DYNAMIC POSITIONING MODES & FUNCTIONS

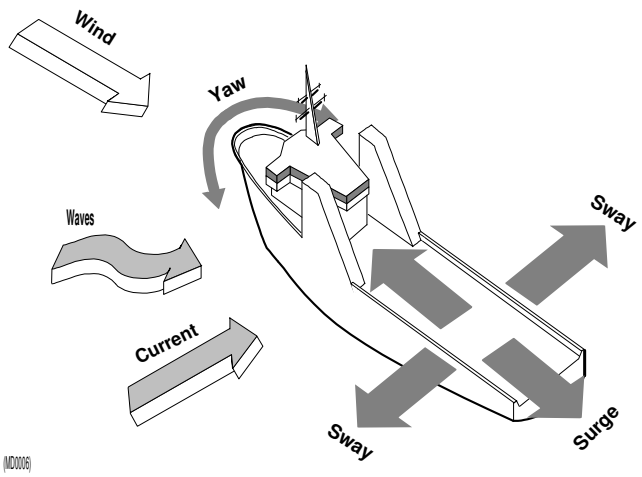
Introduction

The Kongsberg Dynamic Positioning (K-Pos DP) systems are computerised systems enabling the automatic position and heading control of a vessel. Set-points for heading and position are specified by the operator and are then processed by the K-Pos DP system to provide control signals to the vessel's thruster and main propeller systems. The K-Pos DP system always allocates optimum thrust to whichever propeller units are in use.

To control the vessel's heading, the K-Pos DP system uses data from one or more gyrocompasses, while at least one position-reference system (for example, GPS, microwave, hydroacoustic, laser beam or taut wire) enables the K-Pos DP system to position the vessel. Deviations from the desired heading or position are automatically detected and appropriate adjustments are made by the system.

Basic Forces and Motions

A seagoing vessel is subjected to forces from wind, waves and currents as well as from forces generated by the propulsion system. The position-reference systems, the gyrocompass and the vertical reference sensors measure the vessel's response to these forces, i.e. its changes in position, heading and speed. The wind sensors measure wind speed and direction. The system calculates the deviation between the measured (actual) position of the vessel and the required position, and then calculates the forces that the thrusters must produce in order to make the deviation as small as possible. In addition, the system calculates the forces of wind, wave and water current that act upon the vessel and the thrust required counteracting them. The system controls the vessel's motion in three horizontal degrees of freedom - surge, sway and yaw.



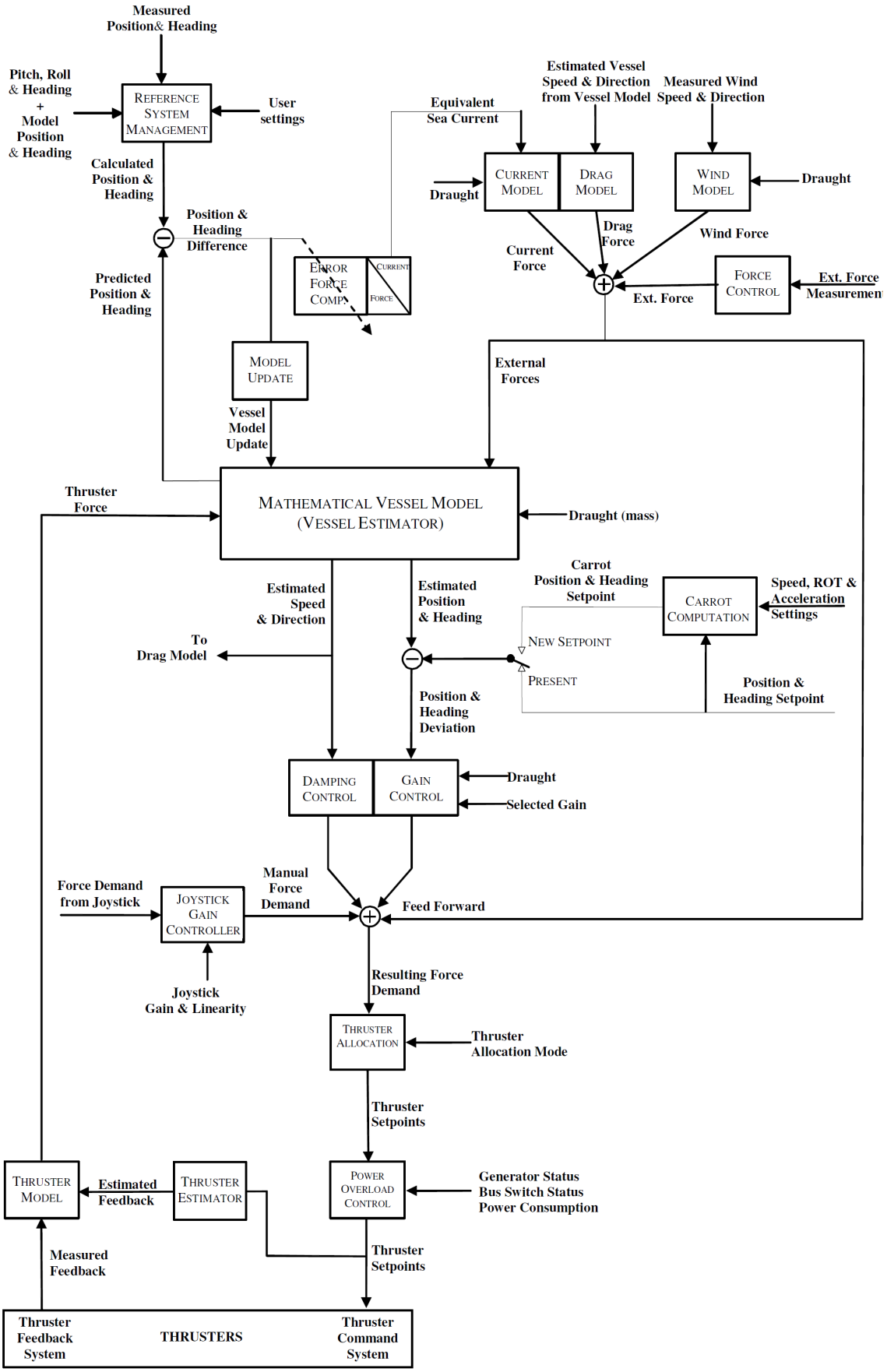
Main Components in the K-Pos DP System

The Mathematical Model

The model is a mathematical description of how the vessel reacts or moves as a function of the forces acting upon it. The model is a hydrodynamic description, i.e. it involves the vessel's characteristics such as mass and drag. The design criterion for the model is an as accurate as possible description of the vessel's motions and reaction to any external forces. The mathematical model is affected by the same forces as the vessel itself. Wind forces are calculated as a function of measured wind speed and direction, while thruster forces are calculated as a function of thruster/propeller pitch/rpm and direction. The system incorporates algorithms for the estimation of sea current and waves, and the forces caused by these.

The main outputs from the mathematical model are filtered estimates of the vessel's heading, position and speed in each of the three degrees of freedom - surge, sway and yaw. The mathematical model itself is never a 100% accurate representation of the real vessel. However, by using the Kalman filtering technique, the model can be continuously corrected. The vessel's heading and position are measured using the gyrocompasses and position-reference systems, and are used as the input data to the K-Pos DP system. This data is compared to the predicted or estimated data produced by the mathematical model, and the differences are calculated. These differences are then used to update the mathematical model to the actual situation.

High Precision Controller block diagram

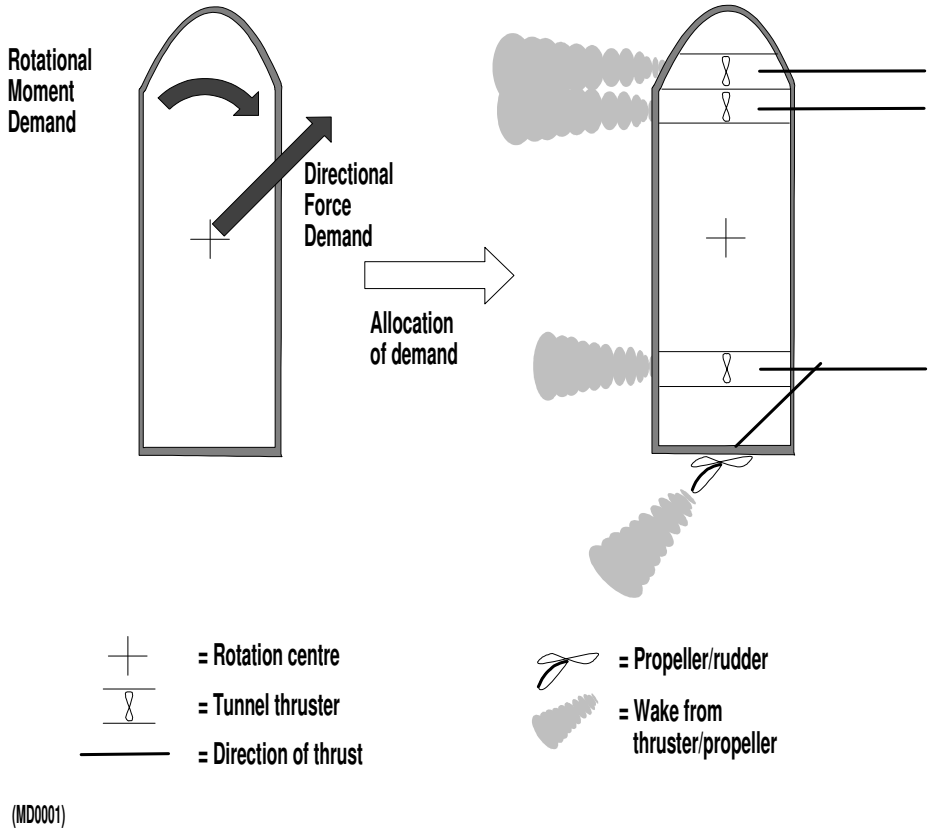


Thruster Allocation

The K-Pos DP system's optimum controller continuously calculates the actual force requirements in the alongship and athwartship directions (the directional force demand), and the required rotational moment (the rotational moment demand).

The *Thruster Allocation* function distributes these force demands as pitch and/or rpm control signals to each thruster/propeller, thus obtaining the directional force and rotational moment required for the position and heading control.

The following diagram shows the allocation of the rotational moment demand and the directional force demand into control signals for each thruster/propeller:



Reference System and Sensor Data Processing

Measurements of a vessel's position and heading at any point in time are essential for dynamic positioning.
Several different position-reference systems are normally used with the K-Pos DP system. The first position-reference system selected and accepted for use with the K-Pos DP system becomes the reference origin (the origin of the internal co-ordinate system).

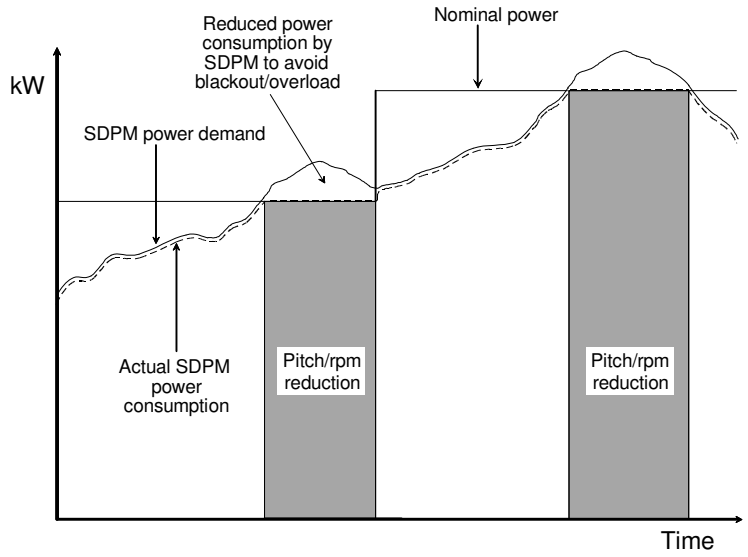
Power Load Monitoring and Blackout Prevention

The *Power Load Monitoring and Blackout Prevention* function performs a dynamic pitch/rpm reduction of the thrusters/propellers to prevent a power blackout situation on a power bus or isolated bus section.

The *Power Load Monitoring and Blackout Prevention* function is prepared for handling the following standard power plant configurations:

- Diesel generators supplying thruster/propeller electro-motors
- Shaft generators supplying thruster electro-motors
- A combination of diesel generators and shaft generators

The *Power Load Monitoring and Blackout Prevention* function is active in all operation modes and is illustrated in the diagram below:

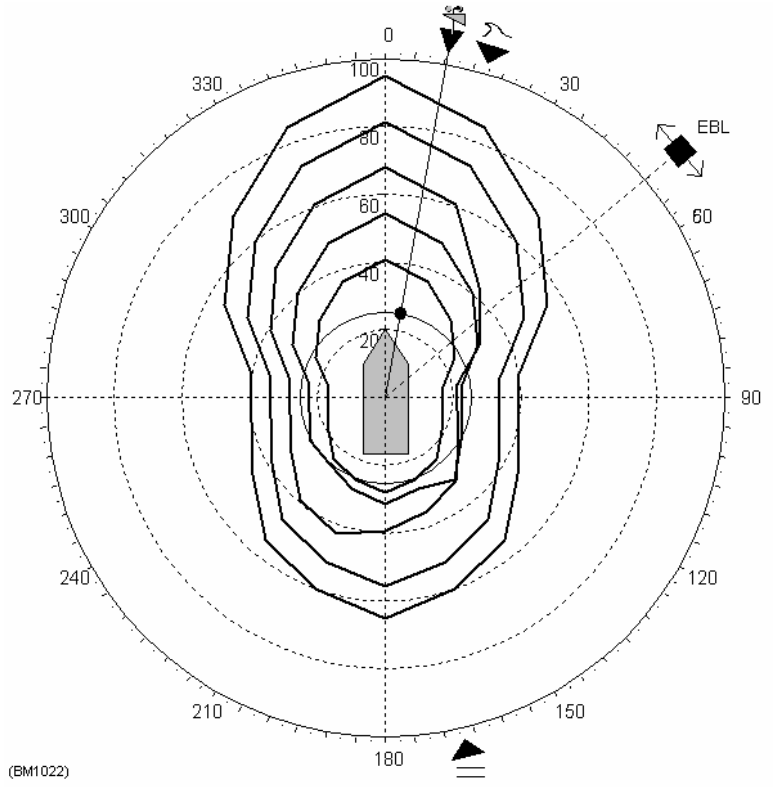


DP Capability Analysis System

The DP Capability Analysis System predicts the maximum weather conditions in which the vessel is able to continue DP operations.

The following situations are evaluated:

- All systems fully operational (all thrusters active and no lack of power)
- Present condition with regard to thrusters and generators
- Loss of one or more thruster units
- Loss of one or more power generators (with possible loss of connected thrusters)



This function is available for diesel-electric propulsion only.

Alarm System

During operation, extensive checking of the data from position-reference systems, sensors and other external systems, as well as from the system itself, is performed automatically. The operator is alerted by audible alarms, flashing lights and messages if any errors or inconsistencies occur.

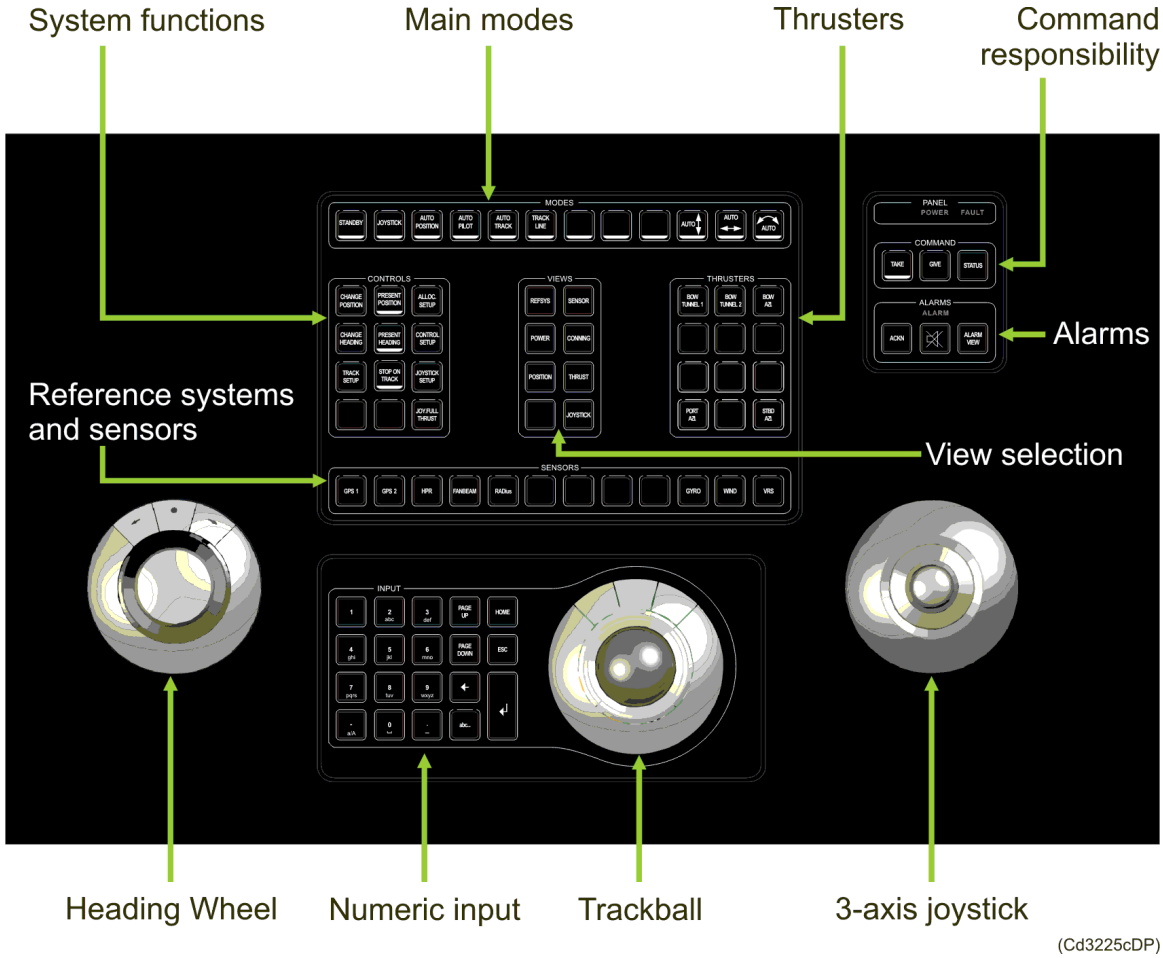
The following elements comprise the alarm system:

- Online Diagnostics
- Message Reporting
- Alarm Advisory Function
- Message Printout

Human Machine Interface (HMI)

The HMI is an important feature, which enables efficient and safe operation of the system by helping the operator to make optimum operational decisions. During normal operation this reduces the risk of human error. Emphasis has been placed on logical operation, effective presentation of relevant information and user-friendliness.

Dedicated buttons are provided on the operator panel for activation of main modes, reference systems, thrusters and other functions where indicator lights are of great importance for situation assessment. Frequently used functions are also initiated from dedicated panel buttons.



The display is organised with four views simultaneously shown on the screen:

- Alarm view. Located just below the Menu bar.
- Performance view. Located top-left.
- Working view. Located right.
- Monitoring view. Located bottom-left.

Built-in Trainer

The built-in trainer is a tool for simulating vessel motion for operator training purposes. The training is performed on the K-Pos DP console with no additional equipment required. Training is carried out without spending valuable time setting up position-reference systems and without running the thruster/propeller systems. The built-in trainer requires that the K-Pos DP system *does not control the vessel*.

The following training functions are available:
- Position Change
- Heading Change
- Simulated Vessel Mode
- Thruster Operation
- Environmental Conditions

Online Consequence Analysis

The *Online Consequence Analysis* function continuously performs an analysis of the vessel's ability to maintain its position after a predefined, worst-case failure during operation. Possible consequences are based on the actual weather conditions, enabled thrusters and power plant status.

Typical worst-case single failures are:
- Failure in the most critical thruster
- Failure in one thruster group (if any)
- Failure in one power bus section

If the consequence of the predefined failure is loss of position, it is reported to the operator via the alarm system. The failure situations that are analysed are in accordance with the requirements for DP Class 2 and 3 operations.

Data Logging System

Extensive data logging functions are available for the K-Pos DP systems. These functions may be used to record operational data or to investigate reasons for an incident.

A complete logging system consists of the following elements:
- Logging output from the K-Pos DP system
- External logging system

These elements can be delivered separately.

Operational Modes

The vessel can be controlled in several different modes. The main difference between these modes is how the position and speed set-points are generated.

- The Manual mode allows the operator to control the vessel manually using a joystick for position control and for heading control.
- The Auto Position mode automatically maintains the required position and heading.
- The Auto Area Position mode automatically keeps the vessel within an allowed area and within allowed heading limits while using the minimum amount of power.
- The Auto Track modes (low speed and high speed) make the vessel follow a specified track described by a set of waypoints.
- The Autopilot mode enables the vessel to steer automatically on a predefined course.
- The Follow Target mode enables the vessel to automatically follow a constantly-changing position set-point.

Standby Mode

The *Standby* mode is a waiting and reset mode in which the K-Pos DP system is in a state of readiness but in which no control of the vessel can be made using the K-Pos DP system.

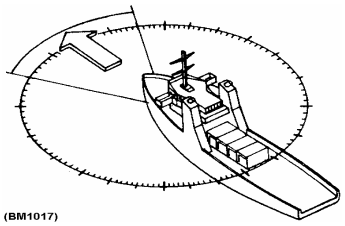
Manual Mode

In the Manual mode, the operator controls the positioning of the vessel using a joystick. The joystick commands the vessel to move in the alongship and athwartship directions (along the surge and sway axes), and to rotate the heading (around the yaw axis).
The following functions are available in the *Manual* mode:

- Joystick Gain Selection
- Environmental Force Compensation
- Bow/Stern Rotation

In Manual mode it is also possible to request automatic position control in either the surge or sway axis alone. This feature is normally combined with automatic heading control so that the operator has manual control of only one of the surge or sway axes while the system stabilises the vessel's motion in the other two axes.

Auto Position Mode


(BM1017)

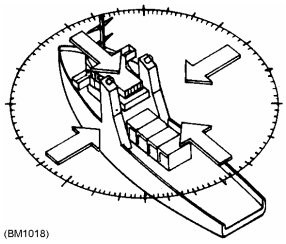
Heading control

The system accurately keeps the vessel at the selected heading. The operator can use one of the standard functions listed below to control the vessel's heading. If the operator selects another heading, the system will automatically change the vessel's heading.

- Present Heading
- Set Heading
- Minimum Power

The following functions are also available:

- Set Rotate Speed
- Heading Alarm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Position control.

The system accurately keeps the vessel at the selected position. If the operator defines another wanted position (Set point), the system will automatically change the vessel's position. The operator can use any of the standard functions listed below to control the vessel's position:

- Present Position
- Marked Position
- Set Position
- Previous Position

The following functions are also available in the *Auto Position* mode:

- Set Vessel Speed
- Position Alarm

Auto Area Position Mode

In the *Auto Area Position* mode, the system keeps the vessel within an allowed area with minimum use of power. This mode is intended for stand-by operations where the vessel must remain within a specified geographical area. The K-Pos DP system allows the vessel to drift away from the centre of the area and from the optimum heading due to environmental forces. The propellers and/or thrusters are used only when the required operational limits are exceeded. Independent limits can be specified for both position and heading:

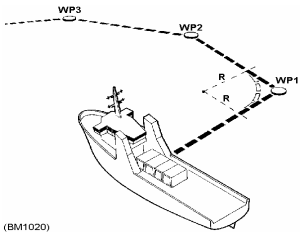
- Early Warning Limit
- Activation Limit
- Alarm Limit

When the limits are exceeded, steady bias forces on the propellers/thrusters are used to obtain smooth positioning with a minimum variation of power.

Auto Track Modes

The *Auto Track* modes enable the vessel to follow a predefined track, described by a set of waypoints, with a high degree of accuracy. These modes cover both low-speed and high-speed operations using different control strategies. The system can automatically switch between the strategies depending on the requested speed. Alternatively, the operator can select the required strategy manually.
In *Auto Track low speed* mode, full position and heading control in all three axes is applied to control the vessel movement. This strategy yields superior control accuracy and allows full freedom in selecting the vessel heading, but is limited to speeds of approximately 3 knots.
The *Auto Track high speed* mode controls the vessel heading (using rudder or thruster azimuth control) to minimise the cross-track error while maintaining the wanted speed. This strategy is applicable at normal cruising speeds.

Auto Track Mode - low speed



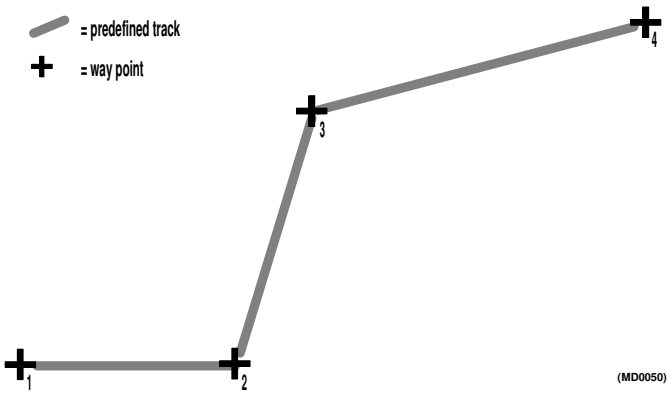
In the Auto Track mode low speed, the speed along the track is controlled very accurately with the possibility to run as slowly as a few centimetres per second.
The positions of the waypoints and the vessel's heading and speed that are to be used for each track section are specified by the operator and stored in waypoint tables. Waypoints can be inserted, modified and deleted as required.
The vessel's heading is controlled by the following functions:

- Present Heading
- Set Heading
- System Selected Heading

The speed of the vessel along each section of the track can either be taken from the waypoint table or specified on-line by the operator using the *Set Vessel Speed* function.

Depending on the thruster installation and the vessel design, the maximum speed for a vessel in *Auto Track low speed* mode should not exceed approximately 3 knots since the effect of the lateral thrusters is reduced at speeds higher than this.

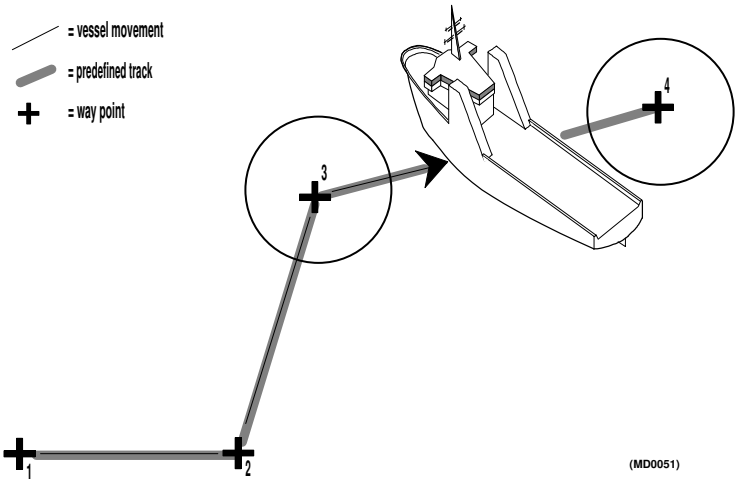
The following figure shows the track a vessel will follow in *Auto Track low speed* mode according to the information contained in the table:



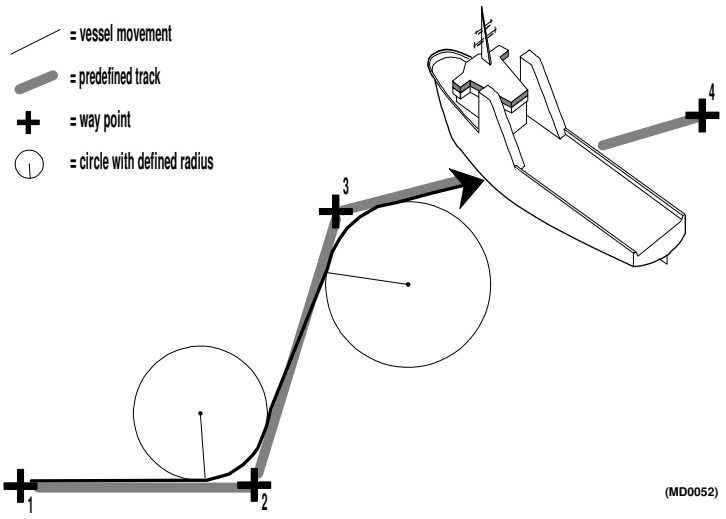
Waypoint Number	North/East Co-ordinates	Speed	Heading
1	1501060/503710	0.3 m/s	270º
2	1501060/503770	0.5 m/s	270º
3	1501140/503790	0.5m/s	270º
4	1501170/503910	0.3m/s	335º

The operator can select between two alternative strategies for passing waypoints:

- Slowing down at each waypoint before continuing to the next (used when the vessel must remain on track, even during sharp turns)



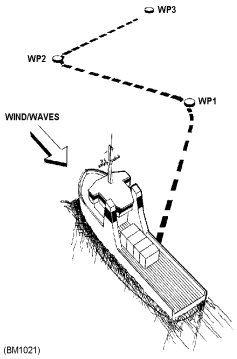
- Passing the waypoint at a constant speed on a segment of a circle. The circle's radius can be:
  - specified on-line by the operator, using the Set Turn Radius function
  - calculated automatically according to the vessel speed, the angle of turn and the vessel's turning characteristics
  - taken from the waypoint table



In addition to the *Present Heading*, *Set Heading*, *System Selected Heading, Set Vessel Speed* and *Set Turn Radius* functions, the following functions are also available in *Auto Track low speed* mode:

- Stop On Course
- Reverse Track
- Leg Offsetting
- Set Cross Track Speed
- Off Track Alarm
- Waypoints from External Computer

Auto Track Mode - high speed

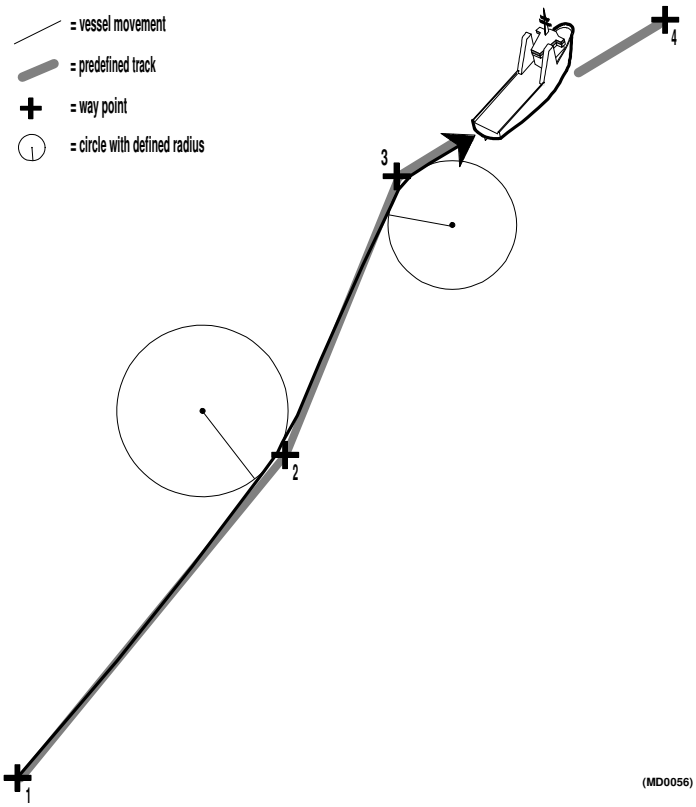


- The Auto Track high speed mode allows the vessel to follow the track at up to the vessel's maximum speed. To keep the vessel on the required track, the required heading is continuously calculated by the system, according to the vessel speed and the direction and magnitude of the environmental forces. The heading is continuously controlled to return the vessel to the track if it should drift off. The operator can limit the difference between the vessel heading and the track direction (the drift angle).

The speed of the vessel along each section of the track can either be taken from the waypoint table or specified by the operator using the *Set Vessel Speed* function. In addition, it is possible at any time for the operator to deselect automatic control of the forward speed of the vessel and use the manual joystick to control the vessel speed. The following figure illustrates a vessel operating in *Auto Track high speed* mode according to the information contained in the table. When passing a waypoint, the vessel maintains a constant speed and follows a segment of a circle.

The radius of this circle can be:

- specified by the operator on-line, using the Set Turn Radius function
- calculated automatically according to the vessel speed, the angle of turn and the vessel's turning characteristics
- taken from the waypoint table

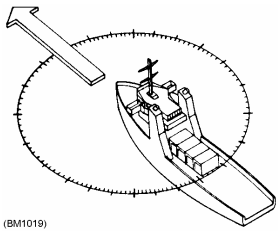


Waypoint Number	North/East Co-ordinates	Speed
1	1501060/503710	2.0 m/s
2	1506060/509710	3.0 m/s
3	1508060/514710	3.0 m/s
4	1513060/517710	2.0 m/s

In addition to the *Set Vessel Speed* and *Set Turn Radius* functions, the following functions are also available in the *Auto Track high speed* mode:

- Stop On Course
- Reverse Track
- Leg Offsetting
- Set Cross Track Speed
- Off Track Alarm
- Rudder Limit
- Waypoints from External Computer

Autopilot Mode



The *Autopilot* mode enables the vessel to steer automatically on a predefined course by accurately controlling the vessel's heading. This mode uses the vessel's propeller(s) and rudder(s) or azimuth thrusters, and compensates for the wind forces acting on the vessel.
The vessel's heading is controlled by the following functions:

- Present Heading
- Set Heading

The following functions are available in the *Autopilot* mode:

- Set Rotate Speed
- Rudder/Azimuth Limit
- Off Course Alarm

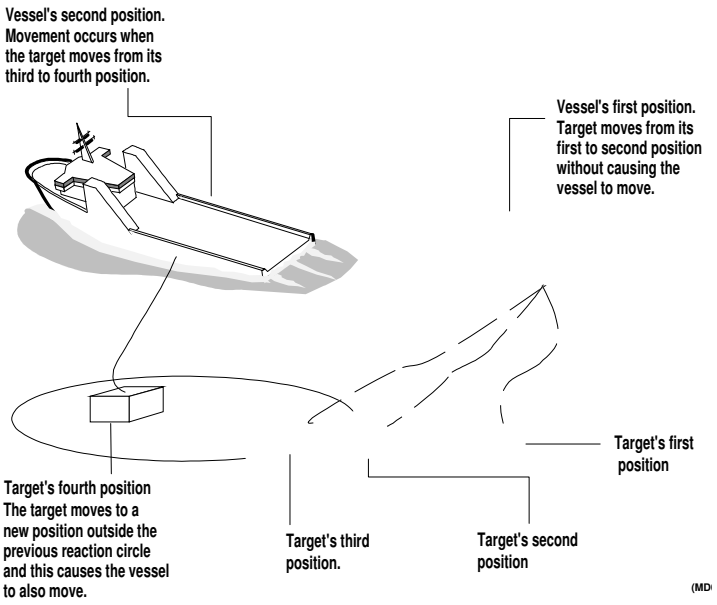
Follow Target Mode

The *Follow Target* mode enables the vessel to automatically follow a moving target and keeps the vessel at a constant position relative to the target. The moving target must be equipped with a mobile reference transponder in order for the K-Pos DP system to monitor its position. If, for example, the moving target is a Remotely Operated Vehicle, then the vessel must be equipped with a Hydroacoustic Position Reference (HPR) system in order for the K-Pos DP system to monitor its position.

The heading of the vessel is controlled by one of the following functions:

- Set Heading
- System Selected Heading

The operator defines a circle of operation within which the target can move without causing the vessel to also move. The vessel only moves when the target crosses the boundary of the circle of operation. The circle of operation is defined using the *Reaction Radius* function.

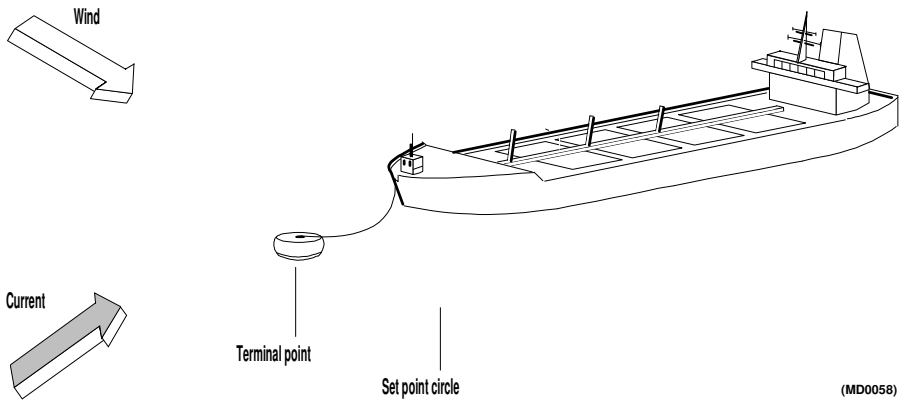


In addition to a reference transponder on the target, an additional transponder must be deployed on the seabed, or another position reference system is required in the vessel.

Offshore Loading

When loading offshore, it is possible to reduce the thruster/propeller force required to retain the vessel's position, relative to the offshore loading buoy, by utilising the stabilising effect of the wind and wave forces acting on the vessel's hull. In order to achieve this reduction, the vessel's bow must always face the environmental forces. Therefore the K-Pos DP system includes special *Weather Vaning* operation modes which cause the vessel to always point towards the environmental forces.

The *Weather Vaning* operation modes cause the vessel to act like a weather vane. The vessel is allowed to rotate with the wind and waves around a fixed point, called the **terminal point.** Neither the heading nor the position of the vessel is fixed. The heading of the vessel is controlled to point towards the terminal point, while the position is controlled to follow a circle, called the **set point circle**, around the terminal point. *Weather Vaning* is illustrated in the diagram below.

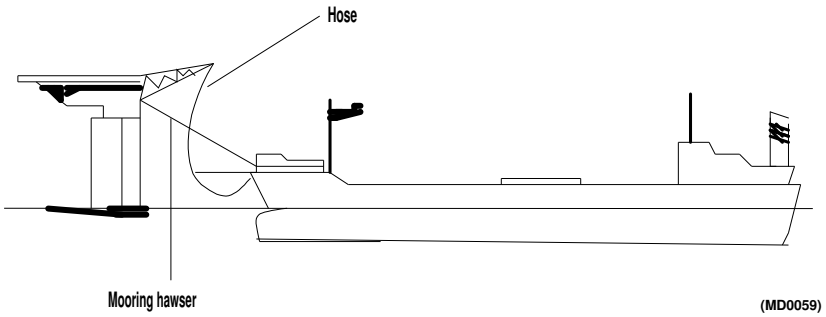


Depending on the type of offshore loading operation, the following functions may also be available:

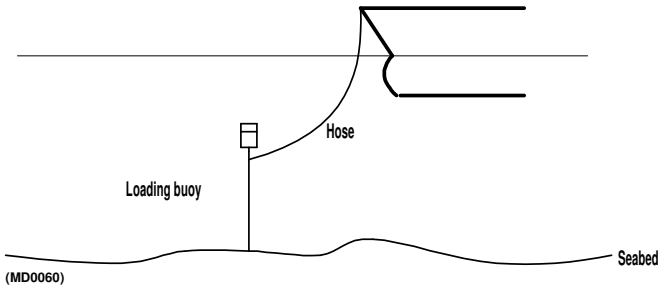
- Terminal Point Selection
- Set Point Circle Radius
- Approach to Weather Vaning Location
- Propeller Bias
- Hawser Tension Compensation
- Manual Bias
- Mean Offset

Depending on the loading concept, different types of *Weather Vaning* operation modes may be used:

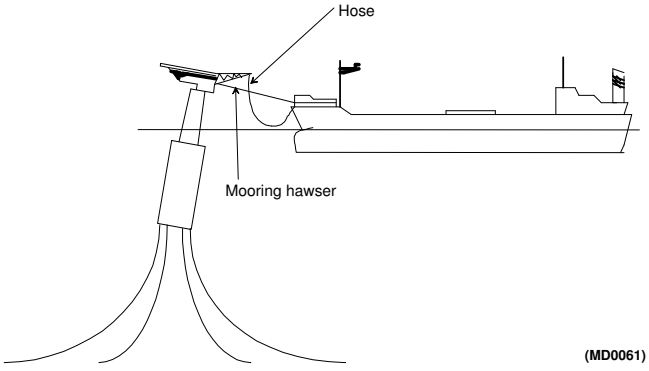
- Single Point Mooring



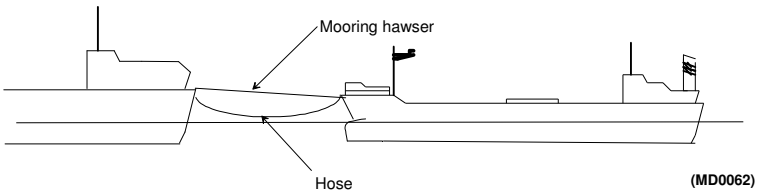
- Loading Buoy without Mooring



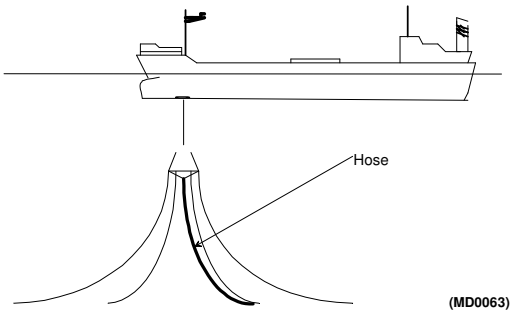
- Floating Loading Tower



- Floating Storage Unit

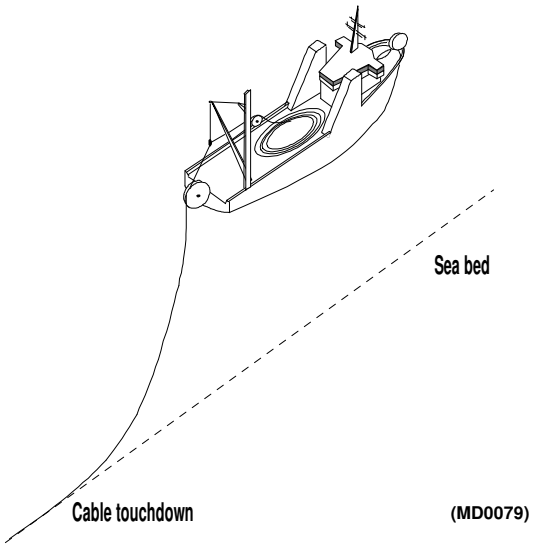


- Submerged Turret Loading



Cable Laying

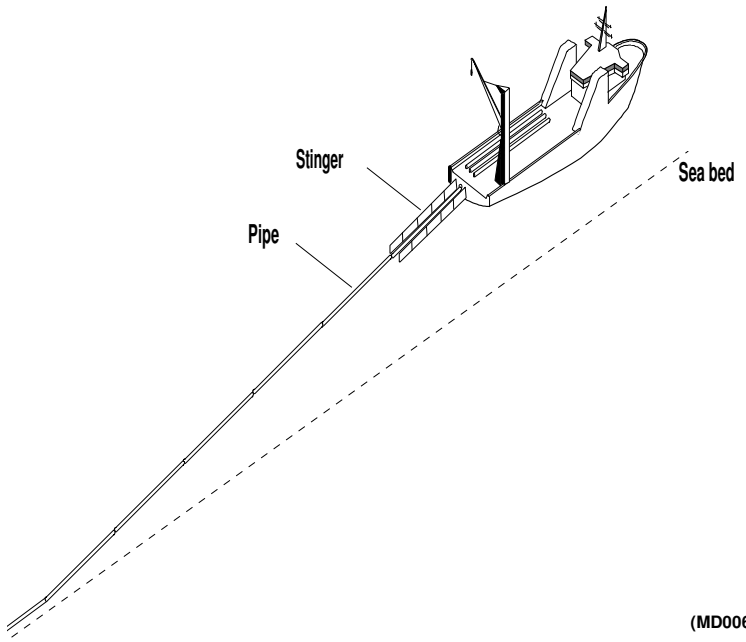
Power and communication cables are transported on reels and are laid either over the stern of the vessel as the vessel moves forward or over the side of the vessel as it moves sideways.



To ensure that the cables are undamaged as they are laid, various tension systems are used. A tension system is designed to control the tension between the cable that is already laid and the cable on the vessel that is waiting to be laid. Therefore the *Cable Tension Monitoring* and *Cable Tension Compensation* functions have been designed especially for cable laying operations. These functions, along with the *Auto Track* mode for controlling the vessel's movements, improve safety and positioning performance when laying cables.

Pipe Laying

When laying stiff pipes, the pipes are transported in sections and are welded together during the pipe laying operation. The sections of the pipes are welded onboard the vessel when the vessel is stationary. The vessel then moves forward a distance of one pipe length, and the welded section of the pipe is moved via a stinger over the stern of the vessel. A stinger is designed to support the pipe as it moves off the vessel. This is illustrated below:



During the pipe laying operations, the K-Pos DP system controls the vessels movements and the *Pipe Tension Compensation* function compensates for the pipe tension to ensure the best positioning performance.

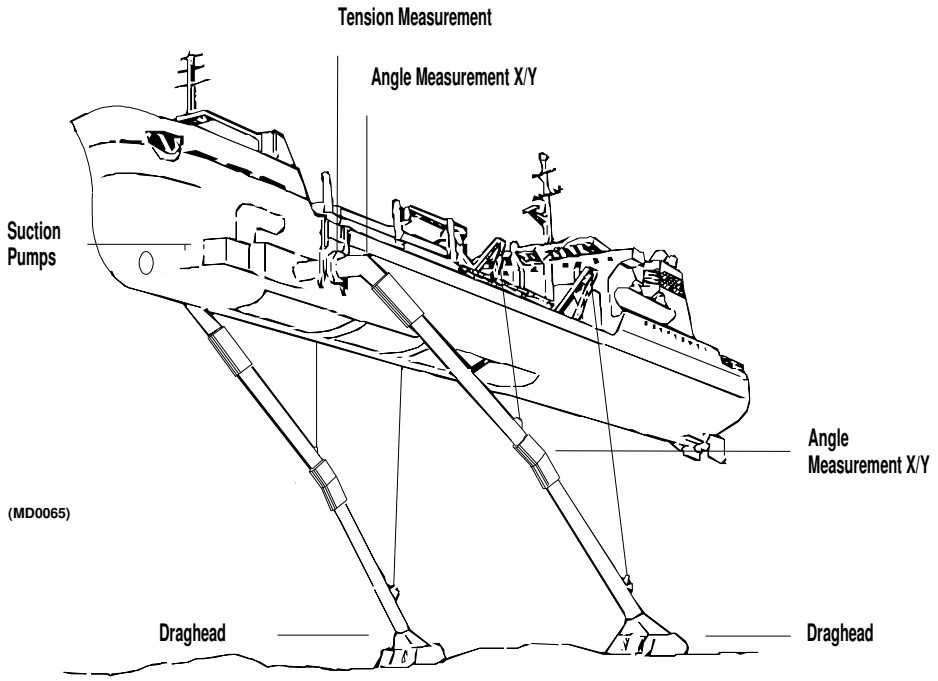
Trenching

Trenches may be dug prior to cable or pipe laying operations and are used to secure the pipe or cable after installation. Trenches are dug by a self-driven trencher or by a vessel towing a plough. The plough itself has no drive machinery; the force needed to pull the plough is supplied by the vessel's propulsion system.

When digging trenches, the K-Pos DP system controls the trencher's movements using the *Follow Target* operation mode, while the *Auto Track* operation mode is used to control the vessel's movements when using a plough to dig the trenches. During trenching operations, the Plough Tension Monitoring and Plough Tension Compensation functions are used to ensure the best position performance.

Dredging

The purpose of a dredging operation is to remove material from the seabed. This is especially important in harbour areas and at river mouths where mud accumulates over time. A dredging vessel is equipped with two suction pipes, which are dragged along the seabed. Material, such as mud and silt, is pumped up into the vessel from the seabed via the suction pipes.
An example of a dredging vessel is shown below:



The dredging vessel moves along parallel tracks. Therefore, to ensure that the whole area is covered, the tracks must be so close to each other that overlapping may occur. However, to achieve an efficient dredging operation, the K-Pos DP functions and operational modes ensure that the area overlapped is kept to a minimum.

The K-Pos DP system's dredging functions measure the dredging forces, suction pipe elevation and azimuth, and automatically compensate for these draghead forces. In addition, the K-Pos DP system handles failure in draghead force measurements to avoid uncontrolled vessel movement and damage to the dragheads. If a permanent failure in the sensor monitoring the draghead's position and tension occurs, the operator can specify the appropriate draghead data, enabling the dredging operation to continue.