Construction, principle of operation and handling of autopilots

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Introduction

Autopilot – device used for automatic steering of the vessel

Autopilot should be capable of:

- Keeping the desired heading/course/trajectory with little deviation and with minimum use of the rudder
- Performing turns fast but without oversteering

Autopilot properties:

- Significant ship’s inertia, depending on the loading condition, ship’s speed, draft, etc.
- Particularly slow rudder speed, complex dependence of the rudder force and rudder angle, asymmetrical speed of rudder movement during increasing and decreasing of ruder angle
- A variety of external impacts (environmental disturbances) related to the influence of currents, waves, wind, etc.
- Complex operating conditions of automatic steering systems, which should ensure efficient, trouble-free operation in a variety of environmental conditions.

Benefits of using autopilots:

- Increase in average speed of the ship
- Savings in ship operation costs
- Reduced voyage time
- Reduced fuel consumption

Automatic steering allows - in comparison to manual steering - to reduce the number and size of ruder angle changes. This results in an increase of average speed of the ship, thus savings on its operation.

Nowadays sea-going vessels are manually steered in principle only during manoeuvrings in ports, canals and straits, and during extremely heavy, stormy weather.

Manoeuvrability of the ship

A ship is said to be **directionally stable** if a deviation from a set course increases only while an external force or moment is acting to cause the deviation.

On the other hand, ship is said to be **directionally unstable** if a course deviation begins or continues to increase even in the absence of an external cause.

A directionally unstable ship is easy to manoeuvre, while a stable ship requires less energy expenditure by its steering gear in maintaining a set course. A compromise between extremes is therefore desirable.

Manoeuvrability of the ship

Manoeuvring characteristics such as turning, yaw-checking, course-keeping and stopping abilities of the ship can be predicted at the design stage by scale model tests and/or computer predictions using mathematical models. Full-scale manoeuvring tests should be conducted to validate these results.

Manoeuvers required by IMO standards include turning circle, zig-zag and full astern stopping tests. When trials are conducted in condition other than full load, manoeuvring characteristics should be predicted for trial and full load conditions using a reliable method (i.e. model tests or reliable computer simulation) that ensures satisfactory extrapolation of trial results to the full load condition.

Causes of the ship's deviation from the course :

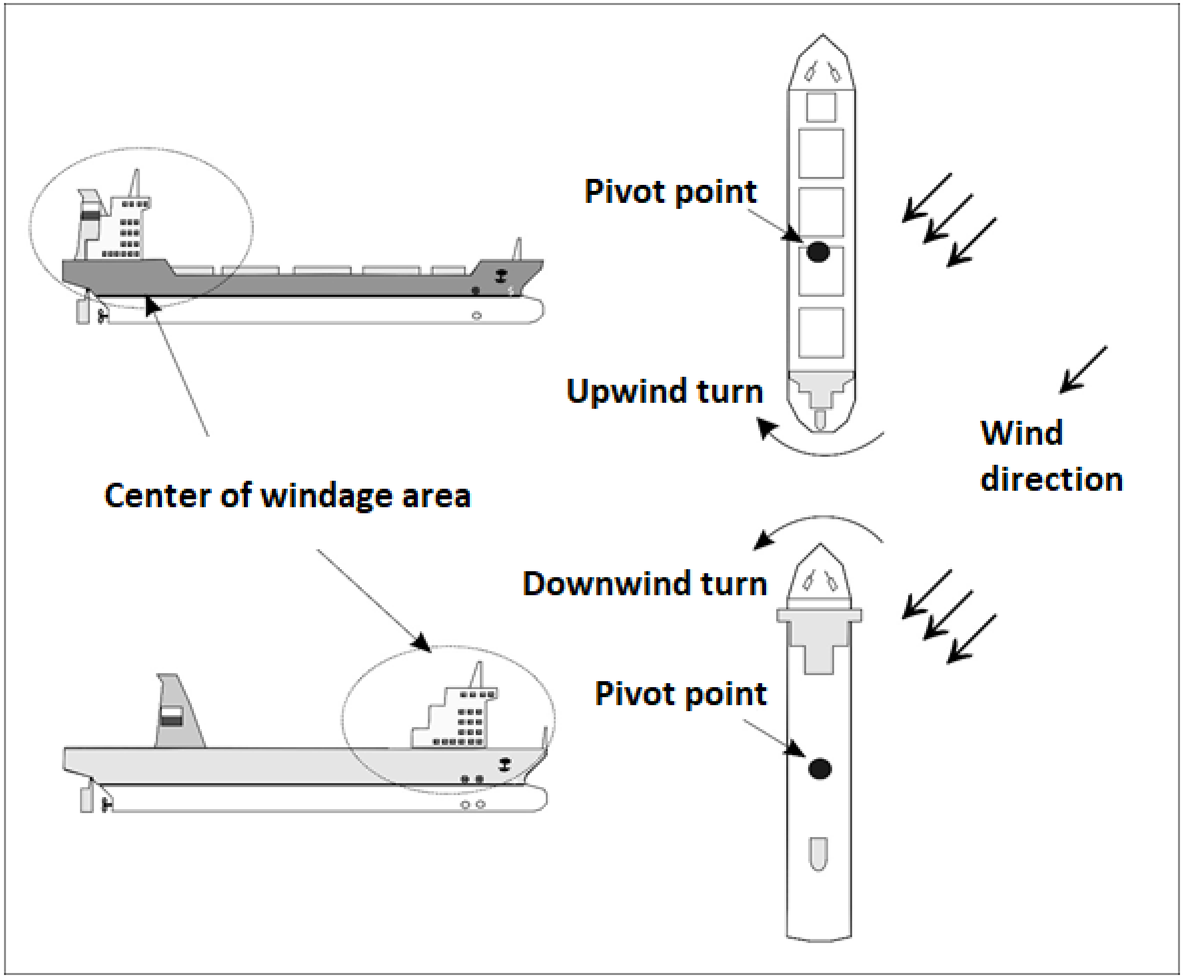
Continuous disturbances

- Static wind force
- List
- Influence of screw propeller

Dynamic disturbances

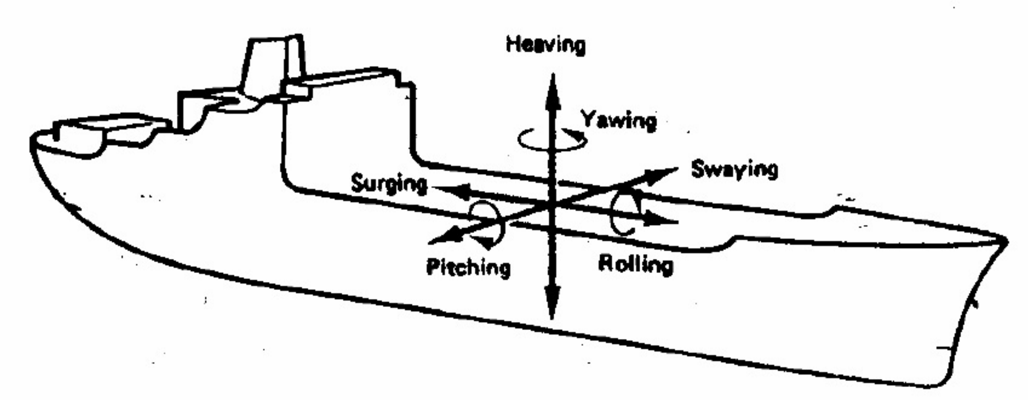
- Rudder angle
- Waves

Wind:

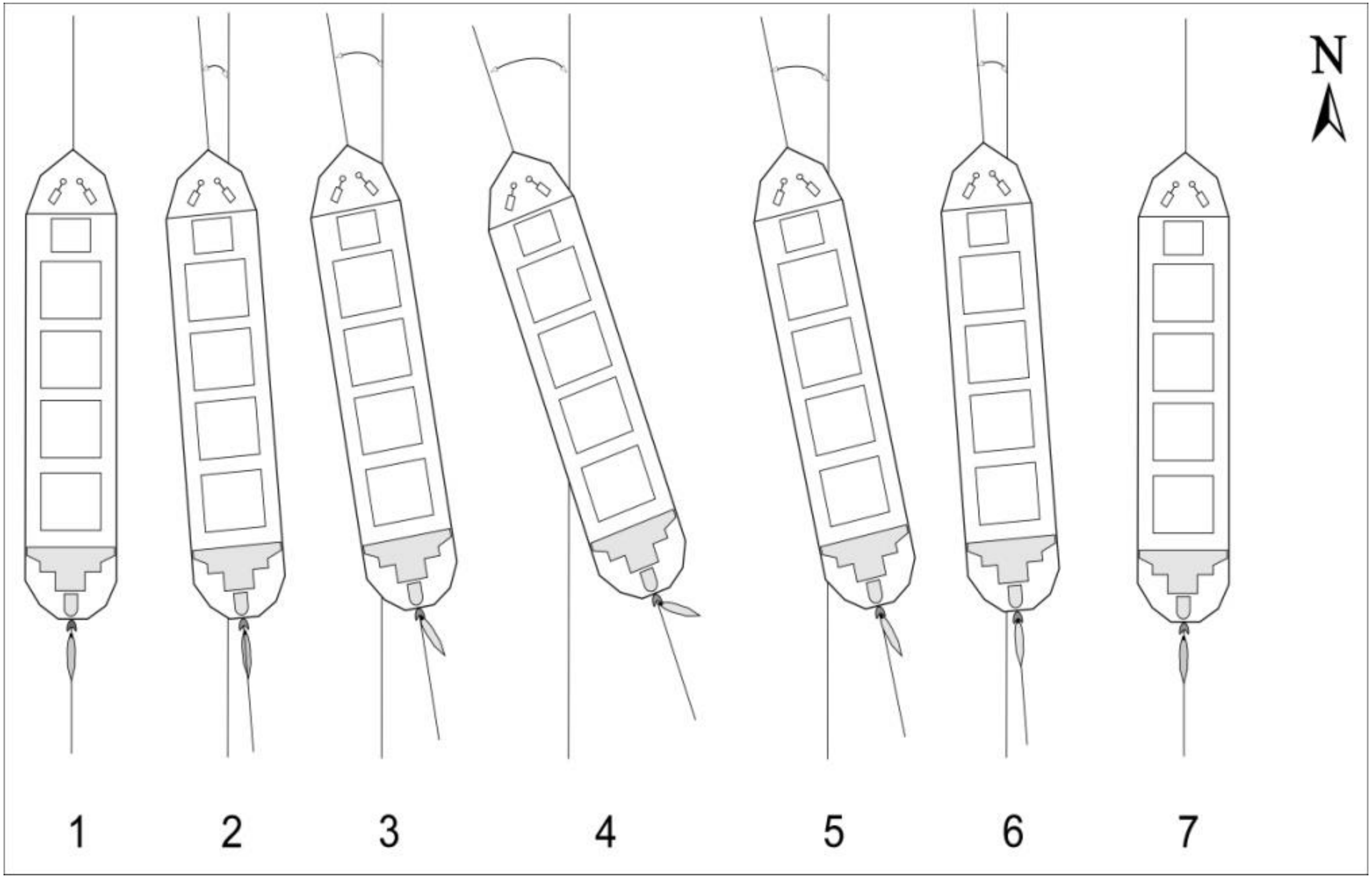

Pivot point
Upwind turn
Center of windage area
Wind direction
Downwind turn
Pivot point

Waves:

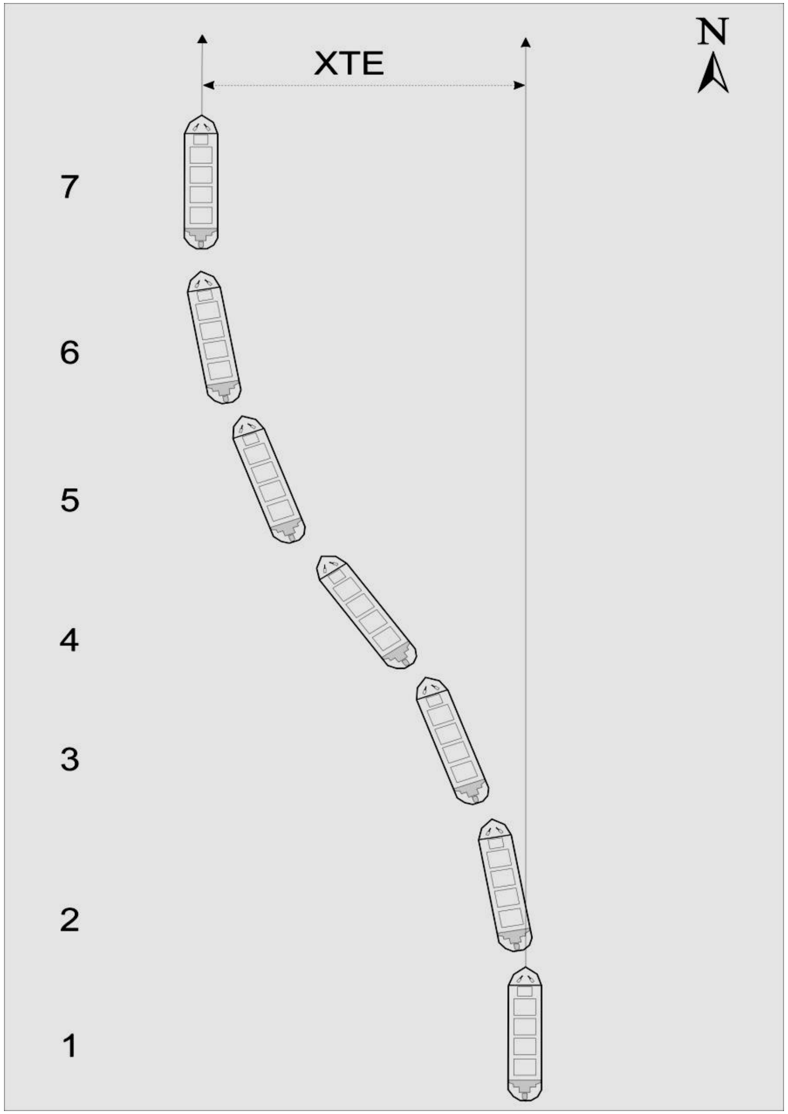
The dynamic impact of the waves on the ship cause immediate deviation of the ship heading in both directions, commonly called yaw. At different angles of the hull of the ship in relation to the wave direction, the amplitude and frequency of yawing are different.



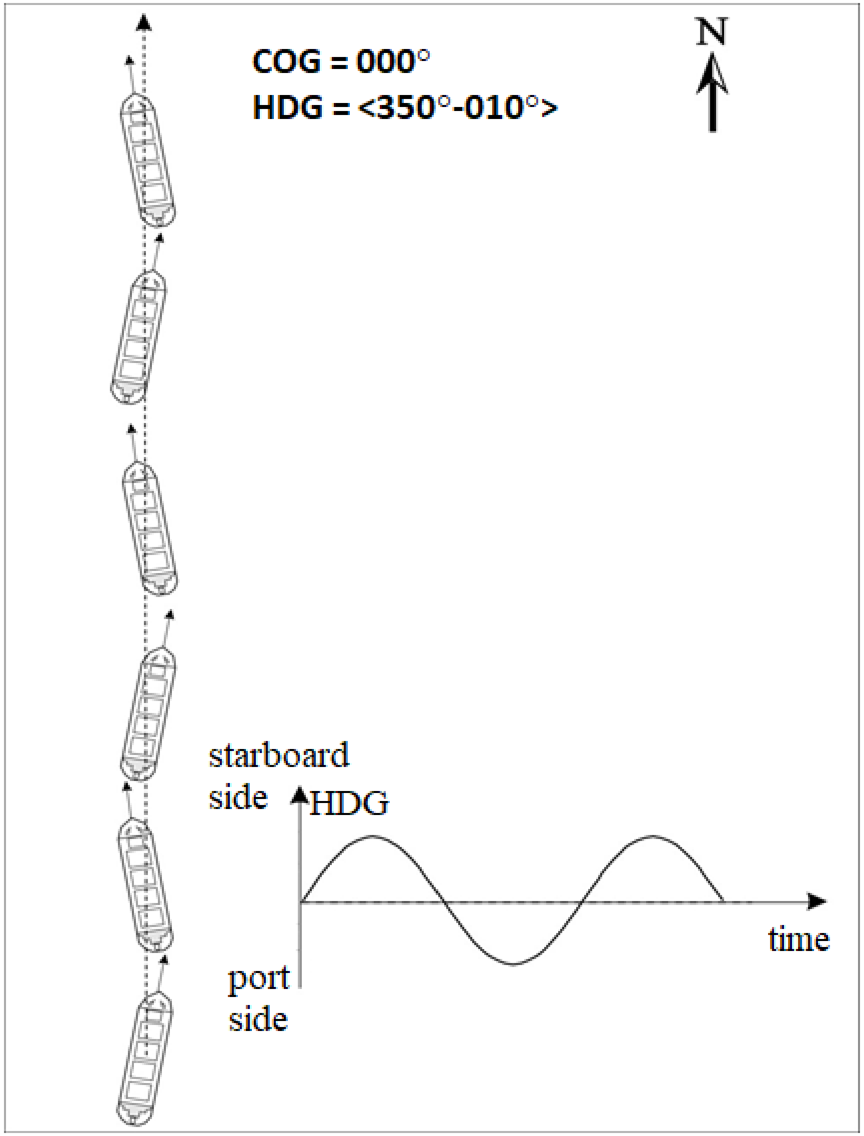
Heading based steering



Heading based steering



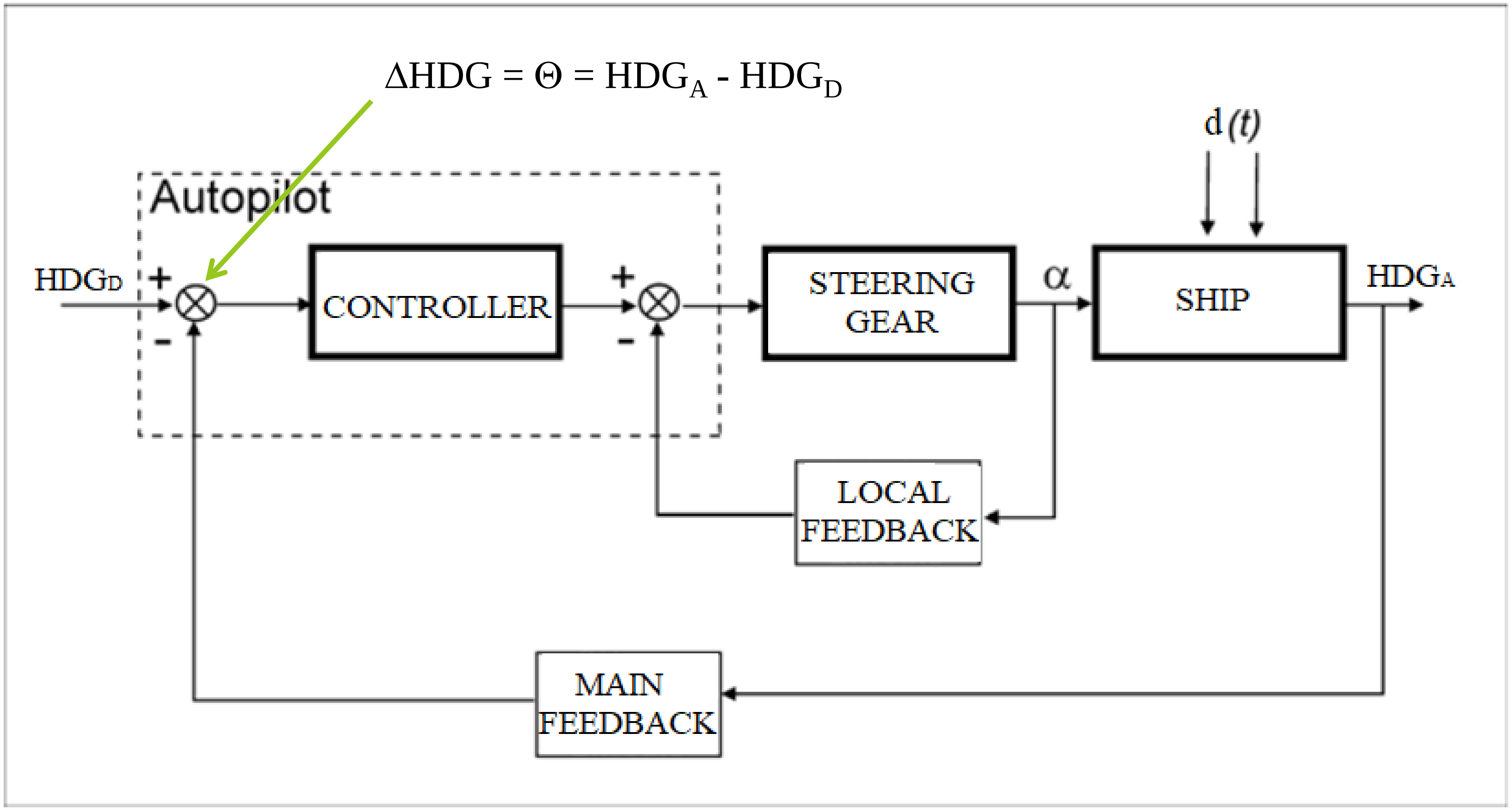
HDG vs. COG



Construction:

In its simplest form an autopilot compares the course-to-steer data, as set by the helmsman, with the vessel’s actual heading data derived from a gyro or magnetic repeating compass, and applies ruder 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.

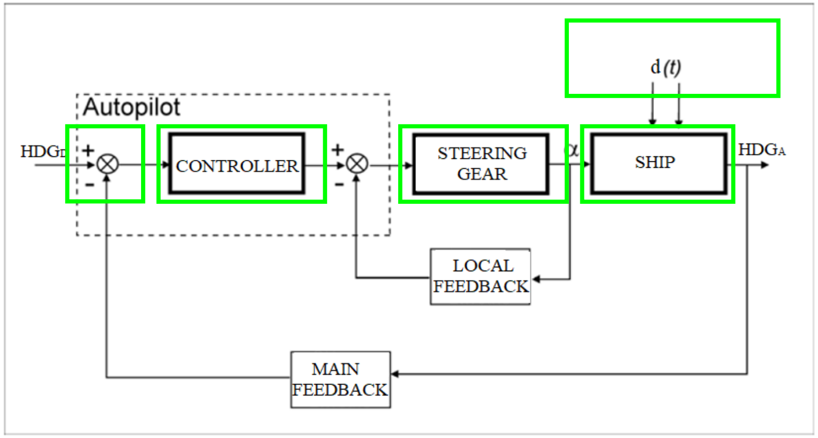
Construction:



$\Delta HDG = \Theta = HDG_A - HDG_D$

HDG_A – actual heading
HDG_D – desired heading
α – rudder angle

Operation:



1. As a result of disturbance or hydrodynamic asymmetry deviation from desired heading - Θ occurs.
2. Deviation is calculated in the summing point
3. Controller calculates the steering signal (desired rudder angle)
4. Steering gear changes the rudder angle
5. Vessel changes the heading

PID controller:

The acronym PID stands for Proportional, Integral and Derivative, which are three different methods of control that work together in a controller to regulate the rudder movement in the most efficient way.

$$\alpha = -\left(A\theta + B\int_{0}^{t} \theta dt + C\frac{d\theta}{dt} \right)$$

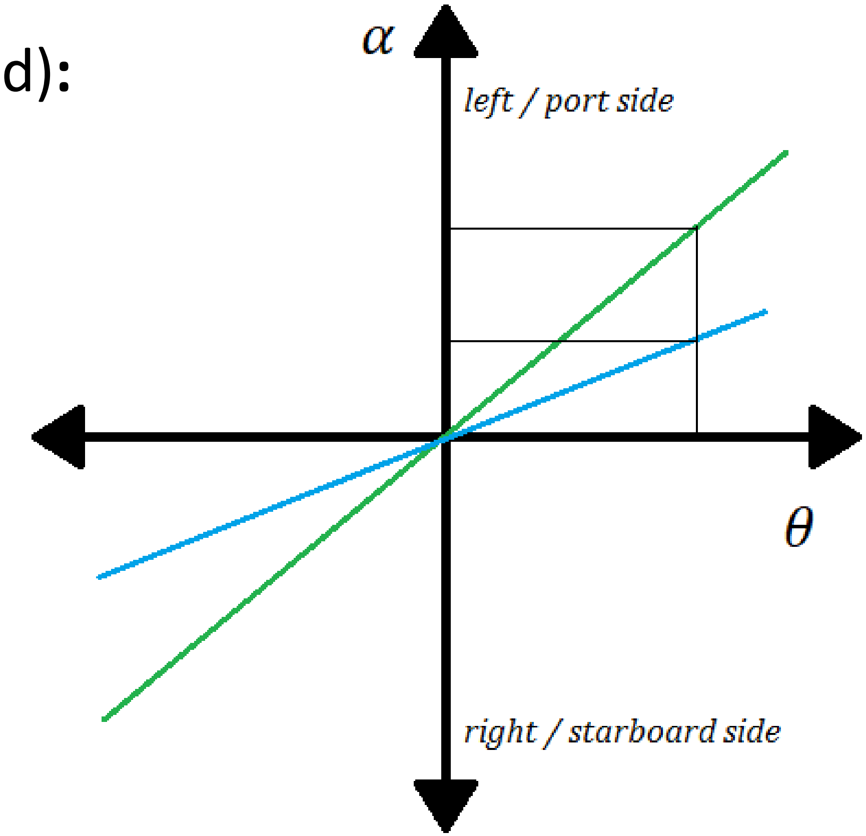
P regulation (Proportional addend):

$$\alpha = -\left(A\theta + B\int_{0}^{t} \theta dt + C\frac{d\theta}{dt} \right)$$

This part of the regulator gives a steering signal (to the rudder) that increases proportionally with the regulation deviation. In other words it means that the regulator will increase the rudder angle gradually as the deviation from the desired heading increases.

P regulation (Proportional addend):

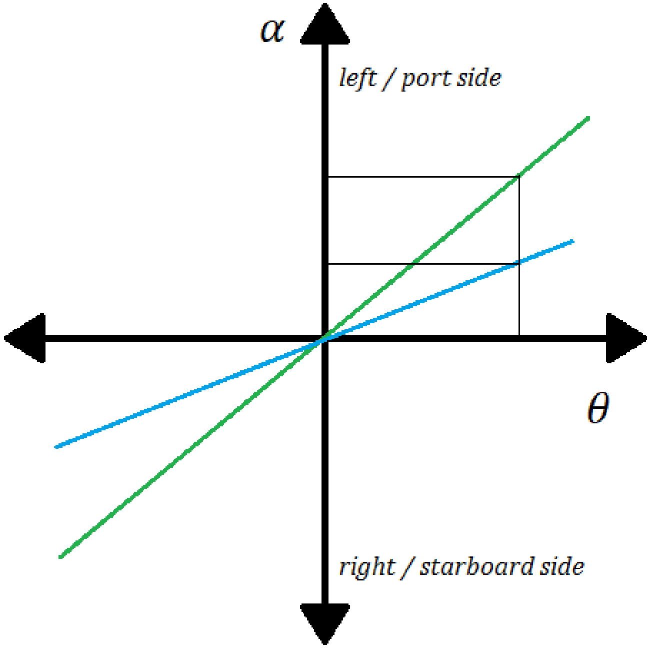
Graphically this can be shown as:



The rise in the curve characterises the amplification or proportionality constant (A) in the regulator, and this can be varied using variable resistance in the amplification circuit. On the autopilot this will normally be called ***rudder.***

P regulation (Proportional addend):

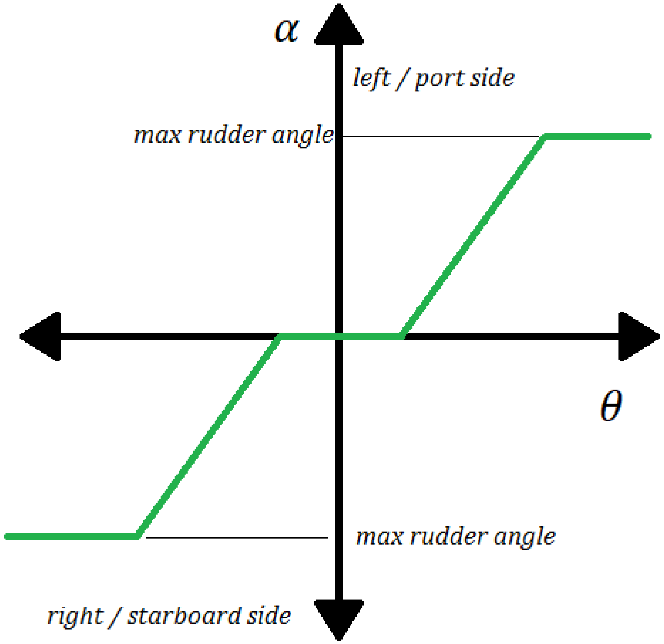
Small proportionality constant (**A**) will lead to relatively little rudder movement and therefore long time to desired heading achievement.



Big proportionality constant (**A**) will give a large rudder movement, which in turn can lead to overswing of the desired value after relatively short time. This in its turn will lead to that the regulator must give the steering signal the opposite way.

P regulation (Proportional addend):

To reduce the number of rudder angle changes caused by little heading changes due to yawing - a range of deviations for which the rudder will not be moved can be adjusted, normally this parameter is called ***yaw***



The P controller alone will not be sufficient for the autopilot to keep in the desired course, since it will not be able to have both good setting abilities and dynamics. Therefore it sets with a constant deviation from the desired value.

I regulation (Integral addend)**:**

$$\alpha = -\left(A\theta + B\int_{0}^{t} \theta dt + C\frac{d\theta}{dt} \right)$$

In this part of the regulator the output signal will be like the integral of the deviation (total of the deviation over time). The output signal in this controller can be described by the area under the deviation curve in time function. The output signal will change regularly as long as there is deviation. Neither will a single I controller be able to work in autopilot alone, but will contribute to that the rudder is given increased movement as long as ship deviates continuously from the course.

D regulation (Derivation addend):

$$\alpha = -\left(A\theta + B\int_{0}^{t} \theta dt + \boxed{C\frac{d\theta}{dt}} \right)$$

The output signal from the D controller will be given by the derivation of the input signal (the deviation). The function of this controller is such that the output signal id different from zero when the input signal changes, hat is to say when the derivate of the input signal is different from zero. In practice this means that if the heading is changed, the D controller will quickly make a rudder movement against the deviation from the course. The quicker the deviation change, the greater the output signal.

PID control:

The problems that are encountered when a vessel shall be kept on a course by automation are of such composite character that one must use the characteristics of all the three types of controller. By using PID controller the required characteristics can be achieved and a system will quickly achieves a stable desired value (heading).

The conventional electronic PID controllers are now often replaced by databased systems. These will be based on digital data processing based on sampling of the input signal. By using digital signal processing it will be possible to build in more advanced functions and filtering. The control function itself will not be different.

Adaptive autopilots / track steering:

In order to achieve optimum performance of the autopilot, on more advanced designs there can be different compensation for the ship’s movement characteristics. As an example, the autopilot can receive information regarding speed, and therefore adjust the settings according to varying speed and steering characteristics. Such systems that adapt to the steering characteristics are called **adaptive autopilots**.

If position data is supplied from a positioning system (GPS) the autopilot can also be programmed to steer according to a programmed route (track). Such function is usually called **track steering**.

Autopilot settings:

Rudder – this control acts in the controller P part and regulates how large a rudder angle the controller shall give a signal for. At max. setting the rudder angle will be large in relation to the deviation that is registered. The control can advantageously be adjusted up at slow speeds, for example. If the control is set too high, the ship will „overreact”, and possibly swing hard in relation to the desired course. If the control is set too low, it will take time to get on to the desired course. In some cases, a low setting could also result in that the ship cannot keep the constant rate of turn (ROT) that is set in the system. At installation of the system there can be a need to set a separate „trim rudder” control to adapt the rudder control to the relevant ship

Autopilot settings:

Yawing / Weather – this control acts in both the P part and the D part of the controller. In the P part it will work as if a „dead band”, or a margin around the desired heading, is entered, where the controller will not respond. In other words, we allow the ship to yaw without the rudder engaging. In this way use of, and wear on the rudder are minimised in heavy seas. A low setting on the control will mean least tolerance and a lot of rudder use. A high setting will be relevant in heavy seas when we wish to reduce use of the rudder. On some modern autopilots the system can learn the movement and optimise controls based on that. On such systems we can often find the control „steering strategy”, where we can choose between „confined waters” and „open sea”. At the installation of the system we my also have a need to set a separate „trim/yaw” control.

Autopilot settings:

Counter rudder – this control acts in the D controller and decides the amplitude of the steering signal. It also decides how much the rudder shall turn momentarily in order to counteract quick heading deviations. At low settings the ship will have a tendency to turn away too much in relation to the desired heading, and there could be a relatively large turn away when the ship shall change course. Since larger ships normally require more counter rudder, the setting must be adjusted to the ship's manoeuvring characteristics. On some systems this time constant is set the first time the autopilot is taken into use. The choice of time constant is made based on the diagram that will accompany the steering system. Instead of entering a fixed time constant, such diagrams can also be entered into the system. In such cases it will be usual that we enter the ship's length, rudder factor or size.

Autopilot settings:

Rudder limit – on all autopilots there is a control where maximum rudder angle is set. For the sake of safety this can be set low i.e. 10 deg., in order to avoid unnecessarily tight turns.

Off-course alarm – all autopilots will give an alarm when the deviation from the desired heading exceeds a given limit. This limit will be able to be set by going into a menu an the autopilot. The alarm function will be disconnected during changes of course and for a short period afterwards.

Autopilot settings:

Rate Of Turn (ROT) – when planning a voyage it can often be advantageous to use the ROT technique in order to follow a certain turn radius. On passenger ships, for example, it can also be desirable to turn relatively slowly in order to prevent discomfort for the passengers. Therefore, all modern autopilots have a function where ROT can be decided. So that this function can work the system must be connected to a log, or the speed at the moment must be entered manually. There can be two modes of entering in a rate of turn:

- Constant radius
- Constant ROT