly useful in simulating physical systems or processes. The analogue computer can be characterised by such terms as continuous variables, small memory, limited accuracy, good and continuous communication with the operator and the scaling of both time and variable magnitude.

The digital computer is excellent for solving complex equations and for obtaining answers in large quantities or with high accuracy particularly useful for optimising a system. Digital computers are more widely used in modern control systems. According to the function of the computer in the control systems, there are two types of control systems which are computer supervisory control and direct digital control system.



### 2. 6. 1 Computer Supervisory Control System ( CSC )

In this system, the principal function of the computer is to generate the reference signals ( various desired values ) for a controller or controllers. So computer hardware is outside the control loops.

In CSC the various desired values are outputs from a computer to controllers as shown in Fig ( 2.15 ). The individual controllers operate their control loops as independent systems. The actual measured values of the various processes are inputs to the computer. A program within the computer will enable the display of information, the changing of desired values in the controllers to ensure optimum operation , and probably the logging of information or data.

The controllers will usually have pulse outputs so that they can be switched on-line and off-line without the need for balancing. The human operator may be able to make minor changes to the computer program but usually the computer is simply operating in a supervisory capacity.

The individual control systems operate independently and , in the event of a computer failure, their controllers can have desired values set by a human operator. This type of system arrangement is inevitably expensive because in this system individual controllers are provided as well as the computer . The method of operation also results in an element of redundancy because the computer and the controllers often operate in parallel. The reliability of the system is high and even in the event of computer failure, the local controllers will still function.

Most data-logging systems are effectively computer supervisory control. The computer will undertake certain programmed tasks but it does not make decisions or actually control. But it does provide the information necessary for the human operator to make decision regarding the efficient or optimal operation of the plant.

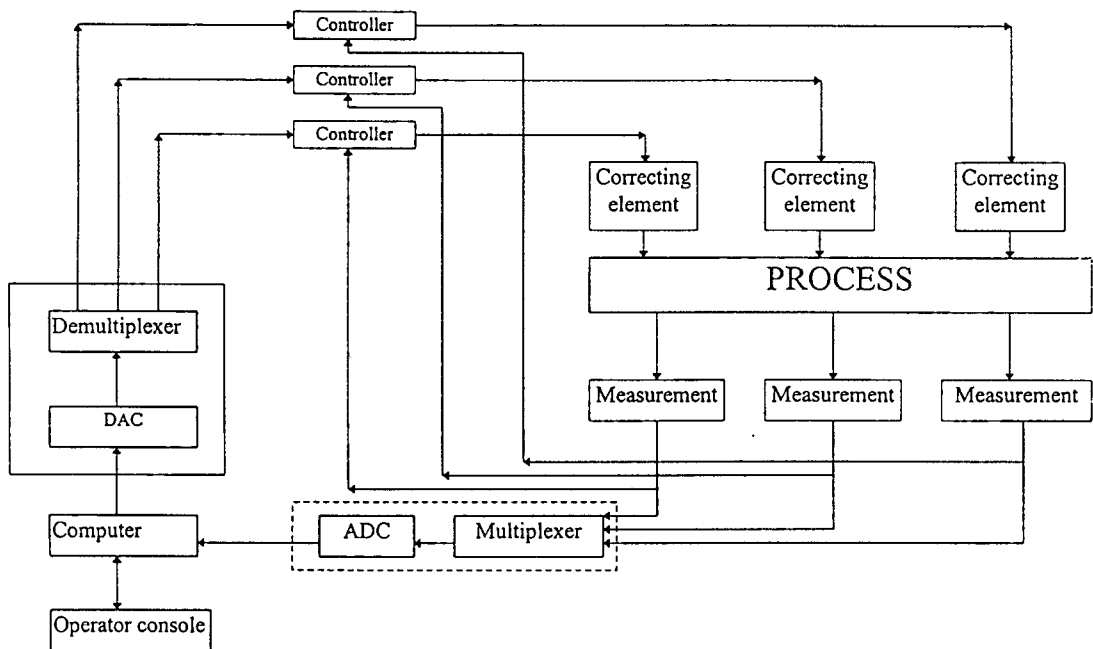
### 2. 6. 2 Direct Digital Control system

In this system as shown in Fig ( 2.16 ), the principal function of the computer is both to generate reference variable data and synthesise the controllers, so the computer hardware forms an integral part of the control loop and the computer is required to

- \* generate the reference variable;
- \* generate error data by comparing the reference data and feedback data?? which will be
- \* generate output data to be converted via the interface, to a driving signal for the actuator, the output data being related to the error data in terms defined by the chosen control algorithm.

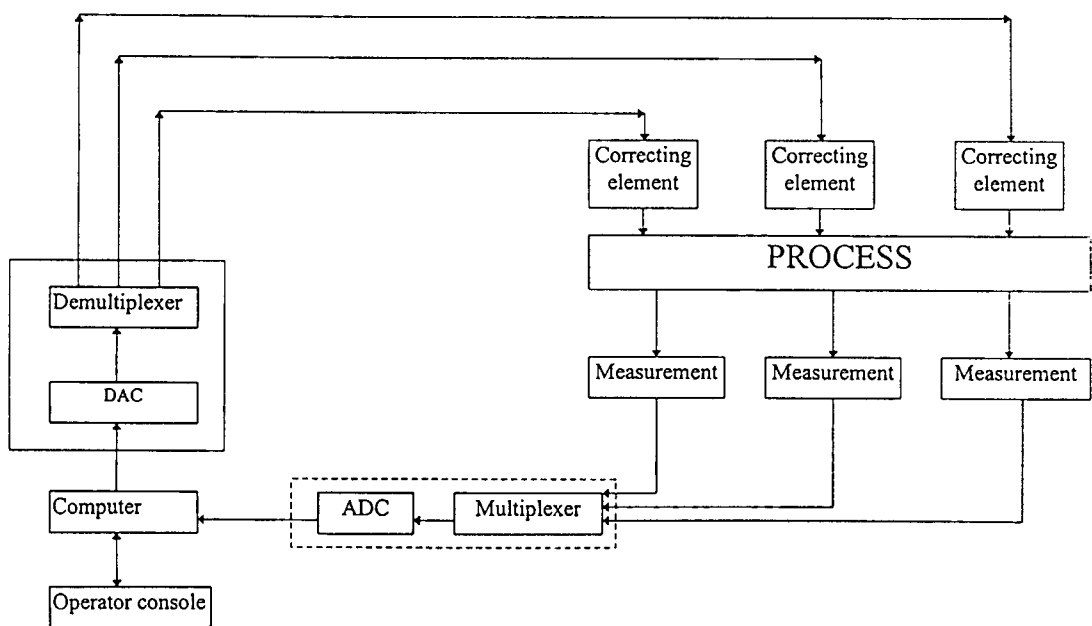
The computer or digital controller operates using numbers in binary code. Complex computations can be achieved with high degree of accuracy at very high speed. The program or instructions for a digital controller can be changed easily to deliver the output to the actuator. A central computer can be used to provide operating instructions or programs to enable efficient or optimal operation of the plant.

Decision making is also an important feature of digital controllers. Programs can be produced to enable the complete start-up of the main propulsion machinery, electrical power supply, etc. A failure in the computer would result in a loss of control.



**Figure 2.15 Computer Supervisory Control**

Adapted from: *Process and control Instrumentation Technology* ( C.D. Johnson, 1977, page 360 )



**Figure 2.16 Direct Digital Control**

Adapted from: *Process and Control Instrumentation Technology* (C.D. Johnson, 1977, page 364)

## **Chapter 3**

### **Developments of Marine Automation Systems**

#### **3.1 Introduction**

Since 1960s ship automation has been developed significantly and rapidly. And latest development is reaching a stage where a crewless had been tried. In this chapter, attempts are made to describe present levels of ship automation in some significant areas .

#### **3.2 Main engine automation**

A control system for a main diesel engine must be able to supply with air, fuel, cooling and lubrication and to operate satisfactorily, the quantity, pressure and temperature levels of these must be maintained within limits prescribed by the engine design. Regulation may be inherent in the engine design or may be subject to external control.

In order to utilise the output of the engine for ship propulsion it is further needed to control the direction and magnitude of the propeller thrust, which may involve varying the direction of rotation and speed of the engine and certainly involves variation of power output between zero and full power.

### **The Elements involved in the Control of Diesel Propulsion Engines**

The primary elements involved in controlling a diesel engine can vary depending on propulsion systems employing it. Therefore these should be discussed parallel with common propulsion systems. There are four common propulsion systems widely used.

( a ) One or two diesel engines each mechanically connected to a fixed-pitch propeller, with or without reduction gearing. Direction of propulsion controlled by changing direction of rotation of engine-propeller system; relation between engine power and speed dependent on characteristics of propeller.

This type of diesel engine installation is the most common type in ocean-going motor-ships. In order to provide the necessary manoeuvring facility, such engines must be capable of being run at speeds between idling and full speed by appropriate adjustment of the fuel input, and of being easily stopped and started in either direction of rotation.

The normal method of starting a direct coupled propulsion engine is to admit compressed air into the cylinders near the beginning of the expansion stroke. This provides sufficient energy to accelerate the engine up to a speed sufficiently high to ensure compression ignition of the fuel. The sequence in which starting air is admitted to the cylinders determines the direction in which the engine rotates and is controlled by distributors, one for ahead rotation and another for astern rotation.

In addition to selecting the ahead or astern starter air distributor, it is also necessary to arrange the appropriate sequence and phasing of fuel pump cams, valve gears, etc., which is normally achieved by rotating the camshaft relative to the crankshaft on a two-stroke engine ( most commonly used ) and in the case of four-stroke engines, by

sliding the camshaft axially relative to the valve and fuel pump mechanisms, thus bringing into operation the appropriate sets of cams.

In all except the smallest engines, the forces involved in operating the reversing mechanisms and starting air supply valves are too large for manual operation, with the result that even the simplest of control schemes involves the use of power assistance. This may be provided by compressed air, sometimes from the starting air supply, or sometimes from alternative supply or by oil, frequently from the engine lubricating oil system, or from an independent system ( in this case probably at higher pressures ).

In spite of these power assistance, control arrangements which are mounted on , or immediately adjacent to, the engine installation and operated by levers, hand wheels, etc., are normally referred to as “ manual ” controls.

When it is desired to centralise the controls for an installation involving one or more engines, perhaps to locate the controls at some distance from the engines and to introduce automatic features, mechanical transmissions become very difficult and complicated to arrange, and transmission of signals, and sometimes the power , necessary to operate the actual control elements on the engine installation is more usually accomplished pneumatically, hydraulically, or electrically.

More complicated control systems frequently use more than one of these media, perhaps sometimes all of these media in related specific areas ,according to their respective advantages and disadvantages when applied to the various functions involved.

The primary elements involved in controlling this type of installation under normal conditions are: the reversing mechanism;

the starting mechanism ;

the governor speed setting and / or fuel pump control rods.

( b ) As ( a ) but with two or more engines per shaft, usually capable of being separately disconnected from the propeller by means of electromagnetic, hydraulic or friction couplings. In this case, direction of propulsion during manoeuvring may be controlled as in ( a ) or by connection and disconnection of engines which are running in opposite direction. Relation between engine power and speed dependent on propeller characteristics and number of engines connected. In this case, control is also provided for the means of engagement and disengagement of the couplings, the details depending on the type of coupling employed.

( c ) One or more engines per shaft connected to a fixed-pitch propeller through a gearbox incorporating reversing elements. Unidirectional engines. Relation between speed and power dependent on propeller characteristics and number of engines connected. In this case, additional controls are required for the reverse-reduction gearbox. The facility to reverse the engines in such a combination is no longer essential, although it may be provided. Moreover, since arrangements are normally provided for disconnecting the engine ( s ) from the propeller shaft, starting and stopping of engines is not necessary for every manoeuvre. The primary elements involved in controlling this type of installation under normal conditions are ;

- the gearbox reversing mechanism;
- the engine disengagement mechanism;
- governor speed setting;

( d ) One or more engines per shaft, with or without reduction gearing, connected to a controllable pitch propeller. Direction of propulsion controlled by changing sense of propeller pitch. Power transmitted dependent on propeller pitch and engine speed, which may be varied independently. In this case, incorporating a controllable pitch propeller can theoretically be controlled simply by variation of propeller pitch ( after the engine has been started initially and provided that the engine is equipped with a governor ), but in practice it is more efficient to employ a system combining



propeller pitch variation with engine speed variation in a way which ensures maximum propulsion efficiency without an excessive torque load being imposed on the engine. It is also usual to retain the facility for starting and stopping the engine during periods of manoeuvring, should this be desirable, and it is not uncommon to employ engines capable of being reversed, in case of failure of propeller pitch control mechanism.

### **Mode of Control**

Marine propulsion engine systems may be controlled by simple mechanical controls or by very complicated and sophisticated control systems, or by a variety of intermediate possibilities. The main distinctions are to be found in :

( a ) the way in which the control elements on the engine are operated, e.g. by manually-operated levers, by fluid power, by electric actuators, etc.;

( b ) the extent to which automatic features are incorporated, for instance to control the sequence and timing of the various control functions; and

( c ) the location of the normal control position, e.g. adjacent to the engine, at a central control position in the engine room, or outside the engine room- most usually on the navigation bridge.

### **Remote and Automatic Controls for Manoeuvring Propulsion Machinery**

The control systems for most types of engines and engine installation can be divided into several sections. These are inter-related and clear separation is not possible, but in studying any particular scheme it is usually possible to distinguish the components associated with the following four functions:

#### **( 1 ).Change of Mode of Control**

Most installations allow for:

( a ) **Manual control**, in case of complete breakdown of automatic systems, normally required by the classification society, and perhaps involving the mechanical

engagement of levers, etc., which, under remote control, are disconnected. Such engagement may have to be made by hand or may be by remote operated clutches, etc., the choice depending on the ease and likely frequency of use.

( b ) **Control by the automatic system from the bridge**, usually regarded as the normal mode of control, and provided with the various facilities required for operation by bridge personnel. Operating controls may be provided amidships only, or on the bridge wings as well, and sometimes, in the case of special vessels, on a docking bridge aft. Arrangements for switching from one bridge position to another are provided for operation by the bridge personnel, operation being possible from one position only at any particular time. Switching from bridge to engine room control or vice versa is normally accomplished from the engine room ( clearly in consultation with the bridge, who must be prepared to accept or give up direct control when switching over )

( c ) **Control by the automatic system from the engine room**. This is an important facility for test and routine maintenance purposes, but is not likely to be much used in operation. The control facilities may be identical to those provided on the bridge, or may be arranged to give more flexible use of the various components in the automatic system. Instrumentation should include all information necessary for monitoring the operation of the engine and of the control system itself. In the case of electronic systems, a simulator unit may be provided to allow operation and checking of the control system without running the plant.

It is very important that it should be possible to change from one mode of control to another very quickly. It may be necessary to do so in emergency and the arrangements should be positive, foolproof and allow no uncertainty about which position is in control and what movement is required.

## **( 2 ) Operation of Reversing Mechanism**

With most installations this is a straight forward “ on-off ” operation involving the operation of one or more hydraulic or pneumatic devices. When integrated into an automatic system, however, there are likely to be :

( a ) **Interlocks**, to ensure that events occur in the correct and safe order. For instance, reversing must not be initiated without stopping the engine first, or conversely if reversing is initiated while the engine is running the fuel supply must be cut off and held off until the reversing sequence is completed. Furthermore, when starting the engine, starting air must not be applied until the reversing elements are in the appropriate position. In this connection, “ wrong way ” interlocks are provided to ensure that the engine will not start unless the reversing mechanism is set for the same direction as that required.

( b ) **Timing or speed-operated mechanisms**, in the case of engines where it is not possible to operate the reversing mechanism unless the engine is stationary or nearly so. In this case, initiation of the reversing sequence while the engine is running will cause the fuel to be cut off, and perhaps some braking device to come into action, but will delay the start of the reversing sequence either for a pre-set time or, more usually, until the engine speed falls to a predetermined value.

## **( 3 ) Operation of Starting Mechanism, including Fuel Control during Starting**

The operation of starting a direct reversing engine consists essentially of applying starting air , after setting the reversing gear in the appropriate direction, and maintaining the supply long enough to accelerate the engine up to a speed at which it will fire on fuel. The acceleration rate of a large engine under starting air is very high, and the required time of application of starting air is very short, particularly when the maximum pressure is available. In order to minimise the use of starting air therefore ( an economy which is always prudent and sometimes essential for the

safety of ship ) a sensitive and quick-acting device for detecting the initial movement of the engine is essential, which function is to cut off starting air when the rpm required for firing are reached. It is not possible to carry out this function on a time basis, which would be the simplest method, as the actual time of application of starting air depends somewhat on the prevailing ship and engine speed when the starting attempt is made. Most automatic systems use electrical methods for controlling starting air , a signal from a tachogenerator being used to trigger a suitable circuit when the necessary rpm ( established by trial and error ) are reached. Other methods are available, however, such as governor-like speed valves acting directly on pneumatic or hydraulic circuit controlling the starting air.

If the engine does not fire at the first attempt, it is usual for repeated attempts to be made up to a maximum number ( e.g., 3 or 4 ) or for a pre-set time, after which manual intervention is necessary against a failure, for instance of the tachogenerator, when the engine is running, as this might initiate an attempt to apply starting air.

If it is required that the bridge should be able to manoeuvre the engine, including starting it, at any time, it is necessary to arrange a remote opening device on each of the isolating or control valves in the starting air supply, since these are normally closed at sea.

Control of fuel admission during starting depends on the engine type. For some engines fuel is not admitted until after starting air has ceased to be applied, but in most cases a pre-set and constant rate of fuel admission is allowed during the starting sequence.

#### **( 4 ) Control of Engine Speed during Running**

The speed of an engine driving a propeller is determined by the amount of fuel admitted. Most modern engines are fitted with variable speed governors which, for a given speed setting, maintain constant engine revolutions by varying the fuel

admission as required ( for instance in different sea conditions or condition of loading of the ship ). This arrangement constitutes a closed-loop in which the actual engine speed is compared with the required speed, and appropriate action is taken to correct any difference. With some automatic control system and the engine governor is used merely to avoid overspeeding, but most systems use the engine governor directly. Excessive loading of the engine may be prevented by limiting the maximum amount of fuel admissible for any particular speed setting, either automatically in the governor or in the control system, or manually under steady conditions. Further refinements of the speed control system may include arrangements for preventing the engine from running continuously within a barred speed range, and for limiting the rate of change of speed as may be necessary to safeguard the engine.

In the case of twin screw ships, arrangements may be provided to maintain the engine speeds reasonably equal, or in some cases precisely so by special equipment which makes fine adjustments to the governor of one engine so that it runs at exactly the same speed and in a fixed phase relationship to the other engine. The fixed phase relationship chosen may be dictated by the propellers or by unbalanced engine couples, and is maintained in order to minimise vibration and noise in the ship.

### **Safety devices**

This control system has a number of interlocks and safety devices present. A running direction safety interlock on the camshaft will ensure that the engine is rotating in the direction required by the telegraph lever, before any fuel is admitted.

Safety cut-outs will operate in the event of loss of lubricating oil pressure, cooling water supplies or over heating. The engine can not start if any of these faults exist since the blocking device will hold the starting lever.

If the engine is running the slide valve will operate and the cut-out servo motor will cut off the fuel supply to the engine. These cut-outs can be overridden in an emergency so that the engine will continue to operate.

An overspeed trip is located at the end of camshaft. This mechanical device will cut off the fuel supply in the event of overspeeding.

Emergency control arrangements are also provided which enable engine starting, direction selection and speed setting without any control media other than levers.

### **Recent Developments**

More recent engine designs have replaced many of mechanical valves, e.g. starting lever blocking devices, with a number of circuits which use pneumatic logic elements. These logic elements were, at first, connected together by individual copper pipes. Use is now made of a "pneumatic printed circuit". This is a composite plastic sheet with pre-machined integral connecting passages for the pneumatic logic elements.

Direction selection is, on some engines, obtained by a separate lever, rather than using the telegraph reply lever. Engine starting may be a press-button instead of a lever, but will still be suitably interlocked to avoid incorrect operation. The overspeed unit is currently a tachogenerator which, when operated, will cut off the fuel supply.

The principal mechanical items, e.g. the starting air control valves, the automatic shut-off valve, the reversing servomotor, the reversing valve and the safety running direction interlock have all been retained in the latest engines. Use is still made of the same three control media, e.g. mechanical linkages, compressed air and hydraulic oil. Although fewer mechanical linkages now exist, those used for emergency operation will always be retained.

### 3.3 Navigation / Bridge Automation

In navigation, knowing the position of the own ship and steering the ship to the desired course are the two necessary matters.

In early days, position of the own ship in open sea was ascertained by taking the position lines of the sun or the stars or the planets. This kind of navigation is called the celestial navigation.

In coastal regions by taking the bearings of the shore objects such as islands, lighthouses, etc., the position of the own ship can be known. This kind of navigation is called the terrestrial navigation. Even in modern days, this terrestrial navigation is still compulsory for the safety of the navigation.

Nowadays, modern electronic navigation aids such as GPS ( Global Positioning System ), radar, ARPA ( Automatic Radar Plotting Aids ), Satellite Navigation, LORAN etc. can be used to ascertain the position of the own ship very exactly.

The control loop which can show the fundamentals of automatic navigation is expressed in the Figure 3.1.

In this figure, Gyro compass is the measuring element. It measures the actual direction of the ship and send the signals which represent the actual direction of the ship to the Autopilot.

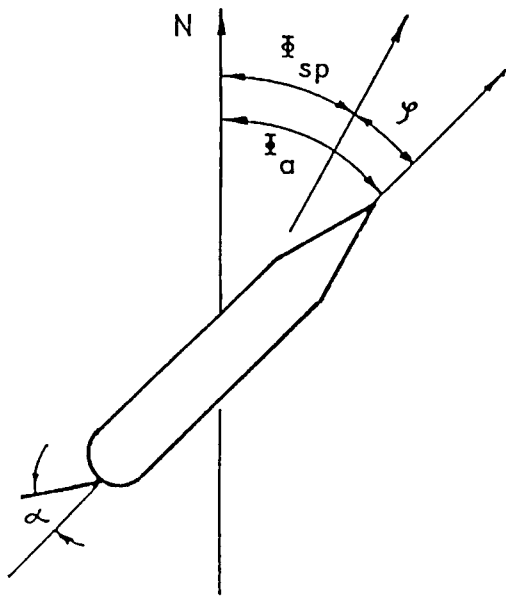
Autopilot is the adaptive course controller. It accepts the signals from the gyro compass and compares them with the course which is set and computes and sends the controlled signals to the steering gear.

Steering gear is the correcting unit. It accepts the controlled signals from the autopilot and moves the rudder to the required angle.

The ship itself is the process which is being controlled.

Wind, swell and current are the outside disturbances for this control loop.

By the developments in sensors such as wind sensor, depth sensor etc. and by the ability to incorporate computers , the modern automatic navigation systems appear as shown in the Figure 3.2 .



- $\bar{\alpha}$  = Course actual
- $\bar{\alpha}_{sp}$  = Course set point
- $\gamma$  = Course deviation
- $\alpha$  = Rudder angle

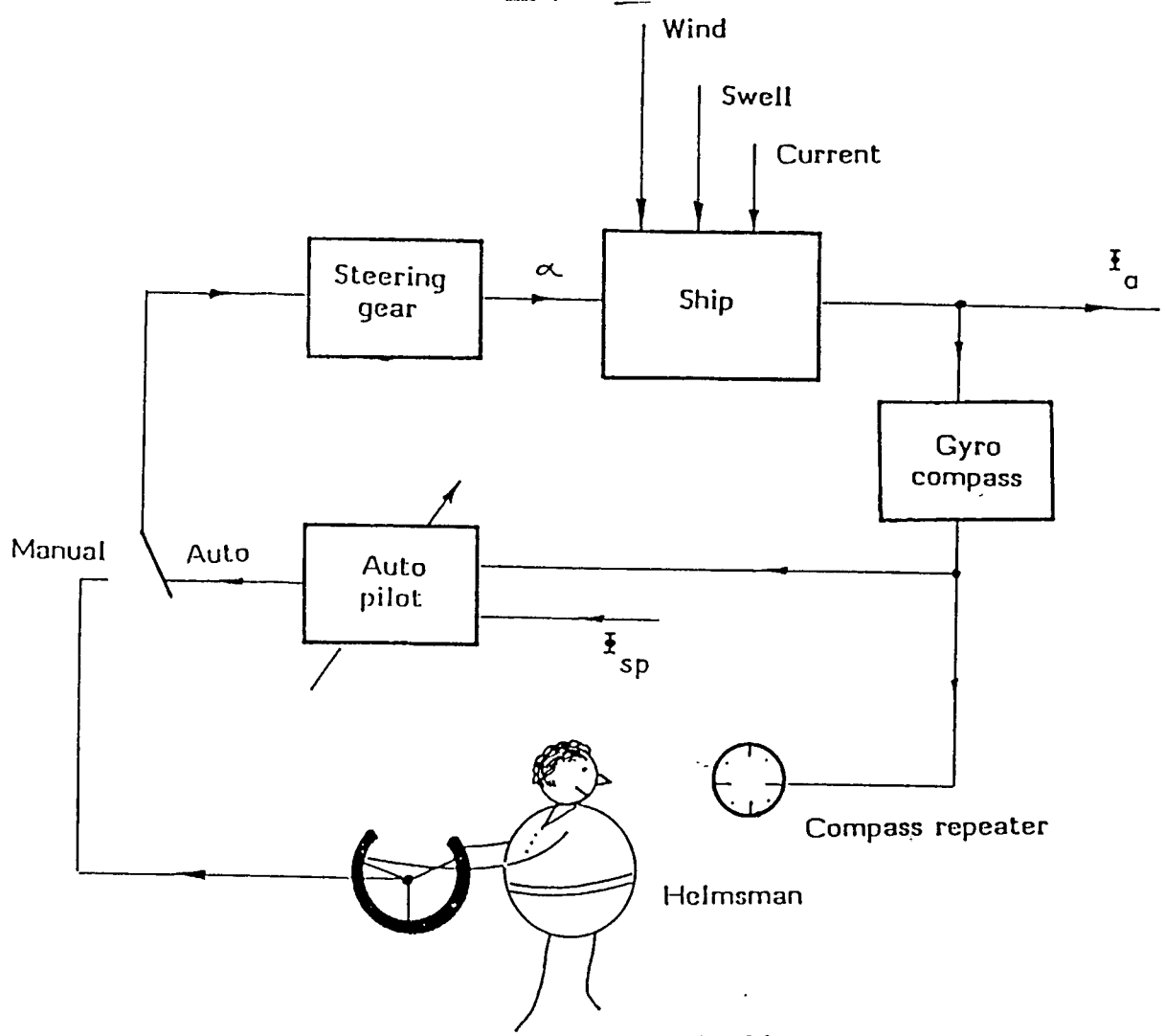


Figure 3.1 Course Control of a ship

Source: Rickert. F. (1996, Lecture Notes)



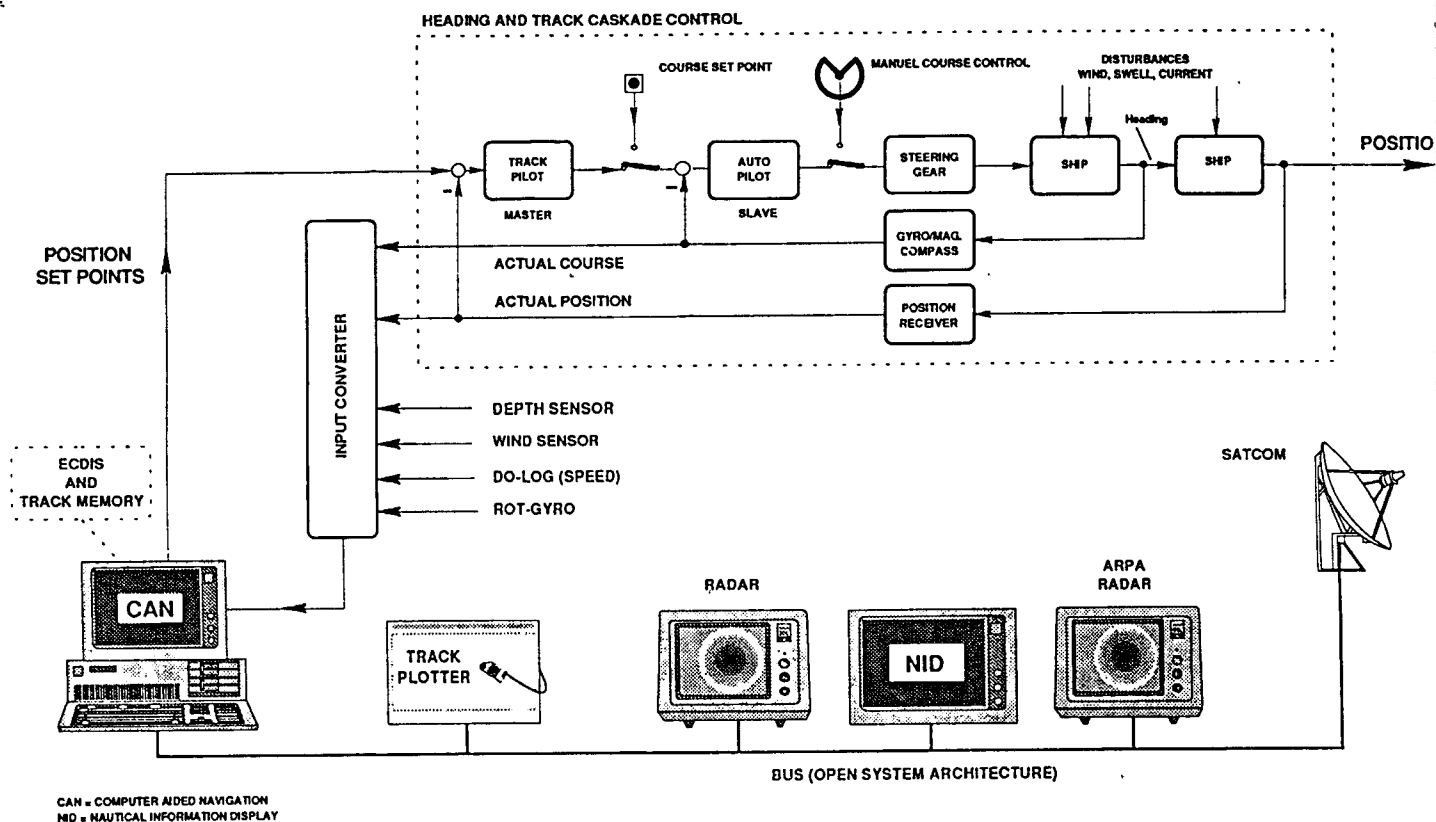


Figure 3.2 The Feature of a Modern Automatic Navigation System

Source: Rickert. F. (1996, Lecture Notes)

### 3.4 Integrated control ship / Ship of the future / One-man bridge control

By introducing information technology ( computer technology ) into ship automatic control systems, ship automation is being developed dramatically during recent decades. The latest computer technology introduced to ship control systems is LAN ( Local Area Network ).

LAN is generally defined as a computer and communications network that covers a limited geographical area; allows every node ( workstation ) to communicate with

every other node; and it does not require a central node or processor. Although LAN could have radii that range from a few hundred meters to about 50 kilometres in the past, but nowadays, LAN can have radii at any distance. One speciality of a LAN is connectivity-the ability for any given point ( node, connection ) to communicate with any other point. In other words, a LAN is a data communications system which allows a number of independent devices to communicate with each other.

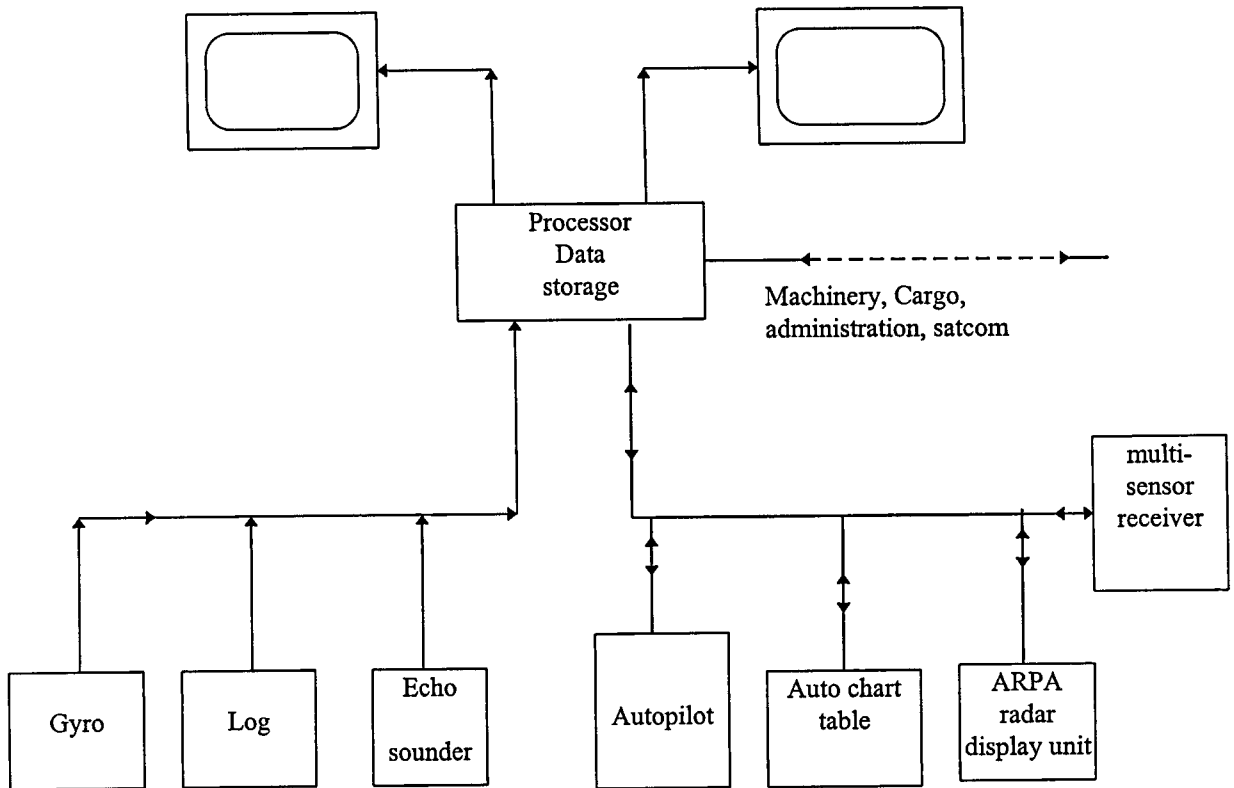
Therefore, in a control system incorporated with a LAN, information can be passed between any of the operating areas by a direct connection or a LAN. This enables the co-ordination of data for processing and decision making and also provides new forms of available data. Data can be displayed on video display units at workstations which are appropriately located around the ship. All available data can be accessed and data may be input at any workstation.

By introducing LAN into ship automatic control systems, it is possible that all the various shipboard operational functions operated by sophisticated equipment are being automated and integrated into one complete control system. There are several names for the ships fitting with this kind of system such as Integrated control ship, Ship of the future, One-man bridge control, etc. Although there are many things to be investigated for practicability, Integrated control ships have been in the experimental stages in some advanced countries since mid 1980s. This system will include bridge systems dealing with all aspects of navigation, cargo control systems, machinery control systems and also administration and management systems. One such system can be expressed as follows.

There are four sub-systems making up the integrated control system.

1. Bridge Electronic System
2. Machinery Control System
3. Cargo Electronic System
4. Management Administration System.

## Bridge Electronic System



**Figure 3.3 Integrated Bridge Electronic System**

source: D. A. Taylor (1987, page 392)

The bridge electronic system uses a single microcomputer, which can drive several stations. Only one workstation can control a particular set of functions at any one time. Usually two workstations are provided in a bridge system. These will control an automatic radar plotting aid ( ARPA ) display, an automatic chart table, a multi-sensor receiver , an auto-pilot and other usual bridge sensors, as shown in Figure 3.3.

The system is able to provide:

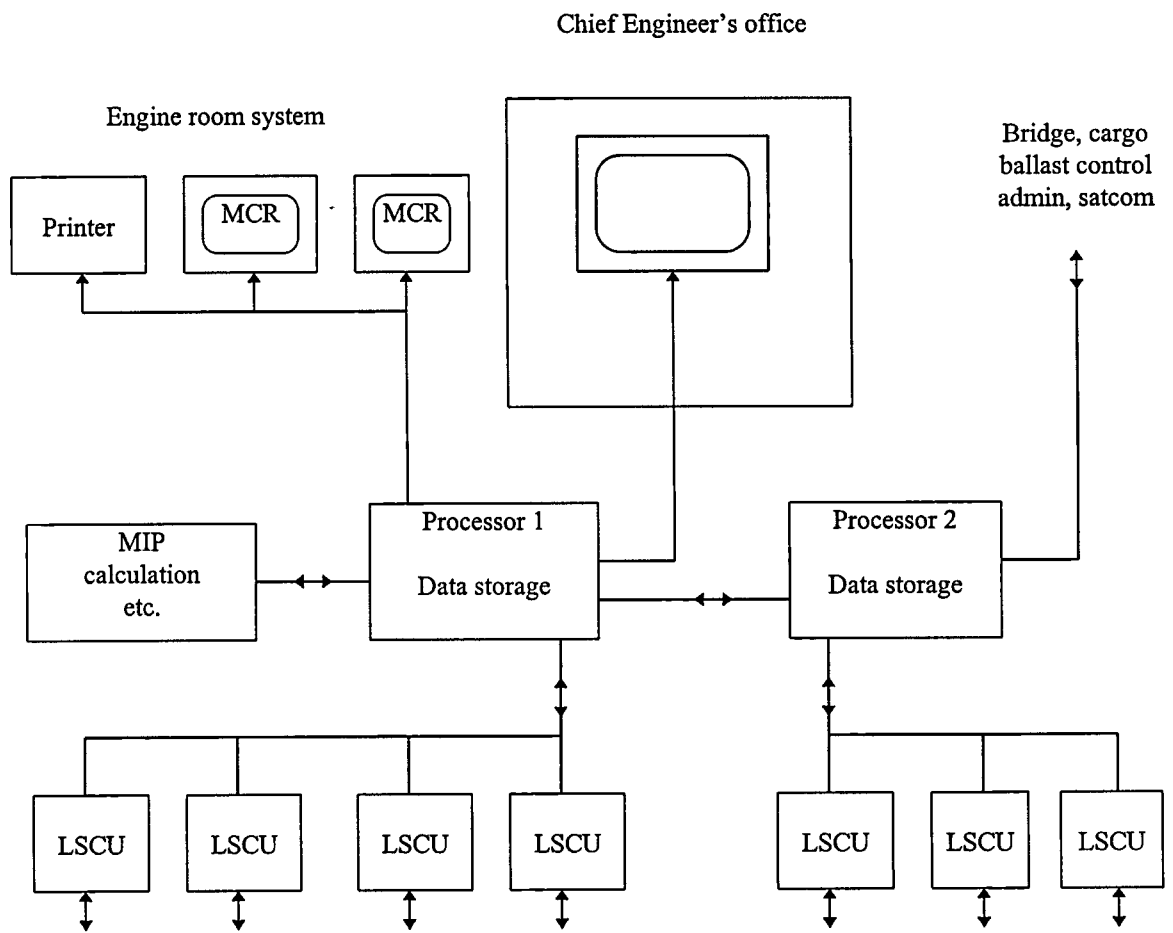
1. automatic position fixing;
2. full interaction with ARPA and the automatic chart table;
3. passage planning and monitoring;
4. auto track keeping;
5. on-board creation of electronic charts;
6. passage economics monitoring;
7. automatic data-logging;
8. automatic display of weather forecasts, warnings and satellite pictures directly via satellite.( Safety NET Broadcasts )

Where other operational areas are fitted with interfacing systems then machinery alarms and performance details, cargo and ballast information, etc. may be displayed on the bridge workstations.

### **Machinery control system**

The ship's machinery control system will have between 100 and 3000 sensing points leading to the various items of plant. There will be a considerable number of workstations and also a certain amount of customising, according to the particular machinery requirements. A fairly typical arrangement is as shown in Figure 3.4, and provides facilities for:

1. surveillance to UMS requirements;
2. performance and condition monitoring;
3. trend analysis;
4. generator control;
5. ballast and fluid management;
6. automatic data-logging.



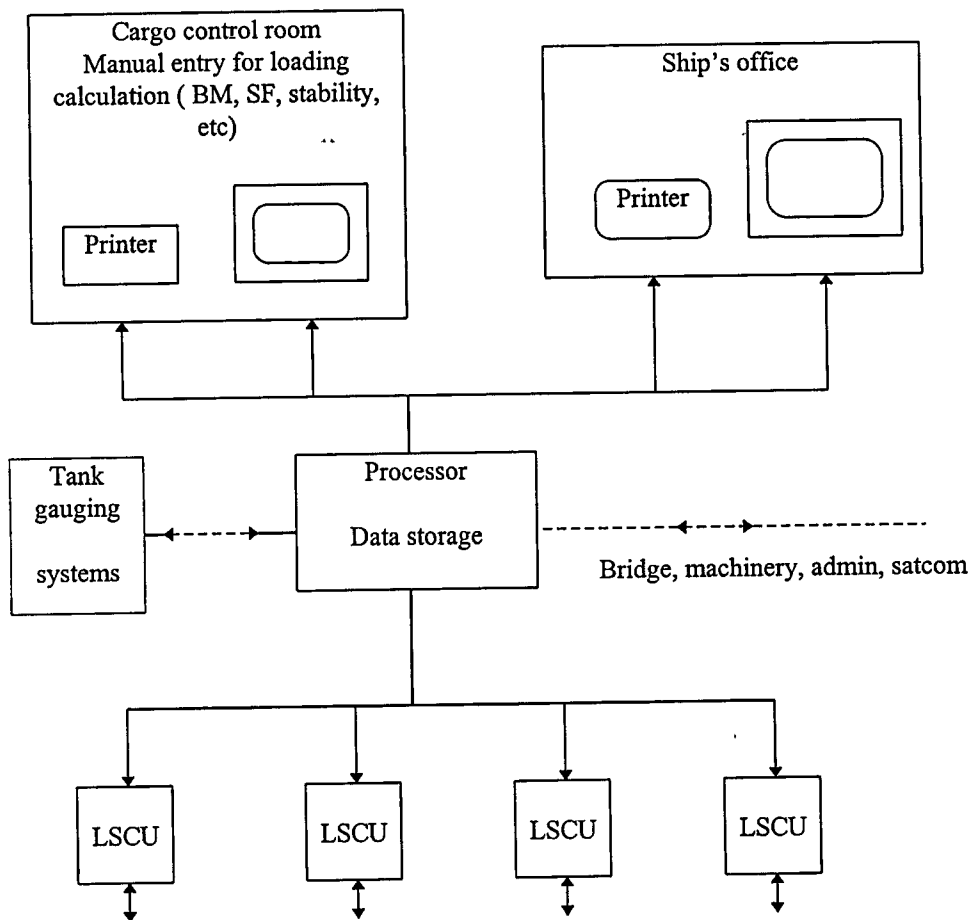
**Figure 3.4 Integrated Machinery Control System**

source: D. A.Taylor ( 1987, page 392)

Inputs from sensors and control outputs are connected to Local Scanner and Control Units ( LSCU ) which are positioned around the machinery space near to the machinery they control. The LSCU has an inbuilt microprocessor and can function independently of the main processor, if necessary. Local control loops are completed by LSCUs for controlling outputs to valves, motors, etc. They also provide the interface for remote commands from the workstations. An error checking procedure operates on each LSCU every two seconds. Local displays are available at the LSCU of all data fed to the unit. Up to seven LSCUs can be connected to a single processor. Only one processor is required to operate the system, the second is a fully duplicated redundant unit. Each processor is used at regular intervals and inbuilt checking facilities operate continuously. A failed processor would be disconnected automatically. If both processors or the communication system between the processors and the LSCUs failed, then each LSCU would revert to the back-up mode. Each LSCU would then operate as an independent alarm and monitoring system which is wired directly to the control console in the machinery control room. The system will carry out machinery surveillance, alarm monitoring and data-logging as required for UMS operation. The data can also be made available to many parts of the ship and an engineer may review everything in his cabin or an office in the accommodation.

### **Cargo Electronic System**

The cargo electronic system uses a single processor with usually two workstations, one in the cargo control room and one in the ship's office, as shown in the Figure 3.5. Each workstation is provided with a printer.



**Figure 3.5 Integrated Cargo Electronic System**

source: D. A. Taylor (1987, Page 394)

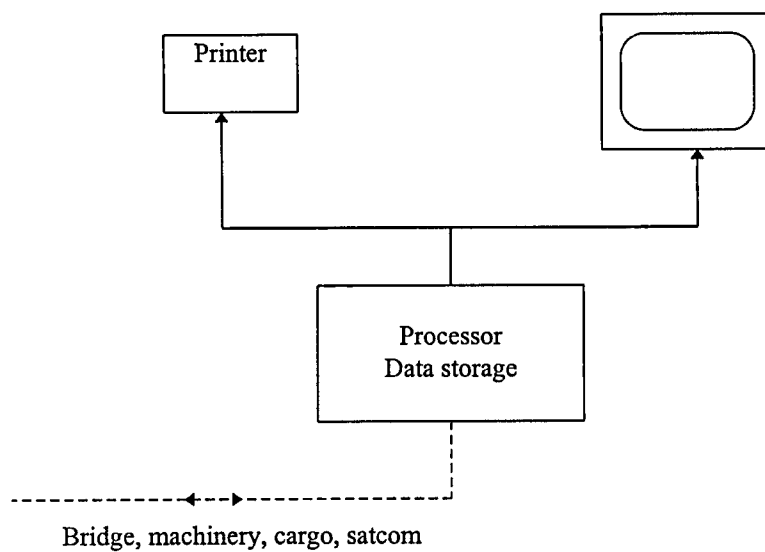
Data may be input to the system manually, e.g. for loading calculations, or directly, e.g. from tank level sensors. The system is able to provide:

1. loading calculations;
2. shear force, bending moment, stability and trim data;
3. cargo management;

4. data-logging and documentation;
5. ballast control.

The system can be interfaced with the bridge or machinery system to enable transfer of data as required.

### Administration system



**Figure 3.6 Integrated Administration System**

source: D. A. Taylor ( 1987, page 395)

The Management Administration System uses one or more PC workstations, each with a printer, as shown in Figure 3.6 of software programs can be run to provide such facilities as :

1. Master's records;
2. wages and salaries;
3. word processing;
4. stores and maintenance planning;
5. stock control.



The processor provides large-scale data storage facilities. The many programs available can be used to reduce tedious administrative tasks, maintain up-to-date records, enable rapid access to information, etc.

### **3 5 Condition monitoring and Knowledge-based System / Expert system**

#### **3.5.1 Condition monitoring system**

From the maintenance management point of view, it is obvious that condition monitoring based maintenance system is the most cost effective system. To implement this, knowing about the condition of the machinery is essential. Traditionally, engineers have relied on inspections at regular intervals, or on occasion to know about the condition of the machinery. However, the time required for visual inspection is not easily available on board ships in service. In some cases , for example it is not possible to open the propulsion machinery of oil tankers while loading and discharging .Therefore , various condition monitoring systems have been developed for accurate assessment of machinery components condition and maintenance prediction.

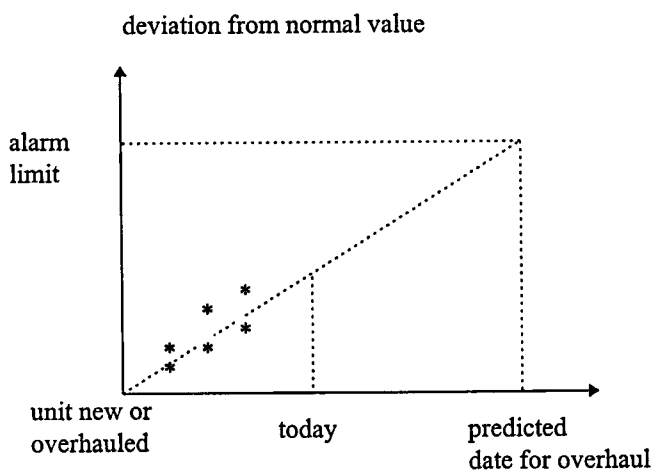
Condition monitoring system implies systematic monitoring of characteristic parameters in order to assess the condition of a component, and compare it with a reference or with accepted limits where a failure or breakdown is likely to occur. Operations of the system is done automatically and output results can be used by human operator to do required maintenance. There are variety of condition monitoring systems for diesel engines which differ widely in the following respects:

- \* The part of the engine being supervised
- \* The number of specialised sensors which are included
- \* The extent of signal conditioning
- \* The algorithm being computed
- \* The man / machine communication systems

There are substantial variations in capital costs as well as in the requirements for specially trained operators.

By incorporating microprocessor and the developments of highly reliable sensors, the condition within a diesel engine relating to combustion pressure indicated pressure, cylinder surface temperatures, condition of piston rings, etc. can be continuously monitored by the condition monitoring system. But the problem of this kind of system is providing a large amount of information and there is a risk of presenting too much data, most of which represents normal operating conditions. So specially trained crew is required for operating and servicing the system.

Establishing trend diagram is the one of the basic functions of condition monitoring system. By measuring the condition parameters from the time when a unit is new or newly overhauled and plotting the difference between these values and reference standard values, trend diagrams can be established as shown in the Figure 3.7 . When a deviation has been developed for some time, the prediction of the future trend can be made by finding the intersection between this and the alarm limit line. Although some condition parameters follow a simple time relationship such as a straight line, some others are very erratic. Therefore this trend concept should be used cautiously.



**Figure 3.7 Principle of Prediction of Future Trend**

Source. J. Listewnik (1996, Lecture Notes)

Present day diesel engine installations are rather complex. Interpretation of condition and diagnosis of malfunction become more difficult. Moreover the broadening of tasks of persons responsible for smooth operation of the installation leads to less experience with the interpretation of machinery's condition and diagnosis of possible failures. These may cause high risk. To reduce the risk, more intelligent monitoring systems are required.

Conventional monitoring systems for diesel engine generate alarms in case system variables exceed unacceptable limits. In addition to this , more advanced monitoring systems are able to detect failures before limits are exceeded, to predict the time when a failure becomes critical and to give recommendation for operation and maintenance.

More advanced monitoring system are based on process models. The process models are used to generate the values of output variables for healthy engine operation as reference. Comparison of the reference and actual values makes it possible to detect engine malfunctioning.

Process models can also be used to determine the symptoms due to failures. With this knowledge it is possible to determine the cause of failures.

### **3.5.2 Knowledge-based or Expert system**

This system provides ship operators with a valuable tool for achieving maximum operating efficiency with minimum downtime and minimum maintenance and repair cost. It is suitable for shipboard as well as shoreside application and provides facilities which ensure smooth and trouble free operation of main diesel engines.

The economic operation of a ship depends on numerous factors, the most important of which are the operating reliability and availability of the main engine. A high level of availability depends upon the engine condition being known at all times, so that any necessary maintenance and repair work can be carried out at the most suitable time in accordance with the ship's sailing schedule. Due to the wide variety of parameters which determine the loads and stresses to which an engine is subjected,

routine maintenance and repair intervals based on statistical methods are today no longer the best solution, particularly in view of the costs involved.

Normally a personal computer is introduced as a diagnostic tool for the monitoring and maintaining of the engine. Basically, it provides automation of the performance evaluation and general operation procedures documented in the engine operational manuals. With the implant of the know-how of an expert engineer, it forms an expert system.

A performance analysis software program is necessary and normally can be used in a personal computer with MS-DOS or PC-DOS operating system normally and require 1 to 2 MB hard disk space according to the program. The program is matched with the make and type of the engine. MAN B&W has developed such a software program for its turbocharged diesel engines called as Computer Aided Performance Analysis (CAPA) . It gives full menu control effected by means of a main menu, and pull down and pop-up menus, where the requested functions, kept in plain text, are selected by means of a highlighted letter or by positioning a selection bar via the keyboard. An electronic system manual is included , and full support is provided by on-line help pop-up windows. In this way the CAPA program work as an off-line system. The engine performance values required for diagnosis are read off the engine's normal monitoring system, and are then entered into the computer for subsequent computation and analysis. The program generates a set of calculated performance parameters corrected to the standard ambient condition. The corrected values are compared to reference curves, and deviations from the reference curves are calculated. From the data, the expert system extracts and shows those parameters which exceed their maximum limits of variation. Moreover, the expert system generates maintenance advice about the components most likely to cause problems, and gives recommendations as to corrective measures to be taken.

### **3.6 Programmable controller.**

Programmable controller are used for various application. Nearly 50% of all automation- task were solved with programmable controllers. These are commonly used on ships as central part of programmable electronic system. A common application for a programmable controller is to replace a control system that would previously have used relays or timers, such as a simple power management system or sequence control system for valves.

Two types of programmable controllers used in automation are wired controller and memory programmed controllers.

In wired controllers switching elements are solidly connected. Such a condition is called relay logic. In this type of controller every change of function has to be done by rewiring the controller and switching elements.

In programmable controller the function of the controller is stored in memory and doesn't depend on the condition of the hardware ( switches, relays, contacts etc. ). The hardware is connected to the inputs and outputs of the programmable controller. The input and output signals are combined by the program stored in the controller. Whenever a change of function has to be done, only the program has to be changed. Before a programmable controller is able to control a process, a program has to be written in a special language and entered into the controller.

This kind of controller is a digitally operating electronic apparatus which uses a programmable memory for the internal storage of instructions for implementing specific functions such as logic, sequencing, timing, counting and arithmetic to control through digital or analogue input/output modules, various types of machines or process.

#### **Working principle**

The programmable controller works basically as a sequencer when used to automate shipboard plant. It first senses the input conditions of interest and then solves the logic equations programmed by the user, based on the current input conditions. It

then sets the required output actuators to function action as dictated by the outcome of the logic equations.

### Input

The input block allows the sequencer to sense the machine input parameters. These may consist of operator switches used to set up and select modes of machine operation and for starting and stopping the machine operation, limit switches used to sense the position of a part, and other sensors or switches used for safety or fault monitoring. In other words: any external parameter which must be provided to the controller for it to make the right decision when running a machine is provided through the input block.

### Sequencer

The sequencer block performs the operations of timing, latching, and control that hardware logic does, except that the operations are done with programmable solid state logic rather than with discrete hardware components. The sequence logic is basically digital codes using digital logic signals.

### Programmer

The sequencer is controlled by a user-defined program that contains the steps necessary to execute the task from the ladder diagram ( or any other mode of entering the program ) which is equivalent to the relay logic. The user program is entered by the programmer. The sequencer itself has its own operating program-sometimes referred to as a micro program- which causes the sequencer hardware to step through the user program and execute it according to the predefined rules of the system.

### Output

In the output block, the output points are turned on or off according to the results of the ladder logic based on inputs at any particular time. The state of the output is

stored in the memory and hence the on or off state of these outputs can be used within other logic equations simply by the program examining the contents of the appropriate memory location. If hardware relays were used, each logic equation would require using a separate set of contacts for a particular output.

## Chapter 4

### Present Syllabus of IMT ( Myanmar ) on Automation

#### 4.1 Marine engineer officer training and certification in the Union of Myanmar

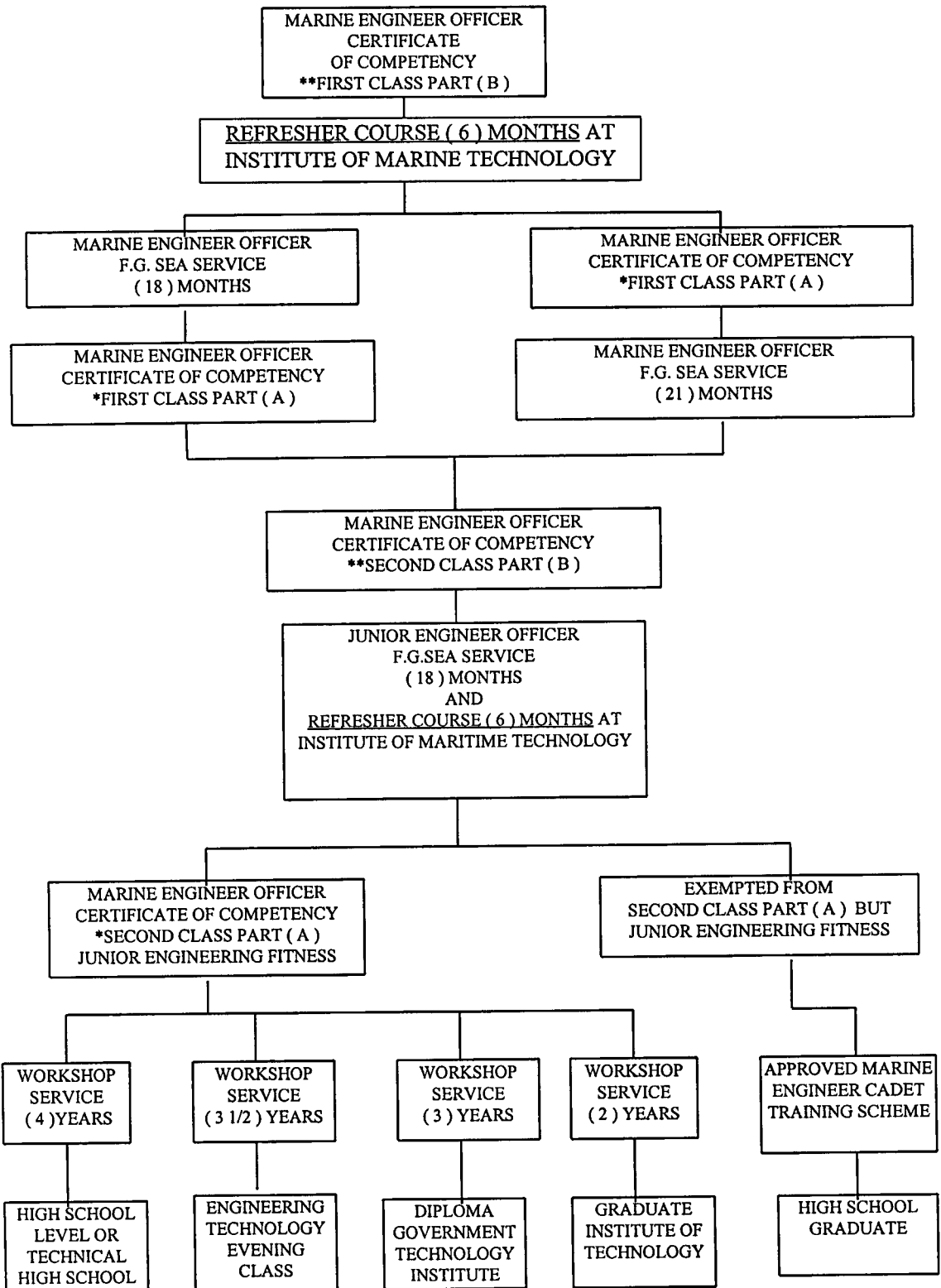
The Myanmar maritime training system follows the old British system of training very closely. The entry requirements of a marine engineer and marine engineering officer training and certification scheme, in the Union of Myanmar, is expressed in the Figure 4.1.

#### Preparatory Courses for First Class and Second Class Engineer Certificate of Competency

A preparatory courses ( also called refresher courses ) of 6 months duration conducted by the Institute of Marine Technology, are the compulsory courses in the marine engineer officer training and certification scheme in the Union of Myanmar.

<b>Subjects</b>	<b>Hours</b>
(1) General Engineering Knowledge	180
(2) Motor Engineering Knowledge	180
(3) Electrotechnology	180
(4) Naval Architecture	180
<b>Total</b>	<b>720</b>





\* WRITTEN EXAMINATION ONLY

\*\* WRITTEN PLUS ORAL EXAMINATION

**Figure 4.1 Marine engineering officer training and certification scheme in the Union of Myanmar**

## **4.2. Syllabi for marine engineers' certificates of competency examinations used in the Union Of Myanmar**

### **4.2.1 Syllabus of some engineering subjects for Second Class Engineer examinations**

Only subjects related to entry standards expressed in Module 9 of IMO model course for chief and second engineer officers are stated here.

#### **Fundamental Knowledge Subjects ( Part A )**

##### **4.2.1.1 Applied Mechanics**

- ( a ) vectors and vector diagrams
- ( b ) velocity and acceleration
- ( c ) mass, acceleration, force, torque, momentum
- ( d ) work, power and energy
- ( e ) centripetal acceleration
- ( f ) sliding friction
- ( g ) moments
- ( h ) lifting machines
- ( i ) stress and strain
- ( j ) pressure vessels
- ( k ) bending of beams
- ( l ) stresses in beams
- ( m ) torsion
- ( n ) hydraulics

##### **4.2.1.2 Heat and Heat Engines**

- ( a ) units and common terms
- ( b ) heat

- ( c ) thermal expansion
- ( d ) heat transfer
- ( e ) laws of perfect gases
- ( f ) expansion and compression of perfect gases
- ( g ) internal combustion engines, elementary principles
- ( h ) ideal cycles
- ( i ) reciprocating air compressors
- ( j ) steam
- ( k ) steam reciprocating engines
- ( l ) steam turbines
- ( m ) boilers and combustion
- ( n ) refrigeration

### **Practical Knowledge Subjects ( Part B )**

#### **4.2.1.3 Electrotechnology**

- ( a ) General: Electrical current by chemical, magnetic thermal and production of light. Electromotive force.
- ( b ) Electric circuit: Units. Series and parallel circuits. Conductance, resistance, specific resistance. Temperature coefficient of resistance. Application of pyrometers, etc..
- ( c ) Electrolytic action: Uses of electrolysis. Faraday's laws. Electro-chemical equivalent.
- ( d ) Cells: Primary and secondary cells. Maintenance.
- ( e ) Magnetism and electromagnetism: Magnetic field. Relative direction of current and field. Flux density. Permeability. Faraday's and Lenz's laws.
- ( f ) A.C : Sinusoidal wave, frequency, maximum r.m.s and average values. A.C.circuits. Inductor and capacitor. Resistance, reactance and impedance.

( g ) Instrument: Switch board indicating instrument. Moving coil, moving iron and dynamometer types. Use of shunt and series resistance. Current transformer. Simple ohmmeter and insulation test.

( h ) Circuits: Single wire, 2-wire, 3- wire and main systems for D.C. Use of fuses and circuit breakers. Earth lamps. Parallel running and synchronising.

( i ) Electrical machines: Construction, general and details. Field circuits. Commutation, windings and maintenance.

( j ) D.C. generators and motors .Protections. Excitation: Voltage control: parallel operation. Types of starters. Speed control and load characteristics.

#### **4.2.1.4. Engineering Knowledge**

( a ) Materials commonly used in the construction of marine engines and boilers and the mechanical tests to which these materials are normally subject.

( b ) Heat and combustion. The properties of steam, fuel, lubricants and other liquids, gases and vapours used in machinery on board ship.

( c ) The use , constructional details and principles involved in the action of the pressure gauge, thermometer, barometer and other meters commonly used .

( d ) The causes, effects and usual remedies for encrustation and corrosion. Feed water and blow densities and scale formation.

( e ) Constructional details and working principle of marine engines. The principles of working and methods of calibration of dynamometers and torsion meters. The method of dealing with wear and tear of machinery parts. Temporary and permanent repairs in the event of breakdown.

( f ) Application of indicator. Calculation of horse power.

( g ) Constructional details and principles of action of pumps and oily water separators. The general requirements concerning feed, fuel, bilge and ballast systems.

( h ) The constructional arrangement, details and working of steering gears, refrigerating machinery, hydraulic and other auxiliary machinery.

( i ) Precaution against fire or explosions due to oil or gas. Flash point. Explosive properties of gas given by fuel or lubricating oils. Spontaneous combustion. Fire

detection. Methods of dealing with fire. Action and maintenance of mechanical and chemical fire extinguishers and other fire-fighting appliances.

( j ) Methods of constructing marine steam engines and boilers.

( k ) The various types of propelling and auxiliary machinery in use.

( l ) Constructional details and working of evaporators, feed water heaters and feed water filters.

( m ) Marine boilers of various modern designs. Prevention of movement of boilers when vessels are pitching or rolling. The determination by calculation of suitable working pressure for boilers of given dimensions.

( n ) Use and management of boiler mountings, with special reference to safety valves and water level gauges. Water hammer.

( o ) Construction details, operation and maintenance of installations for superheating steam and burning coal or oil fuel.

( p ) The principles of working of internal combustion engines. The difference between various types of engines. The difference between various types of engines. Constructional details of internal combustion engines.

( q ) Properties of fuel and lubricating oils generally used in internal combustion engines. The supply of air and fuel to cylinders of engines of different types. Constructional details and working principles of air compressors.

( r ) Methods of constructing marine diesel engines. Methods employed in fitting the machinery on board.

( s ) Starting and reversing arrangements and various operation connected therewith.

( t ) The attention required for operation and maintenance of various parts of machinery. The use and management of valves and safety devices employed.

( u ) Enumeration and description of defects arising from working of machinery. The remedy for such defects.

( v ) Constructional details and management of auxiliary steam boilers, their fittings and mountings with special reference to water gauges and safety valves. Oil fuel and combustion equipment.

## **4.2.2 Syllabus for First Class Engineer Examination**

### **Fundamental Knowledge Subjects ( Part A )**

#### **4.2.2.1 Applied Mechanics**

Only some portions are added to 4.2.1.1 .

( a ) Instantaneous centre to ( b ) of 4.2.1.1

( b ) Fluctuation of speed and energy to ( d ) of 4.2.1.1

( c ) Porter governor , Hartnell governor , simple harmonic motion and vibration of spring to ( e ) of 4.2.1.1

( d ) Forces not parallel to inclined plane and efficiency of square thread to ( f ) of 4.2.1.1

( e ) theorem of parallel axis to ( g ) of 4.2.1.1

( f ) stress due to thermal expansion in compound bars and stresses on oblique planes to ( i ) of 4.2.1.1

( g ) depth of beams to ( l ) of 4.2.1.1

( h ) hydrostatic force and centre of pressure for non- mixing liquids effect of friction and venturi meter to ( n ) of 4.2.1.1

#### **4.2.2.2 Heat and heat engines**

Only some portions are added to 4.2.1.2 .

( a ) Cylindrical wall, transfer of heat from one fluid to another through a dividing wall and heat exchangers to ( d ) of 4.2.1.2.

- ( b ) Universal gas constant, Avogadro's law, Dalton's law of partial pressures and partial volumes and energy equation ( open system ) to ( e ) of 4.2.1.2
- ( c ) Carnot and reversed Carnot to ( h ) of 4.2.1.2
- ( d ) Combined separating and throttling calorimeter to ( j ) of 4.2.1.2
- ( e ) Rankine efficiency to ( k ) of 4.2.1.2
- ( f ) Force on blades and gas turbines to ( l ) of 4.2.1.2
- ( g ) Capacity and performance to ( n ) of 4.2.1.2 and
- ( h ) The whole chapter ENTROPY, which includes entropy of water, evaporation, superheated steam, temperature-entropy diagram and chart, isothermal and isentropic processes to 4.2.1.2.

### **Practical Knowledge Subjects ( Part B )**

#### **4.2.2.3 Electrotechnology**

- ( a ) The magnetic and electric circuits: hysteresis. electromagnetism. Kirchoff's laws.
- ( b ) Distribution system: D.C. 2-wire and 3-wire. A.C. single-phase and three-phase 3-wire and 4-wire. Balancer in 3-wire d.c. system.
- ( c ) Motor starter
- ( d ) Application: parallel operation of shunt and compound generators. Application to Ward Leonard system. Faults and maintenance of machines.
- ( e ) A.C.: Production of an alternating wave form. R.M.S and average values. Form factor.
- ( f ) The series and parallel circuits.
- ( g ) Alternators: construction. Synchronising and reference to load sharing.
- ( h ) Motors: Induction and synchronous types. Single phase motors.
- ( i ) Propulsion: Types using D.C. and A.C. machines. Advantages and disadvantages of electric propulsion.
- ( j ) Single-phase motors: Elementary principles and general description.

( k ) Transformers: Elementary principles and general description.

( l ) Instruments: Simple treatment of dynamometer, watt meter, frequency meter, power factor meter, rotary synchroscope.

( m ) Thermionics.

#### **4.2.2.4 Engineering Knowledge**

Only some portions are added to 4.2.2.3

( a ) The administrative duties of a chief engineer.. Organisation of engine room staff for emergency duties and the use of safety equipment. Organisation of repairs and surveys. Report to owner.

( b ) The recognition of irregularity in the running of engines from indicator diagrams. The rectification of these irregularities.

### **4.3 Recent Syllabus of Automation, Instrumentation and Control Systems course ( AICS ) at the IMT of Myanmar compared to IMO model courses.**

AICS at the IMT is mainly based on IMO model courses but compressed in some parts of the content of the subject.

Scope, objective, class size and staff requirements comply with the guidelines set out in the IMO model courses.

With regard to textbooks, most of the teaching syllabus laid down in Module 9 of the IMO model course for chief and second engineer officer drawn from T1 ( L. Jackson, Instrumentation and Control Systems, 3rd edition. ( Sunderland, Thomas Reed Publication Ltd, 1979 ) ) are skipped in the AICS course at the IMT. But, all of the teaching syllabus drawn from T2 ( G. J. Roy, Notes on Instrumentation and Control, revised edition.( Heinemann Newnes, Oxford, 1983 ) ) is included. Moreover, Chapter 3, Typical Equipment and Components Commercially Available and Chapter 4, Control Systems and Chapter 5, Alarm Indication Systems of B. J.



Smith Application of Automatic Machinery and Alarm Equipment in Ships 1st reprinted.( Marine Management ( Holding ) Ltd. London, 1979 ) are included in AICS course at IMT in order to reinforce the course .

Comparisons of the subject outlines of the IMO model course and IMT course on AICS are presented in the following tables.

**Table 4.1: Comparison of the subject outlines between the IMO model course and IMT's AICS Course**

Subject Area	Hours			
	Lecture (IMT)	Lecture (IMO)	Laboratory (IMT)	Laboratory (IMO)
1 General	0.5	1	--	
2 Measurement of temperature	1	3	--	
3 Measurement of pressure	1	2		-1-
4 Measurement of level	1	2	--	
5 Measurement of flow	2	4	--	
6 Other measurements	2	6	--	
7 Transmission of signals	2	4	1	1
8 Final controlling elements	2	4		--2
9 Control theory	4	12	--	--
10 Principles of pneumatic control	3	4	2	--2
11 Controllers	2	6	--	--
12 Control circuit	2	9	--	--
13 Remote control- diesel Propulsion	1	3	--	--
14 Air supply	1.5	3	--	--
15 Monitoring systems	--	2	--	--
16. Additional*	2	--	--	--
<b>Subtotal</b>	<b>27</b>	<b>65</b>	<b>3</b>	<b>6</b>

Additional\* are chapters 3, 4 and 5 of B. G. Smith Application of Automatic Machinery and Alarm Equipment in Ship.

**Table 4.2 Comparison of IMT's Detailed Teaching Syllabus to IMO's Detailed Teaching Syllabus**

Learning Objectives	Fully Covered	Partially Covered	Uncovered
1 General			*
.1 describes the essential requirements for the automatic operation of marine machinery			*
.2 uses control and instrumentation terminology in its correct context		*	
.3 compares pneumatic, hydraulic and electronic -electrical control systems			*
.4 describes a simple control loop	*		
.5 names analogue and digital devices			*
2 Measurement of temperature			
.1 states that it is common practice to call the measuring instrument for temperatures		*	
.2 states the temperature range for which mercury is used		*	
.3 names the fluids which can be used for the measurement of lower temperatures		*	
.4 describes the principal features of thermometers based on the filled system, including: mercury in steel vapour-pressure gas-filled	*		
.5 describes the principal features of a bi-metallic thermometer	*		
.6 states that the range and accuracy varies according to the material used in the detecting element	*		
.7 sketches and describes resistance-type measuring instrument based on the Wheatstone bridge		*	
.8 describes the characteristics of a thermistor and the conditions for which it is suitable		*	
.9 sketches a circuit used in a thermocouple and describes its operation		*	
.10 describes the principles of an optical pyrometer		*	
3 Measurement of pressure			
.1 describes the principal features of, and compares, the following: -- manometers -- pressure gauges -- twin-bellows differential-pressure cell -- strain gauge	* * *		*

Learning Objectives	Fully Covered	Partially Covered	Uncovered
.2 describes how pressure gauges can be tested on board ship	*		
.3 tests a pressure gauge		*	
.4 sketches calibration curves for a Bourdon pressure gauge showing the effect of: zero adjustment multiplication adjustment angularity adjustment			*
.5 states that calibration and testing is normally performed by specialists			*
4 Measurement of level Direct methods			
.1 describes the principle of inferential methods		*	
.2 describes the principle of a probe element			*
.3 describes a displacement gauge	*		
Inferential methods		*	
.4 explains the principle of inferential methods			
.5 describes a level sensor based on immersed resistors			*
.6 describes a remote boiler-water level indicator		*	
.7 describes a level indicator based on a bubbler system		*	
.8 describes a pneumatic gauge		*	
5. Measurement of flow			
.1 explains the difference between a quantity meter and a rate-of-flow meter			*
.2. explains that a quantity meter is basically a rate-of-flow meter combined with an integrator			*
.3 describes the function of the two elements of a flow meter.			*
.4 sketches a graph to show the relationship between velocity of a fluid and its pressure difference	*		
.5 from objective 5.4 shows that velocity is proportional to the square root of the pressure	*		
.6 explains the situations when extraction's of square roots are necessary		*	
.7 describes the principal features of: -- a rotometer -- an electrical flow meter -- a rotameter		*	
		*	
.8 sketches an orifice and a venturi, showing the direction of flow and the pressure-measuring points		*	

Learning Objectives	Fully Covered	Partially Covered	Uncovered
.9 explains how a manometer can be used as a square-root extractor when measuring the pressure			*
.10 states that extraction of a square root can also be accomplished pneumatically and electrically		*	
6. Other measurements			
.1 explains the principles of a tachometer	*		
.2 explains the principles of a.c. and d.c. electric tachometers		*	
.3 explains the principles of a torque meter based of on the effect of stress in magnetic field		*	
.4 explains how objective 6.3 can be developed to measure power		*	
.5 explains the principal features of a viscometer		*	
.6 describes the application of a photoelectric cell to: an oil-in water sensor a smoke-density detector an oil-,sot detector a flame detector		*	
.7 describes the common types of fire detector			*
.8 describes the principal features of: --an explosive-gas detector -- a vibration monitor -- an oxygen analyser -- a CO <sub>2</sub> analyser -- a relative humidity meter -- salinity measurement -- a dissolved-oxygen meter -- a pH meter	*      *	*  * * *	*  *
.9 describes or performs routine setting up, testing and maintenance of the measuring devices included in objectives 2.7 to 6.8		*	
7. Transmission of signal			
Transmitters			
.1 describes the function of a transducer		*	
Pneumatic			
.2 describes the flapper and nozzle arrangement	*		
.3 explains that is meant by negative feedback and by positive feedback	*		
.4 sketches a flapper and nozzle arrangement with negative feedback	*		
.5 explains the function of a force-balance transducer		*	

Learning Objectives	Fully Covered	Partially Covered	Uncovered
.6 describes the principal features of an electropneumatic transducer		*	
Electrical			
.7 uses a Whetstone bridge used as a transducer		*	
.8 describes the principles of a variable-inductance transducer		*	
.9 describes the principles of a variable-capacitance transducer	*		
.10 describes the principles of an electronic force-balance system		*	
.11 describes the principles of an electronic force-balance system			*
Receivers			
.12 describes the principal features of: a pneumatic receiver integrator a potentiometric pen recorder			*
.13 explains the function of an XY recorder			*
.14 describes the basic principles of a.c- and d-c- position motors		*	
8. Final controlling elements Pneumatic			
.1 states that the final controller might be operated pneumatically, hydraulically or electrically		*	
.2 sketches a diaphragm-operated control valve		*	
.3 describes the characteristics of the motor element and the correcting element in objective 8.2		*	
.4 describes of, preferably, determines by experiment the flow characteristic and applications of: mitre valves vee-ported valves	*		
.5 explains what is meant by "turn-down ratio"			*
.6 describes the conditions which may dictate the need for a positioner		*	
.7 describes the principal features of a positioner			*
.8 explains the circumstances when piston actuators might be used			*
.9 describes the conditions where butterfly valve might be used		*	

Learning Objectives	Fully Covered	Partially Covered	Uncovered
.10 describes a wax-element temperature-control valve and states its normal temperature range		*	
Electrical servomotors			
.11 describes a d.c. servomotor and explains how it varies from the common motor		*	
.12 explains the problems of using a three-phase a.c. machine as a servomotor			*
.13 describes the applications of a two -phase a.c. servomotor, explaining how its characteristics can be varied		*	
Hydraulic servomotors			
.14 describes the principles of a swash plate pump			*
.15 explains the advantages of using high pressures			*
.16 explains the applications of a hydraulic ram servomotor			*
9. Control theory			
.1 sketches a simple automatic control system, using labelled blocks to show the principal elements in the controller, correcting and measuring units		*	
.2 sketches a graph of system response, demonstrating the effect of time lag between input and output signals of detection elements with a linear response		*	
.3 sketches a graph showing phase lag and attenuation (or gain) of input and output signals			*
.4 sketches a graph illustrating control by a two-step controller		*	
Proportional action			
.5 makes a single line sketch of a self-operating liquid level controller and explains its proportional control action		*	
.6 explains the meaning of proportional band		*	
.7 sketches a graph between controlled value and time, to show desired value, set value initial and final offset		*	
.8 states that different load conditions will produce different offsets which may, or may not be acceptable to the control function		*	

Learning Objectives	Fully Covered	Partially Covered	Uncovered
Integral action .9 states that the object of integral control is to		*	
.10 sketches a graph to show integral action against time and effect of varying the integral action		*	
Proportional plus integral action			
.11 sketches an arrangement showing the principle of a proportional plus integral (P + I) control loop			*
.12 sketches and integral control loop for controlling liquid level			*
.13 sketches a P & I control loop for controlling liquid level			*
.14 explains why integral action is not used alone			*
Derivative action			
.15 states that the object of derivative control is to give quicker response to a large change of load and to supplement inadequate proportional damping of control		*	
.16 states that the rate of action is dependent only on the rate of change in error	*		
.17 states that derivative control is transient and must be combined with proportional control (P + )			*
.18 states that adjustments to derivative action must be small to avoid instability	*		
Proportional plus derivative action			
.19 sketches a derivative control loop for controlling liquid level			*
Proportional plus derivative plus integral action			
.20 sketches a (P + D + I) control loop for controlling liquid level			*
.21 explains how the derivative action tends to stabilise a (P + D + I) control loop			*
.22 sketches a three-term controller			*
Split-range control .23 explains the meaning of split-range control	*		
.24 describes applications of split-range control	*		

Learning Objectives	Fully Covered	Partially Covered	Uncovered
Cascade Control .25 explains the principle of a cascade control system		*	
.26 describes the cascade control of the outlet temperature of diesel engine jacket cooling water with varying engine load and varying supply of cooling water		*	
10. Principles of pneumatic control			
.1 sketches the arrangement of a two-step controller, giving the range of air pressures used			*
.2 explains the purpose of a relay			*
.3 sketches a simple relay			*
.4 describes the action of a P + D controller with negative feedback			*
.5 describes the action of a P + D controller			*
.6 explains the principle of operation to a stacked-type controller for: proportional control proportional + integral control proportional + derivative control		*	
.7 explains the principle of a pulse controller	*		
.8 describes of carries out the procedure for adjuration: a proportional controller a two-term controller a three-term controller	*		
.9 performs routine test and maintenance procedures on pneumatic controller			*
11. Controllers			
.1 describes the principles of operation of and electropneumatic controller	*		
.2 sketches a force balance that uses a simple lever principle and describes how this can be used to obtain the following actions: -- proportional -- proportional + integral -- proportional + derivative -- proportional + integral + derivative -- addition or subtraction -- multiplication or division -- averaging	* * * * * * *		



Learning Objectives	Fully Covered	Partially Covered	Uncovered
.3 describes the principles of the Foxboro pneumatic controller and how to adjust it to give variation to the proportional band	*		
.4 describes the action of a Drayton pneumatic controller			*
.5 describes the principles of a fuel-air ratio controller			*
.6 describes the action of a viscosity controller			*
.7 performs routine test and maintenance procedures on the controllers covered by objectives 11.1 to 11.6			*
12. Control circuits			
.1 describes a single-element control for cooling water and lists its applications	*		
.2 describes a split-range control system for fuel-valve coolant	*		
.3 explains why two-element control is sometimes used in cooling systems	*		
.4 describes a two-element cascade control system for piston cooling		*	
.5 describes a control system for lubricating oil temperature	*		
.6 explains the principle of the following coolant systems: ring main series parallel			*
.7 describes a control system for purification of boiler fuel oil			*
.8 describes the control system of a flash evaporator that is heated by engine coolant			*
.9 describes the principles of the control of viscosity of oil fuel			*
.10 describes the principles of control of air conditioning			*
.11 describes the principles of control of a refrigerated chamber			*
.12 describes the principles of the control of the interface level of an oily-water separator			*
.13 describes the lighting-up sequence of an automatic combustion system for an auxiliary boiler	*		
.14 lists the possible reasons for non-ignition or flame failure in objective 12.13	*		
.15 performs routine test, maintenance and fault-finding procedures for the control systems covered by objects 12.1 to 12.15		*	

Learning Objectives	Fully Covered	Partially Covered	Uncovered
13. Remote control- diesel propulsion	*		
.1 states that the control can be electronic, electropneumatic, electrohydraulic or pneumatic			
.2 lists the malfunctions which would signal: alarm engine slow-down engine stop	*		
.3 lists the check which must be made by the control system when starting up a main engine	*		
.4 explains the reasons for limiting rapid engine movements	*		
.5 describes the means of transferring control from one station to another	*		
.6 describes the means of communication between the bridge and the engine-room control station	*		
.7 describes the principles of speed control when a vessel is fitted with a controllable-pitch propeller	*		
.8 describes a control system for a controllable-pitch propeller			*
.9 lists the alarms and indicators which are normally installed in a bridge control panel			*
14. Air supply			
.1 explains the need for instrument air of good quality	*		
.2 describes how the required quality of air can be provided	*		
.3 describes how water is removed from the air	*		
.4 describes the method of drying air	*		
.5 sketches a diagrammatic layout of a system for control and instruments	*		
.6 describes the principles of the following : automatic drain auto-unloader air-line filter filter regulator	*		
15. Monitoring systems			*
.1 desiccates sequences of alarm signals, to include: fleeting alarm condition first alarm in a series of alarms different light intensities and flashing periods audible alarms			*
.2 describes routine checking of alarm systems			*

Learning Objectives	Fully Covered	Partially Covered	Uncovered
.3 describes the basic principles of an alarm scanner and data logger			*
.4 explains the uses of information obtained from a data loggers			*

### Entry standards

Minimum entry standards are MOT second class part ( A ).So, the candidates who have already passed the MOT second class part ( A ) examination of the Union of Myanmar can not cover the level of module 21,( Marine Electrotechnology ) and module 23, ( Operation and Maintenance of Main and Auxiliary Machinery ) although they do cover module 12, (Mechanical Science) and module 20,(Marine Heat and Heat Engines) in IMO model course 7.04 as expressed in fundamentals of automation, instrumentation and control systems of IMO model course 7.02, chief and second engineer officer.

### Teaching aids

Facilities in AICS laboratory at the IMT cannot be divided in the same way as set out in module 9 of IMO model course 7.02. There are no separated parts as set out in the teaching aids section of module 9, while there are mini process models for pressure, temperature, level and flow and boiler air fuel ratios. Only the following are set up in related mini process models.

A2 : resistance thermometer

A3 ; no manometer

A4 ; diaphragm, differential- twin bellows

A5 ; probe element

A6 ; only electrical flow meter

A7 ; no instruments

A8 ; diaphragm-operated control valve with motor, correcting element and positioner

### **Assessment**

The AICS course at the IMT usually starts on Monday, and after five successive weekdays of classes, and private study at weekends and assessment of the students of this course is made on the following Monday. Assessment includes only objective type questions, such as ( a ) true or false questions, ( b ) multiple-choice questions and ( c ) short answer questions. The duration of the test is one hour.

## Chapter 5

### Upgrading Syllabus and Subjects for Automation

#### 5.1. Syllabus and lecture programme

##### **STCW95 Requirements on Automation**

In STCW Code A, which is the mandatory part of STCW95, the following is expressed regarding on the function of electrical, electronic and control engineering at the management level:

##### **Knowledge, understanding and proficiency**

##### **Theoretical knowledge**

Marine electrotechnology, electronics and electrical equipment

Fundamentals of automation, instrumentation and control systems

##### **Practical knowledge**

Operation, testing and maintenance of electrical and electronic control equipment, including fault diagnostics

The phrase “ **including fault diagnostics** ” is additional to STCW78 as well as to the objectives of Module 9 of IMO Model Course 7.02.

Therefore, now is the time to fully implement this IMO Model Course. First of all, the followings should be changed:

### **Entry standard**

As expressed in previous chapters, entry standards for AICS course of the IMT does not cover the entry standards expressed in the IMO model course. If the syllabi for marine engineer's certificates of competency used in the Union of Myanmar are examined, only the candidates who have already passed the MOT second class part B examination can meet the entry standards for this model course . So entry standards should be changed from MOT second class part A to MOT second class part B.

### **Subject outline and detailed teaching syllabus**

By compressing some parts of the course and reducing the total number of teaching hours, it clear that some parts of the course are not covered and some are just partially covered. So the compressed part of the course should be expanded to the level as expressed in the IMO model course. Therefore, the total number of teaching hours should be 71 hours as expressed in the model course; and hence the length of this course two weeks .

### **Assessment**

To promote the quality of the course, the method of assessment is also important to be considered. In addition to the multiple choice and true / false questions, which are included in recent assessment questions set, essay type questions should be added to evaluate the students' ability to deal with a complex problem and to demonstrate the depth of their understanding. Therefore, the duration of test should be extended from one hour to two hours.

However, it does not mean that IMO model courses are the maximum limit to be implemented. Moreover, as found in previous chapters, development of ship automation is very rapid and dramatic during these days. So the institute should try to upgrade the courses by using all available resources to reach the maximum possible level.

Therefore, other courses which can support the AICS course are suggested in the following sub-chapters.

## **5.2 Experimental facilities for electronics**

Fortunately, the following facilities are available in the electronic laboratory of the Institute of Marine Technology. However, these facilities have not been used for Automation, Instrumentation and Control Systems course. Therefore, these facilities should be used in upgrading the AICS course.

1. A-D converter ( counter type )
2. A-D converter ( comparison type )
3. D-A converter ( weighted resistor )
4. PWM-PPM, PPM-PAM converter
5. Mixer and PWM modulator
6. Linear sweep generator
7. Pulse generator and time divider
8. Demodulator and power amp
9. Schmidt , differential and integral circuit
10. Clamp, clip and limiter
11. Muller integrator and Bootstrap circuit
12. Astable and Bistable multivibrator
13. Blocking oscillator and monostable multivibrator
14. power supply ( conductor )
15. DC voltage stabiliser ( semiconductor )
16. metal oxide semiconductor
17. Logic trainer
18. Syncro servo
19. Semiconductor application ( power supply )
20. Diode transistor logic
21. Transistor-Transistor logic

- 22. Decoder and Encoder
- 23. Flip Flop
- 24. Hardware assembler
- 25 Sequence controller
- 26 Computer trainer

### **5.3 Boolean algebra and logic gates**

Boolean algebra is an algebra used for logic systems. Examples of logic systems are: digital computers, digital communications system, control system, and automated control system . Boolean algebra uses only three basic operation: AND, OR and NOT operation. There are five theorems in Boolean algebra for more than one variable, which are:

- \* Associative
- \* Cumulative
- \* Distribute
- \* Absorption
- \* De Morgan's

The logic function can be defined explicitly in the form of a table of state values called Truth Table. To understand Boolean algebra, the students should have acquired the set theory of mathematics. Fortunately, most of the young generation of marine engineers who have passed high school examinations have already learned the set theory in their basic education.

In modern control systems, computers ( especially digital computers ) are used more and more. In fact most of the computers are digital computers.

Logic circuits are what make things happen in digital computers. The major use of logic circuits is to perform arithmetic operations on numbers represented in terms of two- valued , or binary, signals. There are two principal types of logic circuits : those



made of switches and those made of gates. The most common type of building block used in design and analysis of logic circuits is the logic gate. In fact, a logic gate is an electronic circuit used to implement a Boolean function.

To get a certain output variable ( in binary number ) from variable inputs are needed depending on the function of the control system. Such exercises can be practised by students by using Boolean algebra, drawing the Truth Table and finally setting logic gates to form a logic circuit on a logic trainer in the electronic laboratory at the IMT. Therefore, a syllabus for Boolean algebra and logic gates should be added to the subject of Electrotechnology subject of second class part B refresher course to support the Automation course as a supporting subject.

#### **5.4 Other recently available additional supporting courses for AICS course at IMT**

##### **5.4.1 Electronics for engineers**

This course has been conducted based on IMO model course 2.09 since 1995. But to date it is not a compulsory course for marine engineers in Myanmar. The subject areas of this course are as follows:

1. Electrical Safety
  - 1.1 Safety requirements
  - 1.2 Electrical hazards
  - 1.3 Electrical first aid
1. Basic Electrical Principles
  - 2.1 Structure of matter
  - 2.2 Basic theory of electricity
  - 2.3 Properties of electric circuits
3. Operation of D.C. Circuits
  - 3.1 Circuit parameters
  - 3.2 Basic circuit arrangements

#### 4. Operation of A.C. Circuits

##### 4.1 Circuit parameters

##### 4.2 Basic circuit arrangements

#### 5. Solid- State Technology

##### 5.1 Properties of crystals

##### 5.2 Properties of semiconductor crystals

##### 5.3 Intrinsic conduction in a semiconductor crystal

##### 5.4 Impurity conduction in a semiconductor crystal

##### 5.5 The pn junction

#### 6. Electronic Components

##### 6.1 Passive components

##### 6.2 Active components

#### 7. Operation of Electronic Circuits

##### 7.1 Integrated circuit

##### 7.2 Feedback

##### 7.3 Circuit parameters

##### 7.4 Basic circuit arrangements

#### 8. Application

##### 8.1 Practical application

##### 8.2 Numerical problems

Moreover, voltage dividers, half-wave rectifiers, transistor D.C. amplifier, transistor A.C. amplifier, transistor switch, operational amplifiers with laboratory exercises are included in this course.

#### **5.4.2 Introductory Computer course**

This five- week course has been conducted in the IMT since 1990, co-operating with the Institute of Computer Science and Technology of the Ministry of Education of the Union of Myanmar. This course includes:

- \* general overview of computers
  - \* some software application
  - \* BASIC programming language

This course is open to marine officers who wish to acquire knowledge in computer application but not compulsory. As expressed in previous chapters, computers have become an essential device in modern ship automation. So this course would also support AICS course.

### 5.5 The curriculum of Fachhochschule Flensburg ( Germany )

Research Institute for Ship Operation of Fachhochschule Flensburg Polytechnic offers three types of courses to do with automation. They are Automation itself, directly related subjects and supporting subjects. Electronic Digital Control and Control Engineering are directly related subjects and Mathematics, Electronic Data Processing, Physics, Mechanics, Basic Electricity, Electrical Plants, Electrical Machinery and Marine Plants and Engines are supporting subjects.

The schedules for these subjects are shown in the Table 5.1 below.

**Table 5.1 Subject Outlines of Flensburg Polytechnic on Automation**

(a) Basic Study in Marine Engineering ( 3 semester )

Subjects	Semester1 (hours/week)	Semester2 (hours/week)	Semester3 (hours/week)
Mathematics	6	6	-
Electronic data processing	2	-	2 ( 2 )
Physics	-	2	2 ( 2 )
Mechanics	4	4	2
Basic Electricity	4	2	2 ( 2 )
Electronic digital control	-	2	2 ( 2 )
Control Engineering	-	2	2 ( 2 )

(b) Advanced Study in Marine Engineering ( 3 semester )

Subjects	Semester4 (hours/week)	Semester5 (hours/week)	Semester6 (hours/week)
Electrical plants	-	2	2
Electrical machinery	4 ( 2 )	( 2 )	-
Automation	2 ( 2 )	2 ( 2 )	2
Marine plants and engines	4	2 ( 2 )	2

Source: Rickert.F. (1997, Lecture Notes )

( ) = laboratory

1 lecture hour = 45 minutes

1 laboratory hour = 30 minutes

1 semester = 16 to 18 weeks

Obviously,

Total number of lecture hours in Automation

$$\begin{aligned} \text{for semester 4, 5, and 6 (minimum)} &= (2 + 2 + 2) (45 / 60) (3) (16) \text{ hours} \\ &= 216 \text{ hours} \end{aligned}$$

Total number of laboratory hours in Automation

$$\text{for semester 4, 5, and 6} = 144 \text{ hours}$$

### 5.6 Some suggestions by the visiting professors of WMU on modern ship automation

With regard to adjustments on automatic control systems which can be made onboard the ship, **Joop Splinter**, one of the two WMU visiting professors on automation from Hogeschool van Amsterdam ( TMF ) of The Netherlands expressed as follows:

In practice, a lot of the values of the transfer functions of the processes onboard the ship designed by the manufacturers can change due to the dirt, wear and tear of the process.

Such kind of processes are mostly heating systems, such as water / steam heating, viscotherm and so on. These systems are likely to be adjusted on board a ship.

The controllers for main and auxiliary engines are partially adjustable by referencing the main values given by the manufacturer without allowing the speed of the engine to go up and down. Some functions of engine controller can be adjusted and must be adjusted on board a ship.

To be able to adjust the adjustable automatic control systems, in theory, the transfer function of the system must be understood although this is not the case in practice.

When some systems are not completely known, the prediction can be made that the system behaves like a first order process and for such cases the rules of Ziegler & Nichol are the only helpful tools besides the values given by the manufacturer.

However, some systems such as the level control of a boiler are not adjustable on board a ship because fluctuations in water levels and hence, lack of water flow through the pipes can damage the pipes of the boiler due to possible extreme heat.

Dr. F . Rickert from Flensburg, another WMU visiting professor on automation pointed out roughly that higher mathematics is not needed so much for marine engineers who have to do the job related to automatic control systems onboard the ship.

He claimed that the main problem is that there is no text book specialised for marine engineers covering modern developments in ship automation. He added, moreover such text books are necessary to be modified every two years because of very rapid and dramatic changes in this field.

## Chapter 6

### Conclusion and Recommendations

#### 6.1 Conclusion

During the last decade the developments of automation applicable to ships were very rapid and drastic and are still being continued in every area of ship operations.

By incorporating information technology, widely used up to LAN, it is technologically feasible that all ship operations can be integrated and controlled from one place, such as in an integrated bridge control system. On the other hand, by integrating in that way automatic control systems become more and more complex. Further, an increase in automation is always followed by reduced manning.

So even to operate the automatic control systems on board the ships, reduced crew needs to have enough understanding and skills about the systems. Nowadays in some developed countries, it is considered that the basic knowledge of automatic control systems is necessary to be taught even to deck officers.

An advanced condition monitoring system can lead the repair and maintenance system of ships from the corrective maintenance system concept to the preventive maintenance system concept. The mean time between overhaul (MTBO) for a slow speed diesel engine can be achieved up to 25,000 hours in standard conditions. Major

overhaul of ship machinery will be carried out ashore. This will lead to an increase in sailing time and reduced over all maintenance of machinery on board.

Moreover, most decision making on operations, maintenance and repair of all the major pieces of machinery have to be made relying on the data given by the related automatic control systems.

No matter how the automatic control systems are developed, human beings are still needed not only to operate them properly and efficiently but also to respond to emergency cases which can occur, caused by unexpectable or unpredictable internal or external disturbances.

The world is now in the so called second industrial revolution. By nature, it is unavoidable for developing countries to follow the developing trend. Accordingly, developing countries also have to use highly automated ships in their national fleet in the near future. It is therefore necessary to educate and train thoroughly their marine engineers to be competent in ship automation to serve in their own national fleet as well as to serve in international fleets.

Therefore, marine engineers onboard ships have to be able to diagnose whether the automatic control systems are working properly or not and to make adjustments accordingly. Thus, conventional marine engineers will probably be trained to become almost specialist control engineers in the 21st century in addition to their conventional expertise.

Therefore the AICS courses for the future should be able to provide the following:

- \* Knowledge of common onboard measuring, steering, control and alarm systems, their installation, composition, function use and maintenance;
- \* Knowledge of computer-based measuring, steering, control and alarm systems, their installation , composition , function, use and maintenance;

- \* Knowledge of the analysis of errors / failures in measuring, steering, control and alarm systems;
- \* Proficiency in calibrating, starting up and adjusting measuring and control systems;
- \* Proficiency in reading and interpreting documentation about instrumentation technique; or  
Practical knowledge of how to read and understand technical manuals;
- \* Knowledge of the theories on which to base the consideration of technical control problems; or  
Competent understanding of the theories of linear systems; or  
Understanding of control theories;
- \* Competence in analysing and criticising offers from dealers of commercially available equipment;
- \* Understanding of the functions of advanced control methods; or  
Practical knowledge to understand the function of advanced controllers;
- \* Acquaintance with developing trends within measuring and control technique or  
Knowledge about new developments in the field of measurement and control.

Accordingly, the content of the future AICS courses should include the followings:

### **Part A**

#### Measuring technology

##### 1. The accuracy of the system

- \* Sensors for temperature, pressure, level, flow, force, angle, revolution, density, conductivity, pH, viscosity, concentration and humidity ( moisture );
- \* Signal standards converters: Analog to Digital ( A/D ) and Digital to Analog (D/A ) calibration- exercise.



## 2. Control Engineering ( Techniques )

- \* Process dynamics : stage answers, time constants and downtime.
- \* Control principles: Constant control, P ( proportional ), PI ( proportional + integral), PD ( proportional + derivative ) and PID ( proportion + integral + derivative ) control.

## PART B

### 1. Control Engineering ( technique )

- \* Cascade control, split range control, two-step control, multiple step control, floating control, self-adapting control;
- \* Optimisation and adjustment with practical exercise;
- \* Working principles and components :
  - pneumatic, hydraulic, electronic and computerised controllers and auxiliary components;
- \* Computerised monitoring systems, CSC, DDC and bus oriented systems.
  
- \* Logic algebra.
- \* Steering principles combination; time and sequence steering.
- \* Working principles: relay, electronic and computerised systems.

### 2. System for measurement, alarms, steering and control

- \* Examples of systems onboard: Construction, function and operation.
- \* Reading of drawings and simple fault diagnosis or trouble shooting.

## PART C

### 1. Control theory, analysis

- \* Evaluation of systems with frequency response analysis.
- \* Bode diagram and Nyquist diagram

## 2. Sequential Control

- \* Sequential control and interlocks
- \* Solution of sequential control problem

## PART D

### 1. Control theory, system analysis.

- \* Stability analysis, accuracy and speed
- \* The principles of adaptive controllers
- \* Non-linear process.

### 2. Measurement, alarm, and control-systems.

- \* CSC, DDC , bus oriented system and LAN
- \* Example of computerised system on board: construction, function, operation and fault diagnosis or trouble shooting.
- \* Exercise in operation and programming of system for steering, control and alarms systems.

## **6.2 Recommendations**

In order to accomplish AICS courses which can cover modern developments in ship automation, in the future, the following recommendations are made related to the IMT of the Union of Myanmar.

### **Detailed teaching syllabus**

To develop its own detailed teaching syllabus, experts who are highly qualified in the related specific field and a great deal of research work in modern developments are needed. For these reasons, it is impossible for the IMT to develop its AICS courses in this way. Therefore, IMO training advisors and consultants should be requested to make further developments by reviewing recent model courses for AICS courses in the same way they did to implement STCW78.

### **Teaching aids**

Until now, most maritime education and training systems are knowledge-based. Trainees and junior officers gradually acquire the necessary skills, under the guidance of more experienced colleagues on board ships, by applying their theoretical knowledge already obtained from education and training.

Because of the reduced manning trend, the above systems are not suitable in the future. Therefore, laboratory and simulator training will become necessary in the near future.

Similar to difficulties in other institutes of developing countries, the IMT of the Union of Myanmar needs technical assistance and funding to purchase laboratory equipment and simulators. To solve these problems, the government of the Union of Myanmar may request technical assistance from IMO and also negotiate with shipping companies for funds to purchase such equipment.

### **Teaching staff**

Teaching staff participate in a vital role in achieving the objectives of the education and training system. Therefore, they should be given the opportunity to upgrade their knowledge of advanced technologies in their related specific fields. This could be achieved in two different ways:

- \* by making provision for them to attend specialised courses in an advanced university, such as the Research Institute for Ship Operation at Flensburg Polytechnic in Germany.
- \* by allowing them to serve for short periods on ships fitted with modern equipment and design.

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