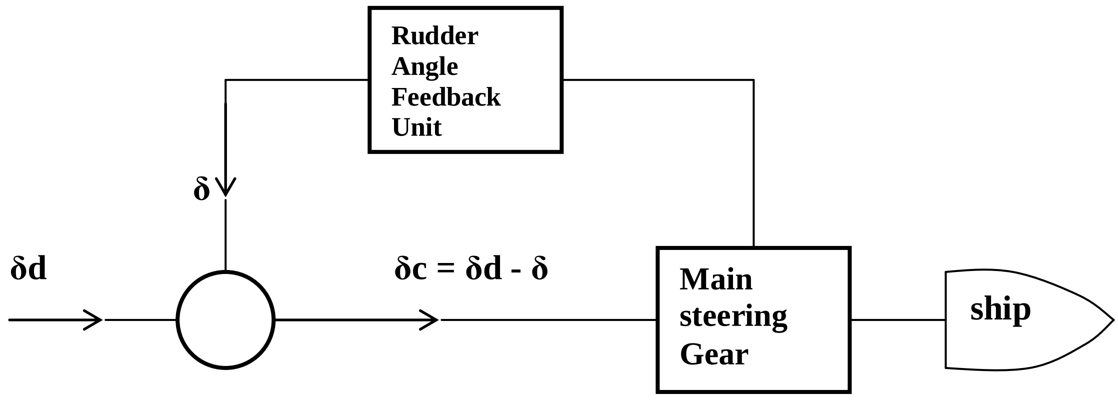
Ship Steering

Rudder Control Loop



δ rudder angle signal
δd rudder demand signal **$\delta c = \delta d - \delta$**
δc rudder command signal

This loop positions the rudder and is controlled by the rudder demand signal δd from a hand helm (fixed wheel or portable hand unit) or the controller of an autopilot .

The rudder demand signal is compared with a rudder angle signal δ from the rudder repeatback unit to produce a rudder command signal δc . The rudder command signal energizes the appropriate solenoid on the direction control valve .

The rudder moves to an angular position where the rudder angle signal and rudder demand signals are equal . The rudder command signal is zero . This is termed FOLLOW UP action since the rudder position will follow changes of the rudder demand signal from the steering wheel . The helmsman employs this action to steer the ship and maintain the lubber line on a demanded heading .

Manual Steering

The navigator instructs the helmsman (or wheelsman) to steer a demanded heading using the gyrocompass or magnetic compass .

The helmsman visually assesses , on the compass , the difference between the demanded heading and the direction of the ship's head as indicated by the compass lubber line . This difference is termed the heading deviation or heading error .

In order to reduce the heading deviation the helmsman turns the steering wheel and generates a rudder demand signal which activates the steering gear and positions the rudder.

The helmsman observes the position of the rudder on the rudder angle indicator . When the ship's head begins to swing toward the demanded heading he will position the rudder amidships . He may position the rudder in the opposite direction , termed counter rudder , so that the ship , due to its large inertia , comes to rest pointing in the correct direction without overshoot .

He must then maintain the lubber line as close as possible to the course , or intended heading , he has been instructed to steer .

The overall performance of a ship being manually steered is greatly influenced by the ability of the helmsman . His reactions are based on an overall assessment of the information he receives in the form of visual signals , both quantative , from the rudder angle indicator and compass , and subjective in the form of visual clues from the external environment .

Manual steering is necessary in port approaches and heavy traffic where specific course alterations are required ; the helmsman may sometimes be instructed to apply various degrees of rudder angle .

Abilities of a Helmsman

The abilities of an experienced Helmsman in a manual steering loop are :

(i) Knows how many degrees of rudder to apply for a given heading deviation
(ii) Knows if a ship requires permanent helm to counteract a constant disturbance
(iii) Knows if counter rudder is required to prevent overshoot
(iv) Knows not to apply any rudder unless the ship veers off the demanded heading beyond a certain limit .

AUTOPILOT OR AUTOHELM

The automatic steering gear should be as good as an experienced Helmsman . Most automatic steering systems can be designed to give a more consistent and desired standard of performance . The disadvantage of a human operator as part of a continuous feedback control loop are :

(i) attention can wander
(ii) fatigue and mental stress can affect performance
(iii) high cost of man hours

An automatic steering system , autopilot or autohelm , should perform two main functions :

(i) deviate ship's heading as little as possible from course despite external disturbances from wind and sea , this is termed COURSE KEEPING .

(ii) Change course smartly with minimum overshoot , this is termed COURSE CHANGING .

(iii)

Both the above should be accomplished with minimum rudder movement to minimize

(i) steering gear wear which can ultimately degrade steering performance .
(ii) drag , to keep fuel consumption low

Maximum fuel economy ,assuming constant thrust power , requires the sailing distance to be covered in minimum time . This requires reduction of course errors , which can cause elongation of distance (negligible effect) , and the reduction of rudder drag with consequent loss of forward speed .

AUTOMATIC STEERING CONTROL LOOP

The navigator sets the course selector to the demanded heading ψd . The heading demand signal is compared with the ship's heading signal ψ given by the gyro or magnetic compass and any difference , termed heading deviation ψe , is processed by the controller to produce a suitable rudder demand signal δd .
The rudder control loop , as previously described , positions the rudder such that $\delta=\delta d$ and δc is zero .
The ship's heading ψ will change and in a direction so as to reduce the heading deviation ψe .
The only position of equilibrium , or steady state , is when the ship is on course and there is zero error in both control loops .

$$\psi = \psi d \ ; \ \psi e = 0 \quad \text{and} \quad \delta = \delta d \ ; \ \delta c = 0$$

In practice the condition of equilibrium is disturbed by the ship's propulsion and the effects of wind , tide and sea state . Wind and tide are often relatively permanent biases . In order to compensate for these disturbances the rudder demand signal is normally set , by controls within or on the controller , to equal the sum of a series of quantities derived from the heading deviation signal .

AUTOMATIC STEERING CONTROL LOOP

ψ heading

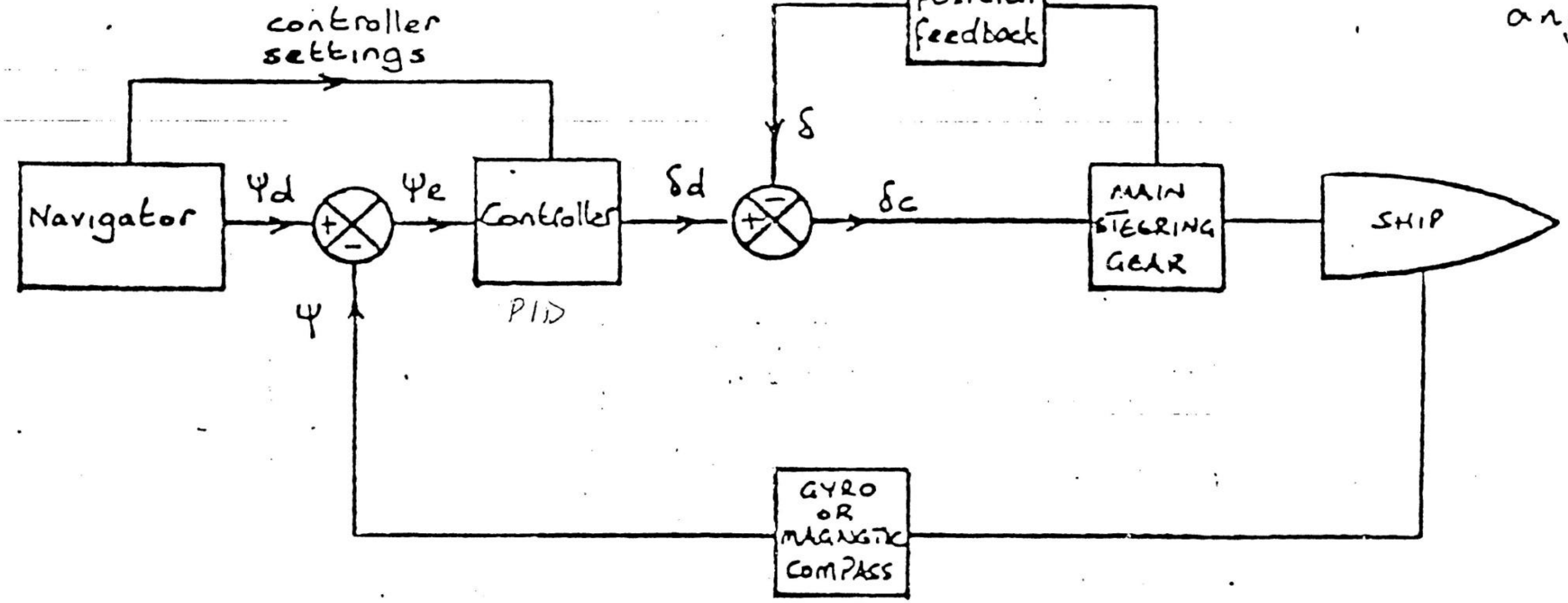
ψ_d heading demanded

ψ_e heading deviation (error)

δ rudder angle

δ_d demanded rudder angle

δ_c commanded rudder angle



Q- With reference to an auto pilot which uses three terms controller system:

- a- Identify the three terms. (4m)
- b- Name each with its corresponding auto pilot control. (4m)
- c- Describe the function of each item. (12m)

a- Proportional, Derivative & Integral terms

b-

- A quantity proportional to heading deviation ' The Proportional Term'.
- A quantity proportional to the rate of change of the heading deviation ' The Derivative Term'.
- A quantity proportional to the integration of the heading deviation ' The Integral Term'.

c-

g1 **Proportional term**: The proportional circuit produces signal when heading deviation is present and the gain determines the rudder angle achieved for each degree of heading deviation. The related gain control can be labelled gain, rudder, rudder multiplier, rudder, ratio and rudder response.
The controller adjust the gain between approximately 0.5 and 3 . Thus for example 3 degrees of heading error will result in rudder angle any where between 1.5 and 9 degrees depending on gain setting.
It is set as lowest as possible without the ship wondering from the demanded heading. A higher setting is required when the ship is loaded or is operating at reduced speed. Too high setting without further control features causes instability or oscillation about the demanded heading.

g2 **Derivative term**: The derivative circuit produce a signal when the heading of the vessel is changing. The high inertia of the ship and the proportional gain setting will cause to over shoot and oscillate about the demanded heading. The derivative signal will provide damping and reduction of the setting time. The gain of the derivative term is used to compensate for low changes. A ship in ballast needs less counter rudder.
The related gain control can be labelled counter rudder or rate multiplier. , rate.

g3 **Integral term**: Due to wind hitting the ship's structure, tides and the effect of the ship's proportion (propulsion), it may be that with rudder in mid-position, the ship steer slightly to port and starboard. The integral circuit give a bias to the rudder to maintain ship's heading on the demanded heading. The related gain is normally pre-set during ship's trial. In some auto pilot the rudder bias is manually applied by a control which can be labelled: standing helm, permanent helm, weather helm, rudder off set or rudder trim.

Controller

The Rudder demand Signal at the o/p of Controller is the sum of Three signals which are desired from the Heading error signal at the i/p to the Controller.

$$S_d = g_1 \varphi_e + g_2 \frac{d\varphi_2}{dt} + g_3 \int_{T}^{0} \varphi_e \, dt$$

Rudder demand Signal = Proportional Term + Derivative Term + Integral term

(5)

(i) RUDDER :

Modifies the ratio of the number of degrees of rudder ordered to correct a given course error. Increasing the setting increases the amount of rudder ordered.
A fully loaded vessel or a vessel moving at slow speed requires more rudder to correct a given course error than one in the light condition or when moving at a higher speed. In heavy weather the setting may have to be increased.

(ii) WEATHER:

Creates a band in which no action is taken by the controller and allows the vessel to recover naturally from repetitive yaw. Inc-reasing the setting increases the amplitude of yaw that can occur before rudder is ordered by the controller. Used in heavy weather and sea conditions where it may require frequent adjustment.

(iii) COUNTER RUDDER:

Adjusts the amount of counter rudder ordered by the controller to compensate for the rate of change of course error. If the setting is increased more counter rudder is ordered.
The use of this control helps to prevent overshoot when a vessel returns to course and also to prevent large course errors building up ie a developing course error is anticipated and counter rudder ap-lied before a significant error can build up.
In heavy weather this control may have to be reduceced to allow the vessel to yaw naturally.

(iv) PERMANENT HELM :

This control applies a permanent rudder angle bias such that rudder may be applied even when no course error exists. It is used when the vessel falls off course more to one side than the other to wind or sea conditions or the steering stability of the vessel.

Note: Permanent helm is frequently applied automatically (Integral Controller Action) where it is automatically reset after each course change.

(v) RUDDER LIMIT:

Sets a limit on the rudder angle that may be used.

ADAPTIVE STEERING MODULE (ASM)

In order that good course keeping is maintained at all times the watch officer will have to make frequent adjustments to the manual controls, eg rudder, weather, counter rudder etc. This is not always possible when the officers workload is high and when course, speed, wind and sea conditions are continuously changing.
An ASM is simply an autopilot using PID control techniques linked to a microcomputer. Contained in the computer is data relating to the heaviour of a "model ship". Course keeping performance is continuously fed to the computer where it is compared against that of the model ship and rudder commands for the actual ship are predicted. The computer ensures that corrective rudder is only used when course keeping is affected by environmental conditions and not by the natural yaw of the vessel. An ASM will continuously adjust the rudder commanded to meet the prevailing conditions and there is no need for

the watch officer to make manual adjustments.

The benefits of an ASM are:

(i) Removes the need for operator adjustments.

(ii) Ships natural yaw not smoothed out which reduces the need for excessive rudder angles or movements resulting in less rudder drag and wear on the steering gear.

(iii) Improves fuel consumption.

(iv) Achieves good course changing stability which is important in coastal waters.

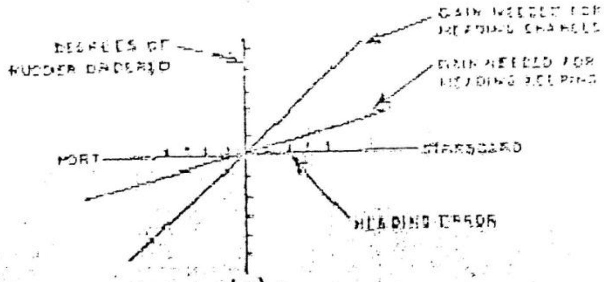
Double gain (Dual Gain) Weather Control

The weather adjustment or sea-condition control together with the dual gain signal processor allows Bridge personnel to provide proper automatic Pilot responsiveness under different sea conditions, In certain seas particularly quarterly seas, ships' dynamics and rudder characteristics do not permit heading to be maintained too closely. Attempting to do so only causes excessive rudder activity with no noticeable increase in heading keeping performance. Here is how the Dual Gain signal processor and weather adjustment performed.

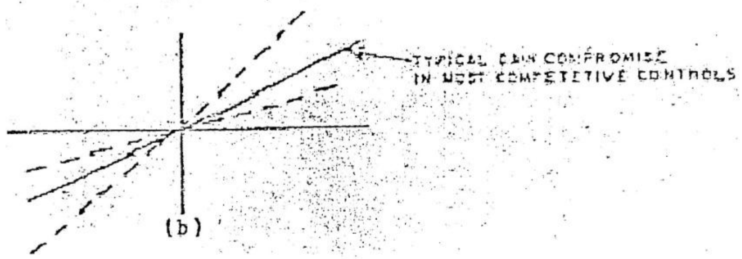
Gain in steering control terminology means the amount of rudder order per degree of heading deviation. Dynamically ships need higher gain to make heading changes smartly and a lower but no zero gain when keeping heading. With single gain auto pilot controls, the gain selected is a compromise as shown in figure(b) which favors heading keeping, often resulting in sluggish heading changes. Furthermore, most automatic steering controls de-sensitize their controls in heavy seas by inserting a "Dead Zone" to avoid excessive rudder activities. Dead zone as used in a steering control is a band in the control system whose width or limits in terms of degree of yaw, right or left, must be exceeded before the rudder is moved. In other systems the width or limits of Dead zone are set by the weather adjustments. Higher settings correspond to a wider Dead zone. Effective control gain in the Dead zone is zero thus ships with auto pilots using these form of control must yaw in excess of zone limit before rudder is applied to correct heading error. this type of control design allows the ship to wallow or meander in an un-controlled manner while in Dead zone. When the ship has exceeded band limits, rather large excursions can result. These large rudder excursions in effect slap the ships to bring her head to an indeterminate position within the Dead zone.

Furthermore, a steering gear itself may develop its own dead zone or slack due to mechanical wear, response time, or possibly design. When a control system Dead zone is superimposed on the Dead zone in the steering gear, stability of the system deteriorates. Unwanted rudder oscillation can occur, giving excessive steering engine and rudder activity. If rudder activity is reduced by decreasing the gain using operator controls, less accurate heading keeping results.

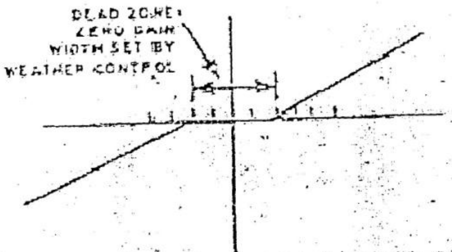
With the Dual gain control design of auto pilots, no Dead zone exists. Rudder position and hence vessel's head is under control at all times. The weather adjustment selects the switch over points between the two gains. This design feature permits the control circuits to be sensitive to the faint initial effects of those forces caused by sea, wind, hull or propulsion characteristics. If uncorrected , small forces can cause large heading deviation. To counteract these forces early, the auto pilot control orders small amounts of corrective rudder. If the ship should yaw outside the low gain band, the high gain available automatically orders proportionally greater amounts of rudder up to the selected rudder angle limit to keep the ship heading correct. Once the ship head is within limits of the low gain band, the gain is automatically reduced. With this system, the vessel is under total control at all times without instability or excessive rudder activity with minimum rudder drag and low fuel consumption.



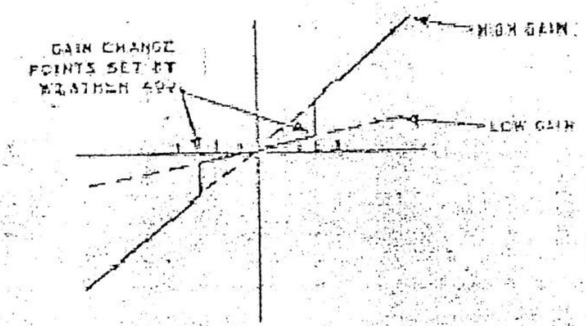
(d)



(b)



(c) SINGLE GAIN PROPORTIONAL CONTROL



(d) DUAL GAIN PROPORTIONAL CONTROL

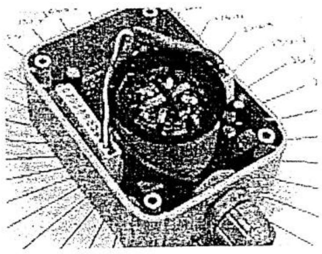
FLUXGATE

The basic **fluxgate compass** is a simple electromagnetic device that employs two or more small coils of wire around a core of highly permeable magnetic material, to directly sense the direction of the horizontal component of the earth's magnetic field. The advantages of this mechanism over a magnetic compass are that the reading is in electronic form and can be digitized and transmitted easily, displayed remotely, and used by an electronic autopilot for course correction.

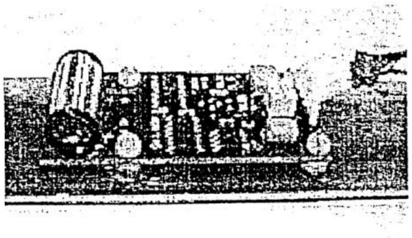
To avoid inaccuracies created by the vertical component of the field, the fluxgate array must be kept as flat as possible by mounting it on gimbals or using a fluid suspension system. All the same, inertial errors are inevitable when the vessel is turning sharply or being tossed about by rough seas. To ensure directional readings that are adequately stable, marine fluxgate compasses always incorporate either fluid or electronic damping. An alternative is to use a 3-axis fluxgate magnetometer to provide a 3D flux vector, and the magnetic heading is derived from the flux on a plane perpendicular to gravity, thus providing immunity from pitching, and rolling.

Fluxgate magnetometer

A fluxgate magnetometer consists of a small, magnetically susceptible, core wrapped by two coils of wire. An alternating electrical current is passed through one coil, driving the core through an alternating cycle of magnetic saturation, *i.e.,* magnetized - unmagnetized - inversely magnetized - unmagnetized - magnetized. This constantly changing field induces an electrical current in the second coil, and this output current is measured by a detector. In a magnetically neutral background, the input and output currents will match. However, when the core is exposed to a background field, it will be more easily saturated in alignment with that field and less easily saturated in opposition to it. Hence the alternating magnetic field, and the induced output current, will be out of step with the input current. The extent to which one is the case, will depend on the strength of the background magnetic field. Often, the current in the output coil is integrated, yielding an output analog voltage, proportional to the magnetic field.



A fluxgate compass/inclinometer

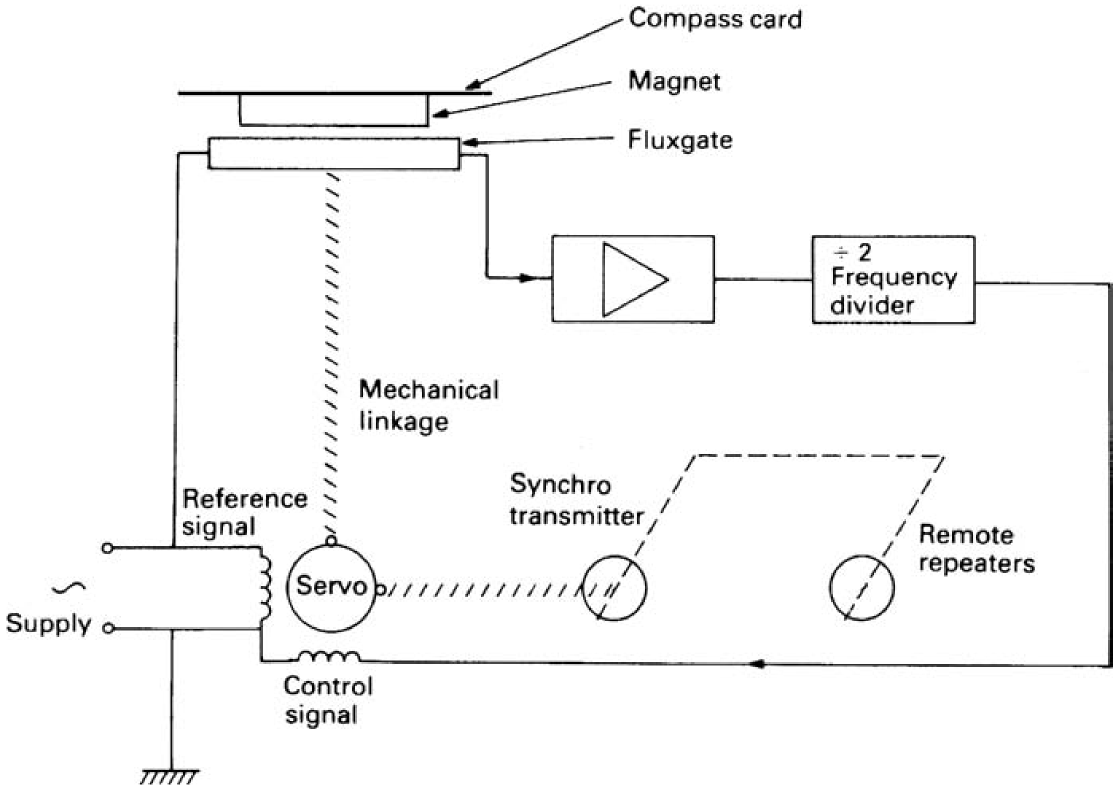


A uniaxial fluxgate magnetometer

A wide variety of sensors are currently available and used to measure magnetic fields. Fluxgate magnetometers and gradiometers measure the direction and magnitude of magnetic fields. Fluxgates are affordable, rugged and compact. This, plus their typically low power consumption makes them ideal for a variety of sensing applications.

The typical fluxgate magnetometer consists of a "sense" (secondary) coil surrounding an inner "drive" (primary) coil that is wound around permeable core material. Each sensor has magnetic core elements that can be viewed as two carefully matched halves. An alternating current is applied to the drive winding, which drives the core into plus and minus saturation. The instantaneous drive current in each core half is driven in opposite polarity with respect to any external magnetic field. In the absence of any external magnetic field, the flux in one core half cancels that in the other and the total flux seen by the sense coil is zero. If an external magnetic field is now applied, it will, at a given instance in time, aid the flux in one core half and oppose flux in the other. This causes a net flux imbalance between the halves, so that they no longer cancel one another. Current pulses are now induced in the sense winding on every drive current phase reversal (or at the 2nd, and all even harmonics). This results in a signal that is dependent on both the external field magnitude and polarity.

There are additional factors that affect the size of the resultant signal. These factors include the number of turns in the sense winding, magnetic permeability of the core, sensor geometry and the gated flux rate of change with respect to time. Phase synchronous detection is used to convert these harmonic signals to a DC voltage proportional to the external magnetic field.



A flux gate system used in conjunction with a Magnetic compass

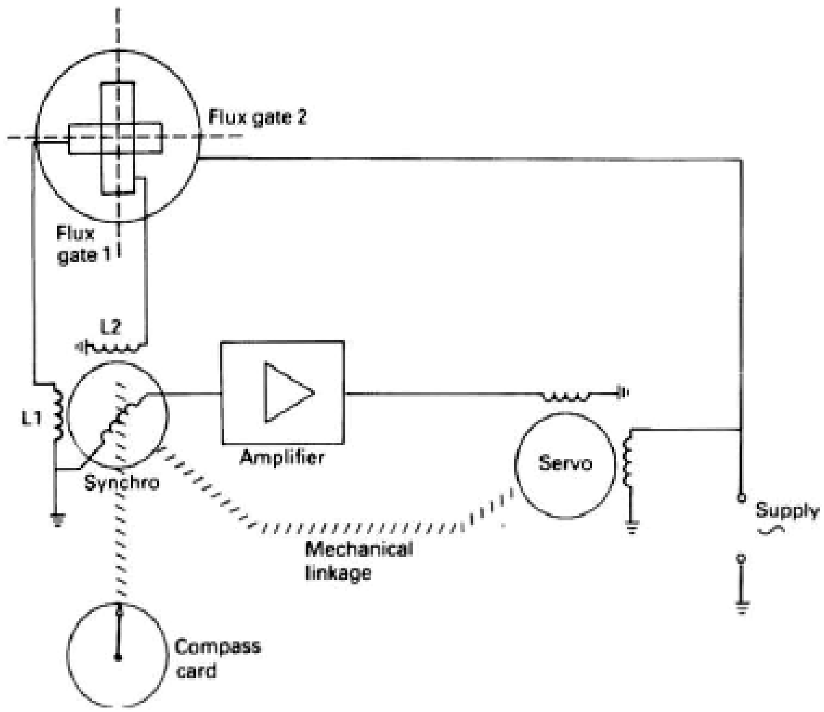


Figure 8.53 A simplified diagram of a dual axis magnetometer type of magnetic compass.

Chapter 9

Automatic steering

9.1 Introduction

It has already been implied that a modern merchant vessel must be cost-effective in order to survive the ever-increasing pressure of a financially orientated industry. A good automatic pilot, often called an Autohelm, although a registered trade name, can improve the profit margin of a vessel in two ways. First, it enables a reduction to be made in the number of ships' personnel, and second, a considerable saving in fuel can be achieved if the vessel makes good its course with little deviation. This chapter, dealing with the principles of automatic pilots, enables the reader to understand fully the electronic systems and the entire operator control functions.

Early autopilots were installed in the wheelhouse from where they remotely operated the vessel's helm via a direct drive system as shown in Figure 9.1. This figure gives an excellent indication of system first principles.

Although efficient, the main drawback with the system was the reliance upon a hydraulic telemotor system, which required pressurized tubing between the transmitter, on the ship's bridge, and the receiver unit in the engine room. Any hydraulic system can develop leaks that at best will cause the system to be sluggish, and at worst cause it to fail. To overcome inherent inefficiencies in hydraulic transmission systems, they have been replaced with electrical transmitters, and mechanical course translating systems have been replaced with computer technology.

9.2 Automatic steering principles

Whatever type of system is fitted to a ship, the basic principles of operation remain the same. Before considering the electronic aspects of an automatic steering system it is worthwhile considering some of the problems faced by an automatic steering device.

In its simplest form an autopilot compares the course-to-steer data, as set by the helmsman, with the vessel's actual course data derived from a gyro or magnetic repeating compass, and applies rudder correction to compensate for any error detected between the two input signals. Since the vessel's steering characteristics will vary under a variety of conditions, additional facilities must be provided to alter the action of the autopilot parameters in a similar way that a helmsman would alter his actions under the same prevailing conditions.

For a vessel to hold a course as accurately as possible, the helm must be provided with data regarding the vessel's movement relative to the course to steer line. 'Feedback' signals provide this data consisting of three sets of parameters.

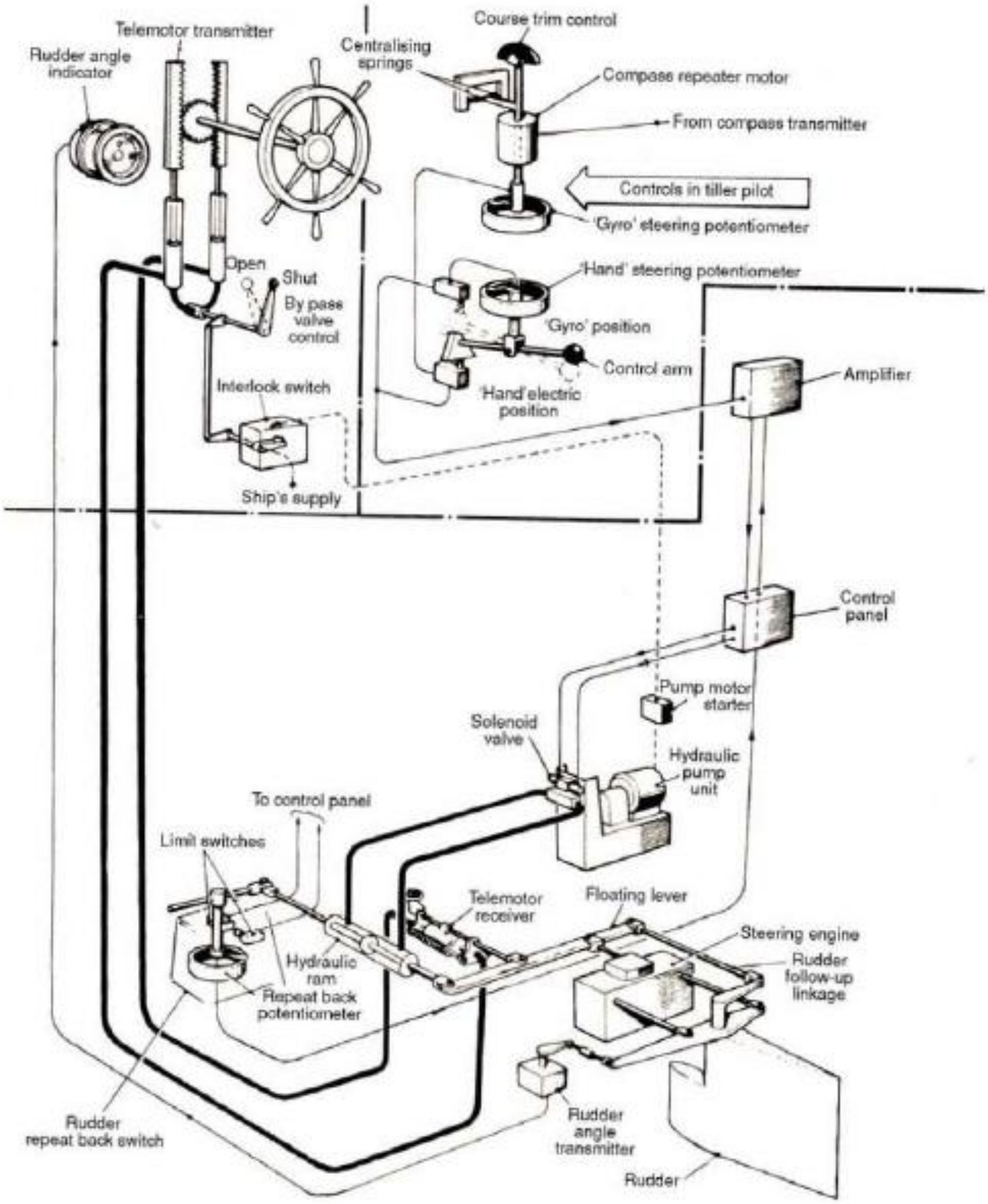


Figure 9.1 An early electro-mechanical autopilot system using telemotors. (Reproduced courtesy of Sperry Ltd.)

- Position data: information providing positional error from the course line.
- Rate data: rate of change of course data.
- Accumulative error data: data regarding the cumulative build-up of error.

Three main control functions acting under the influence of one or more of the data inputs listed above are: proportional control, derivative control and integral control.

9.2.1 Proportional control

This electronic control signal causes the rudder to move by an amount proportional to the positional error deviated from the course line. The effect on steering, when only proportional control is applied, is to cause the vessel to oscillate either side of the required course, as shown in Figure 9.2. The vessel would eventually reach its destination although the erratic course steered would give rise to an increase in fuel expended on the voyage. Efficiency would be downgraded and rudder component wear would be unacceptable.

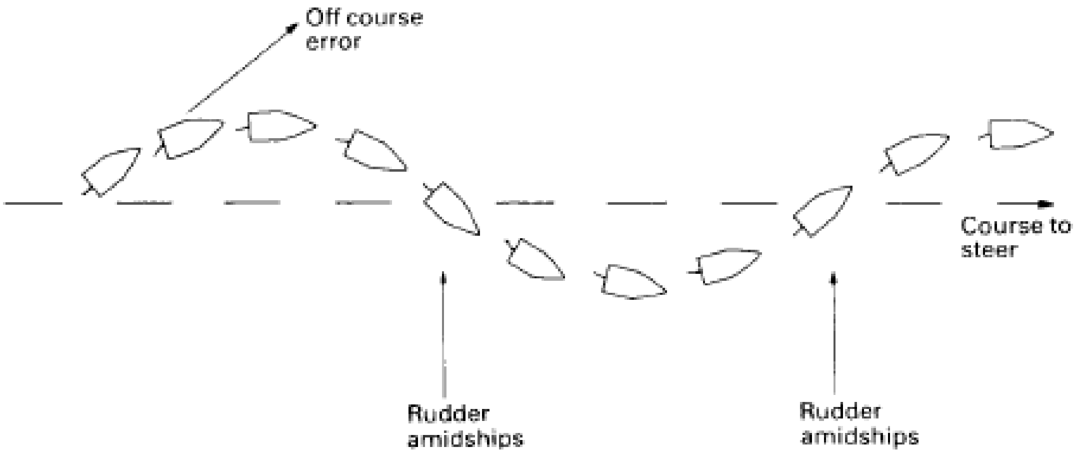


Figure 9.2 The effect of applying proportional control only. The vessel oscillates about the course to steer.

At the instant an error is detected, full rudder is applied, bringing the vessel to starboard and back towards its course (Figure 9.2). As the vessel returns, the error is reduced and autopilot control is gradually removed. Unfortunately the rudder will be amidships as the vessel approaches its course causing an overshoot resulting in a southerly error. Corrective data is now applied causing a port turn to bring the vessel back onto course. This action again causes an overshoot, producing corrective data to initiate a starboard turn in an attempt to bring the vessel back to its original course. It is not practical to calculate the actual distance of the vessel from the course line at any instant. Therefore, the method of achieving proportional control is by using a signal proportional to the rudder angle as a feedback signal.

9.2.2 Derivative control

With this form of control, the rudder is shifted by an amount proportional to the 'rate-of-change' of the vessel's deviation from its course. Derivative control is achieved by electronically differentiating the actual error signal. Its effect on the vessel's course is shown in Figure 9.3.

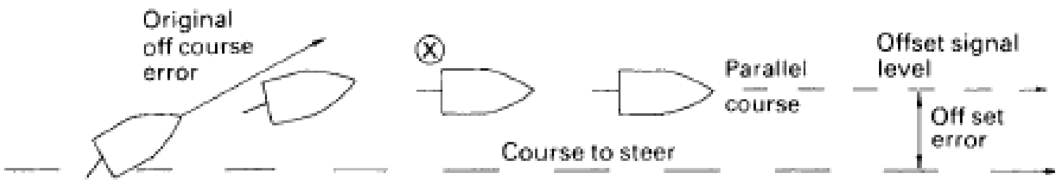


Figure 9.3 The effect of applying derivative control only.

Any initial change of course error is sensed causing a corrective starboard rudder command to be applied. The rate-of-change decreases with the result that automatic rudder control decreases and, at point X, the rudder returns to the midships position. The vessel is now making good a course parallel to the required heading and will continue to do so until the autopilot is again caused to operate by external forces acting on the vessel.

An ideal combination of both proportional and derivative control produces a more satisfactory return to course, as shown in Figure 9.4.

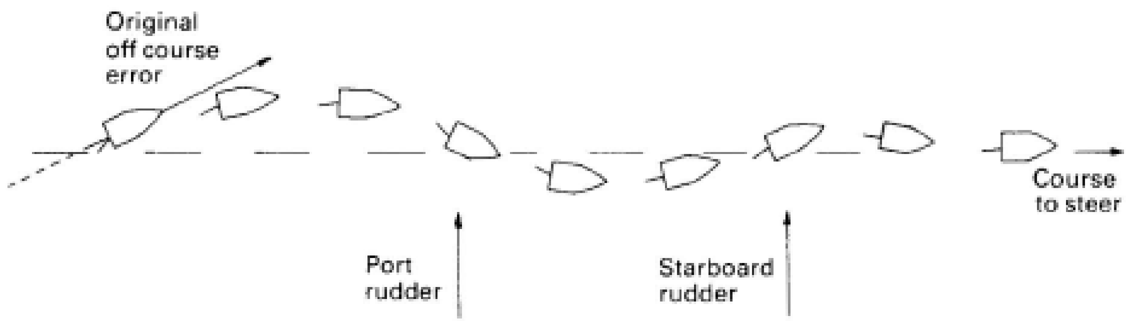


Figure 9.4 Applying a combination of proportional and derivative control brings the vessel back on track.

The initial change of course causes the rudder to be controlled by a combined signal from both proportional and derivative signals. As the vessel undergoes a starboard turn (caused by proportional control only) there is a change of sign of the rate of change data causing some counter rudder to be applied. When the vessel crosses its original course, the rudder is to port, at some angle, bringing the vessel back to port. The course followed by the vessel is therefore a damped oscillation. The extent of counter rudder control applied is made variable to allow for different vessel characteristics. Correct setting of the counter rudder control should cause the vessel to make good its original course. Counter rudder data must always be applied in conjunction with the output of the manual 'rudder' potentiometer, which varies the amount of rudder control applied per degree of heading error.

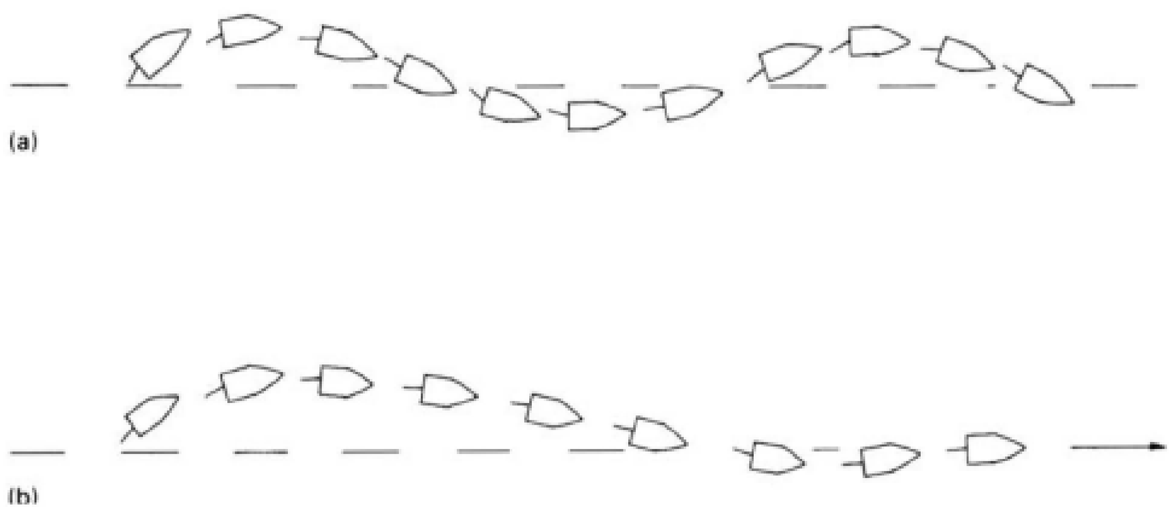


Figure 9.5 (a) If 'counter rudder' and 'rudder' controls are set too high, severe oscillations are produced before the equipment settles.(b) If 'counter rudder' and 'rudder' controls are set too low, there will be little overshoot and a sluggish return to the course.

Figures 9.5(a) and (b) show the effect on vessel steering when the counter rudder and rudder controls are set too high and too low, respectively.

9.2.3 Integral control

Data for integral control is derived by electronically integrating the heading error. The action of this data offsets the effect of a vessel being moved continuously off course. Data signals are produced by continuously sensing the heading error over a period of time and applying an appropriate degree of permanent helm.

In addition to proportional control, derivative control and integral control, autopilots normally have the yaw, trim, draft, rudder limit, and weather controls, which will be dealt with in more detail later in this chapter.

9.3 A basic autopilot system

The simplest form of autopilot is that shown in Figure 9.6. An output from a gyro or magnetic repeating compass is coupled to a differential amplifier along with a signal derived from a manual course-setting control. If no difference exists between the two signals, no output will be produced by the amplifier and no movement of the rudder occurs. When a difference is detected between the two sources of data, an output error signal, proportional in magnitude to the size of the difference, is applied to the heading error amplifier. Output of this amplifier is coupled to the rudder actuator circuit, which causes the rudder to move in the direction determined by the sign of the output voltage. The error signal between compass and selected course inputs produces an output voltage from the differential amplifier that is proportional to the off-course error. This type of control, therefore, is termed 'proportional' control. As has previously been shown, the use of proportional control only, causes the vessel to oscillate either side of its intended course due to inertia producing overshooting.

With a Proportional, Integral and Derivative steering control system, the oscillation is minimized by modifying the error signal (ψ) produced as the difference between the selected heading and the

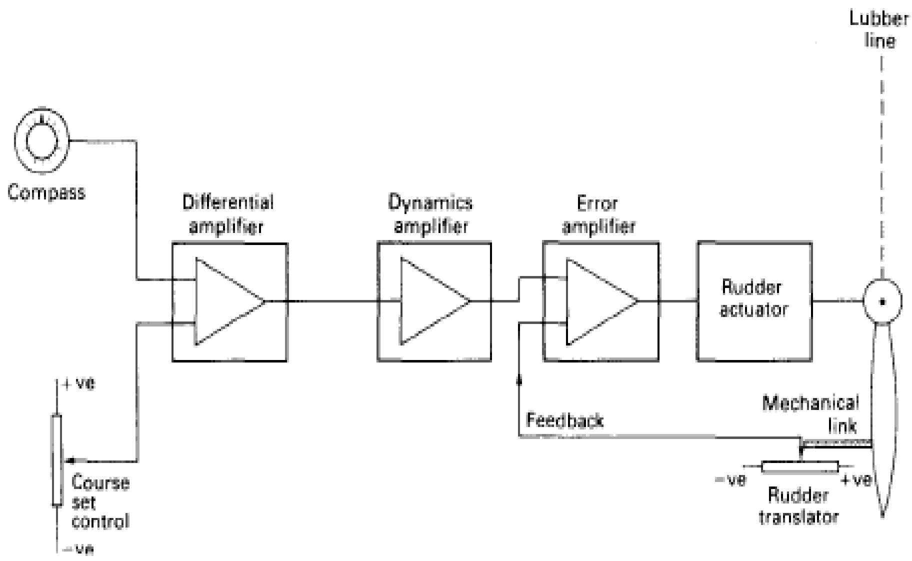


Figure 9.6 A simple autopilot system.

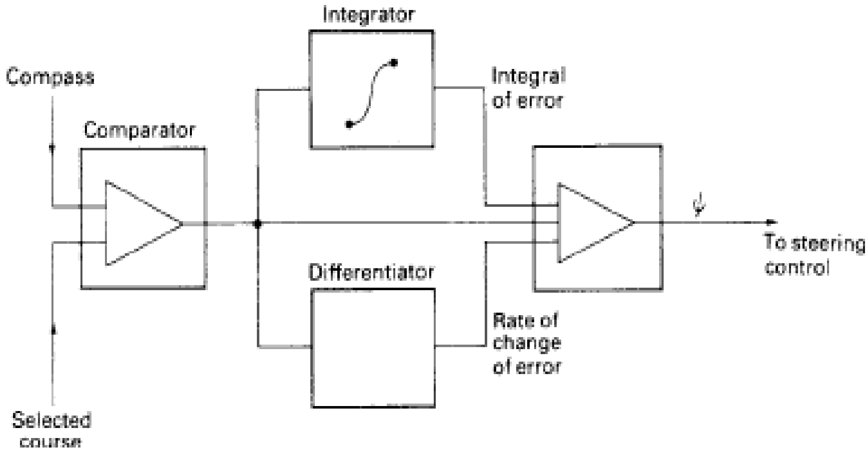


Figure 9.7 Error signal summing circuit.

compass heading. Figure 9.7 shows that a three-input summing-amplifier is used, called a dynamics amplifier, to produce a resultant output signal equal to the sum of one or more of the input signals.

The demanded rudder error signal (ψ) is inspected by both the differentiator and the integrator. The differentiator determines the rate of change of heading as the vessel returns to the selected course. This sensed rate of change, as a voltage, is compared with a fixed electrical time constant and, if necessary, a counter rudder signal is produced. The magnitude of this signal slows the rate of change of course and thus damps the off-course oscillation. Obviously the time constant of the differentiation circuit is critical if oscillations are to be fully damped. Time constant parameters depend upon the design characteristics of the vessel and are normally calculated and set when the vessel undergoes initial trials. In addition, a 'counter rudder' control is fitted in order that the magnitude of the counter rudder signal may be varied to suit prevailing conditions.

Permanent disturbances of the course due to design parameters of the vessel must also be corrected. These long-term errors, typically the shape of the hull or the effect of the screw action of a single propeller driving the ship to starboard, may be compensated for by the use of an integrator. The integral term thus produced is inserted into the control loop offsetting the rudder. This permits proportional corrections to be applied about the mean offset course (the parallel course shown in Figure 9.3). The offset signal amplitude causes a permanent offset-error angle of the rudder. The output of the dynamics amplifier is now the total modified error signal (ψ) which is regulated by the 'rudder' control to determine the amount of rudder correction per degree of heading error to be applied.

An overall simplified diagram of an autopilot is shown in Figure 9.8.

The rudder error amplifier is provided with variable sensitivity from the 'weather' control, which in effect varies the gain of the amplifier by varying the feedback portion of the gain-determining components. In this way the magnitude of the heading error signal required, before the output from this amplifier causes the rudder to operate, may be varied. Using this control a delay in rudder operation may be imposed if weather conditions cause the vessel to yaw due to a heavy swell aft of the beam.

Under certain conditions, mainly draft and trim of the vessel, a degree of permanent rudder may be required. The 'permanent helm' control provides an input to the rudder error amplifier that may be positive or negative depending on whether the rudder needs to be to starboard or to port. Since the effect of rudder movement does not influence the setting of this control, the rudder will remain

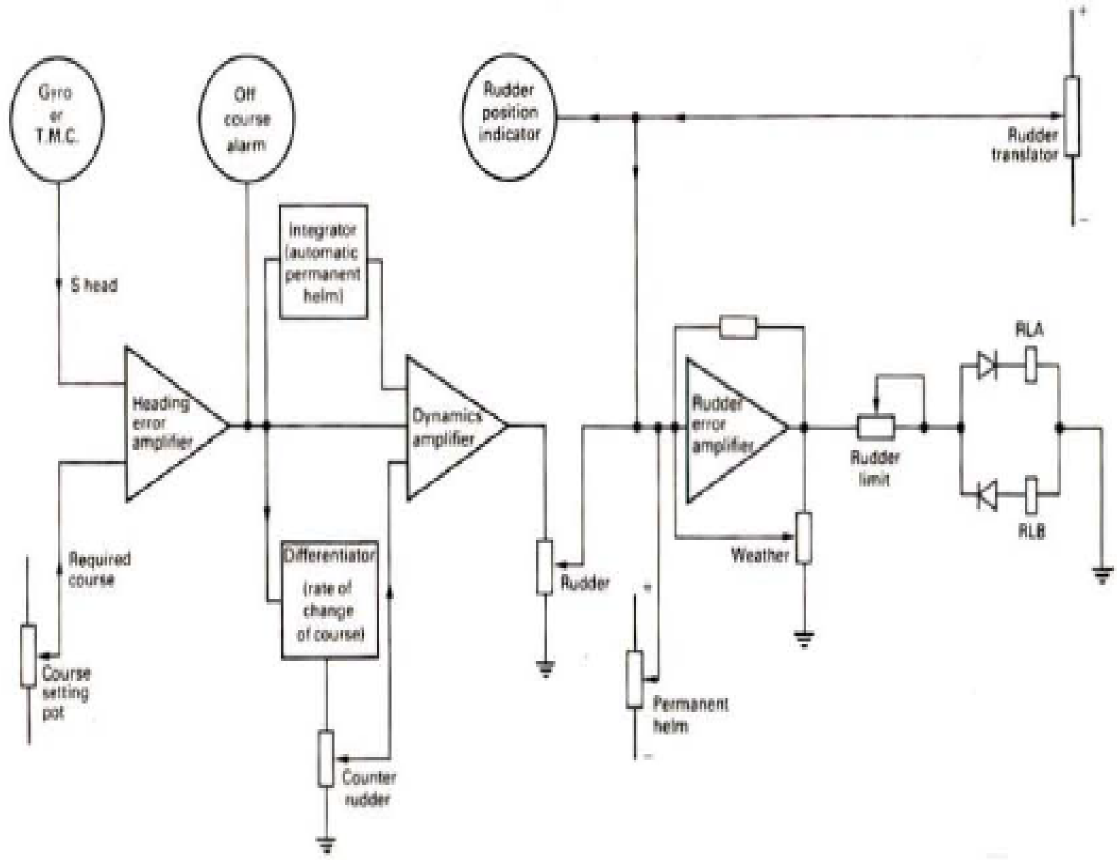


Figure 9.8 A simplified diagram of an autopilot system.

permanently in the position set by the control (assuming no other control signals are produced). Permanent helm will also be applied automatically by sensing the build-up of heading error in the integrator circuit.

In the system described control relays RLA and RLB are used to switch power to the steering gear contactors, which in turn supply power of the correct amplitude and polarity to the prime rudder mover. As the rudder moves, a mechanical linkage drives the slider of a potentiometer to produce the rudder feedback signal. Output from this 'rudder translator' potentiometer is normally used to indicate the instantaneous rudder angle. Excursions of the rudder may be limited by the manually operated 'rudder limit' control which fixes the maximum amount by which the rudder may move from the midships position.

An off-course alarm circuit senses the error signal at the output of the heading error amplifier and causes an audible alarm to be sounded when a signal amplitude outside pre-determined limits is detected. A manual off-course limit control (not shown) is provided to enable an operator to select the point at which the alarm will sound.