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DESIGN

A New Generation DpDt System for Dredging Vessels

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Introduction

Until last year most DpDt Systems in use on board of dredgers were designed for the offshore industry, with slight modifications for coping with the peculiar forces in dredging.
Dredging companies generally do not have a very positive attitude towards DpDt systems:

- Substantial sailing time required for tuning added to the procurement costs make such systems rather expensive.
- A poor performance (compared to that obtained by the human operator) during common dredging conditions do not encourage use of the system in those conditions where it can perform reasonably well.
- Not a very user friendly design to address the inherent complexity and the often poor integration with other maneuvering control systems (such as manual control systems) are no great encouragement either to use a DpDt system.

One of the drawbacks of today's DpDt systems from a dredger point of view is, that they are designed primarily for the offshore industry and that slight modifications are expected to coop with the peculiar forces that occur while dredging. Unfortunately for their designers, dredging operations can be characterized by

- huge and variable water currents,
- very often power limitations, caused by the dredging process, and
- wildly varying very large forces operating on the ship due to the dredging.

Thus it is no wonder that the trained human operator on board a dredger can easily outperform today's DpDt systems.
Nevertheless, it is not difficult to fathom that a properly working DpDt can be beneficial to improve the yield of the dredging process. But given the wide arrange of problems to be solved, a successful design is hardly possible without detailed knowledge of not only ship motion control but also about dredging automation and about how to execute dredging operations.
Therefore, three company's joint forces to develop a new generation DpDt system augmented with properties especially suited for dredging vessels:

- IHC systems; a company specialized in dredging automation,
- Imtech Marine & Industry; with years of experience in ship motion control,
- and Dredging International; a dredging company with interest in optimizing the dredging process.

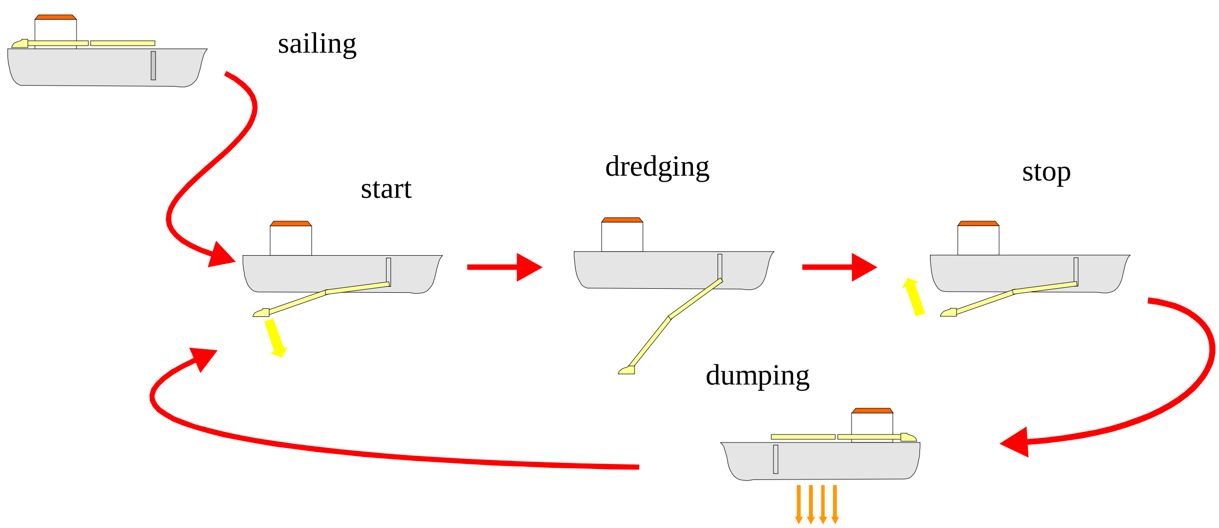
Together, they have developed a new generation Plug & Play DpDt system that has proven itself almost immediately upon her maiden voyage last year.

The paper discusses how the problems of today's DpDt systems have been solved and how the resulting DpDt system has been integrated with the dredging process. It illustrates this with measurements carried out on board of the first ships equipped with these new systems.

The operational use of a DpDt System on board of dredgers.

The dredging cycle

To understand why DpDt Systems on board of dredgers are hardly ever used, it is necessary to have some understanding of the different phases that can be recognized within a full dredging cycle:



1. The cycle starts with moving from some quay or anchor location.
2. The ship has to sail to the dredging location.
3. In-survey of the dredging location may be required if that was not performed by a special survey vessel; that means echo-sounding the dredging area by the dredger itself.
4. The dredging process (setting overboard the dredge heads and starting the pumps) is prepared.
5. The dredging is executed.
6. The dredging dredging process is stopped (stopping the pumps and hoisting the dredge heads).
7. The ship sails to a dumping / pumping-ashore / rain bowing area.
8. Dumping / pumping-ashore / rain bowing is executed.
9. Unless the work was finished, sailing to the dredge location and restarting the dredging cycle from phase 4. Otherwise, the next phase will be executed.
10. Out-survey of the dredging location may be required if that will not performed by a special survey vessel.
11. The ship has to sail to some harbor or to some other dredging location.
12. The cycle stops with the execution of a berthing operation.

From these phases, one may deduct that the DpDt modes for a dredging vessel are those summarized in the following table:

	phase	action	Speed (kn)	DpDt mode	Cycle time	name
1	Start Sailing	Position changing		Manual control or Dynamic Positioning	< 1 hour	Manual / DP-auto
2, 11	Sailing	Heading control or track control	> 10	High speed sail pilot or track pilot	Day ..weeks	Sail pilot / DT-Sail
7, 9, 11	Sailing	Heading control or track control	> 10	High speed sail pilot or track control	1 .. 6 hours	Sail pilot / DT-Sail
4, 11	In/out-survey	Heading + track control	>3	Medium speed sail pilot + track control	1 .. 6 hours	DT-Dredge
4	Start dredging	Swith over to 5			< 5 min	
5	Dredging	Heading control (+ eventually track control)	1..3	Medium speed auto pilot (+ track control)	1..2 hours	(DT-) Dredge
6	Stop dredging	Switch over to 7	>10	High speed sail pilot (+ track control)	< 5 min	Sail pilot / DT-Sail
8a	dumping	Heading + track control	0 ..1	Low speed auto pilot (+ track control)	15 min.. 2 hours	(DT-) Dump
8b	pumping-ashore / rain bowing	Position keeping	0	Dynamic Positioning	1 .. 2 hours	DP-auto
12	Stop Sailing	Position changing		Manual control or Dynamic Positioning	< 1 hour	Manual / DP-auto

As can be seen from this list, the operational modes change frequently. Most of these operational phases take less than one hour. Only phase 2 and 11 may require days or even weeks.

Within the dredging and dumping processes mode changing may be required too, e.g.

- When dredging only small spots (to equalize the bottom).
  In that case small tracks are made (5..20 min), and after each track the following spot much be reached (sometime by sailing backwards).
- The same may apply for dumping, e.g. when covering undersea pipelines or cables. In the last phase of the covering process it suffices to reach only those places without enough coverage.

Thus, from an operator point of view, it is important to be able to change easily between these modes. Even more important, under all conditions the operator has to be able to intervene in a very simple manner (when another vessel interferes, when some component fails, during start-up or shutdown of the dredging process). Taking parts of the control on manual, while other parts still are under control of the automation has to be possible; bumpless transfer between changing to and from automatic control is paramount.

Control problems

Besides the operational phases, there are also control aspects that are typical for a dredging vessel:

- *Rapidly changing, very large dredge head forces*
  The dredging process itself is a very raw process. Dredging is achieved by trailing a dredge head alongside of the vessel. The force of this dredge head can change within seconds from zero to maximum, depending on whether or not the dredge head is touching the bottom. Also the amplitude of the force can change rapidly, even when the dredge head remains at the bottom; changing soil properties is one of the potential causes. In fact, the dredge head force is generally much larger than

any force required to resist wind, current or to obtain a desired trailing speed.
Thus, a control algorithm that cannot act immediately upon such a rapidly changing dredge head force is bound to allow for large heading, track or position changes. As the experienced operator will compensate immediately when he sees that the dredge head touches the bottom, he will be able to obtain a much more accurate control.

- *Operating up to the actuator limits*
  More often than not, DPDT control algorithms on board a dredging vessel have to coop with power limitations. The pumps of dredging process requires almost half the main engine power and the other half is required to overcome the resulting suction forces and to maintain the trailing speed. And when pumping ashore, virtually all power of one engine may be used to obtain the required yield.
  As a consequence, the control algorithms have to be able to deal with the fact that often the demanded actuator positions cannot be reached or cannot be reached in time.

- *Operating in confined conditions*
  Some dredging operations are carried out in conditions where there is hardly any room for maneuvering. Typical examples are dredging in a narrow waterway with dense traffic or close to offshore constructions. In those conditions, not only a high track-sailing accuracy is required, but it is also essential that hazardous conditions are quickly recognized and that the proper actions are clear to the operator and can be executed easily.

Lessons

The properties mentioned above became visible after a study conducted to find out why the standard available DP/DT-systems were hardly ever used on board of dredgers after the acceptance trials. From this study, a number of requirements could be formulated that are important for a DpDt system to be placed on board a dredging vessel:

- A simple to use Human Machine Interface with a very clear distinction between important - often used - functions and less important (not often used) functions.
- A simple way to switch between manual and automatic control and between the several DP/DT modes.
- Easily adjustment of desired settings, such as:
  - Sailing/trailing speed,
  - Heading and
  - Track.
- Accurate compensation of dredging forces.
- A clear way to coop with limitations.
- High accuracy of DP and DT operations (short settling time = time to reach desired DP point or become “on track”.
- Short installation and commissioning time (i.e. Plug and Play properties).

In other words, in order to design a DpDt system for dredging vessels, three aspects had to be addressed:

1. A substantially better *Human Machine Interface* to overcome the threshold fear of the average operator
2. Control algorithms that can coop with *large irregular dredging forces* and that can outperform the human operator
3. *Plug and Play*; a software architecture and design procedure that makes on board tuning no longer a necessity.

A new DPDT system

Problem 1: improving the Human Machine Interface

To meet the above-mentioned requirements, it was decided to design a new human interface. Throughout the design process, continuously feedback was provided by end users. This resulted in a new, user-friendly interface, with the following properties:

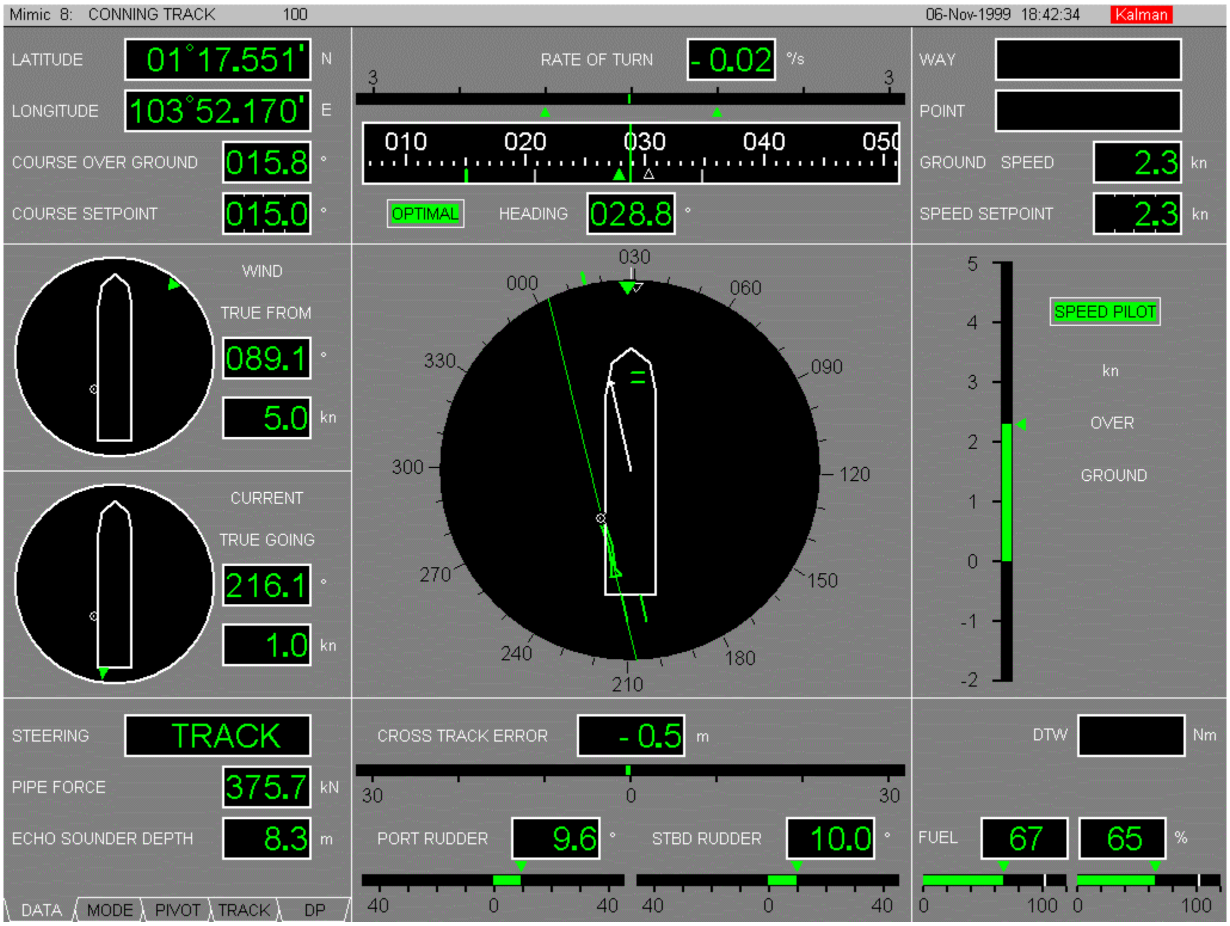
- **Centralized Position.**

It is designed to have a centralized position within the navigation console. That way, switching over between manual and automatic control can be performed without changing control position. By placing the DpDt system in such a centralized position the controls for manual operations (steering wheel, levers for propulsion and bow winches) can also be used in semi-automatic modes.

- **Simple command panel.**

A new command panel has been designed with a minimum amount of buttons and signal lamps. The functionality is limited to the bare essentials, not much more than auto / manual selections of the available control modes and some status indications. In addition, the DpDt system uses the available manual control components (steering wheel, levers) as inputs.

- **VDU display.**



All advanced functionality is present through the VDU display. This provides automatically all information that is relevant for the selected operation mode. In addition, it provides access to the advanced functionality of the DpDt system.

- **One big on/off switch**
  This switch determines whether the DpDt functionality can be addressed or whether the system is merely stand-by. In case of the latter, the operator has full manual control of the actuators without any potential interference by the DpDt system.

In practice, operators praise the simplicity of control. Some fictive examples of applying the system may help understand why.

Example 1: Sailing towards a dredging area and dredging

1. *Start Sailing*
   The Helmsman uses manual controls (steering wheel and truster levers) to move the ship from the jetty. While doing so, he checks whether or not the DpDt system has any serious problem. If that is not the case, he places the on/off switch to DpDt. Although the DpDt system is now within the control loop, this is hardly noticeable to the Helmsman. He is still using the steering wheel and thruster levers to control the vessel. The DpDt panel will indicate that heading control is 'manual' and that speed control is 'lever'.
   The ship has to wait for a few minutes for another ship to leave the area and the Helmsman decides to press 'DP-Auto'. Immediately, the system starts maintaining the current position and heading using the available actuators.
2. *Sailing to working area*
   After some time, the Helmsman turns the heading button to change the heading setpoint. As soon as he can depart, he presses 'Surge Manual' and puts the joystick forward to accelerate the ship (the levers follow the joystick setpoint).
   As soon as the ship starts to move, he decides to press 'Transit' to use again steering wheel and levers to control the ship. He pushes the lever full ahead and, upon reaching the intended speed, he presses the button 'Speed Pilot'. The acceleration stops as the system maintains the ship speed. The Helmsman selects 'Track control' and the current course is used as desired track, which also appears at the ECDIS system. The system now compensates for current and wind. Subsequently, the Helmsman selects a planned track at the ECDIS system and presses 'ECDIS' at the DpDt system. The track line is replaced by the planned track and the system starts following the planned track and speed. Prior to each waypoint, the system asks the Helmsman whether it may execute the planned change.
3. *Dredging*
   Upon reaching the dredging area, the dredging process is prepared. The Helmsman selects 'Lever' and pulls the lever full reverse. Upon reaching 4 knots, the Helmsman selects 'Dredge pilot' (this includes a speed pilot). At the Survey system, the Helmsman selects the track to be dredged and, the system starts moving to that track. Upon reaching the track, the dredge operator lowers the pipes to the bottom and the dredging process is started. The speed pilot automatically increases the propulsion power to overcome the suction forces. Dredging suction and ship speed setpoint are modified by the operators to get the optimal yield without giving in to the required accuracy.
4. As soon as the ship is fully loaded, the dredge operator stops the dredging process. The Helmsman selects 'Transit', pushes the lever to full ahead and turns the wheel to accelerate quickly to the dumping area. Upon reaching the proper heading he selects 'Track control' and shifts his attention to the ECDIS system to select the planned track that will bring him to the dumping area.

Practice has shown that the design choice to enable manual control through the DpDt system has effectively removed the threshold to use this complex (for a novice operator) system.
Except for the very beginning, the Helmsman in the above example is continuously using the facilities of the DpDt system. Thus, the system is able to guarantee smooth transfer from one control mode to the other and to monitor continuously for potential problems with steering gear or propulsors.

Example 2: Dredging a trench through an underwater dune

Assume the ship is positioned in front of the dune and the Helmsman has selected 'DP-Auto'.
The Helmsman uses the track ball to select the pivot point tab page at the conning screen. There, he selects as pivot point the dredge head. The Survey system shows the Helmsman where to start dredging.

He has to move to ship 12 m forward and 6 m aside. The Helmsman uses the track ball to point the new position at the conning screen and the system moves the ship to position the dredge head on the intended position. When the dredge head is lowered, the ship position changes slightly as the DpDt system takes into account the changing tube angle.
The Helmsman uses the track ball to select the current position as 'favorite position 1'. Subsequently, he starts sailing along a track by just pushing the DT-Dredge push button and sets the speed setpoint to 1 kn. Simultaneously, the dredge operator starts dredging.
After 50 m, the dredge operator lifts the pipe. The Helmsman selects 'favorite position 1' as the new setpoint and the vessel starts moving back to the original starting position. Upon reaching that position, the procedure is started again.

This procedure was used successfully during the DEME's first dredging job with the Nile River. This was the cleanup of the bottom of **Monaco Harbour**. A foundation for a new (350 metre long) pier was made on this bottom. In this case the cleanup had to be performed by dredging about 200 meters forwards and than sailing back to start a next dredging track ('favorite position').

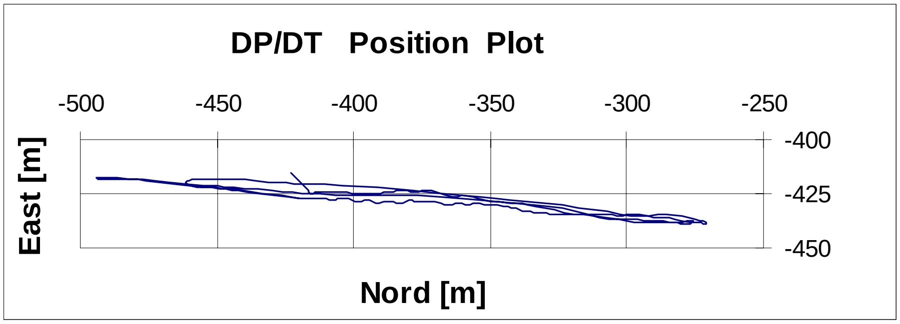


Figure 1; Back and forth tracks: North / East plot

Figure 1 shows this action;
Two dredging tracks in the DT-mode, followed by sailing back in DP mode to the stored 'favorite position'.
This is more clearly expressed in the time graph figure 2.

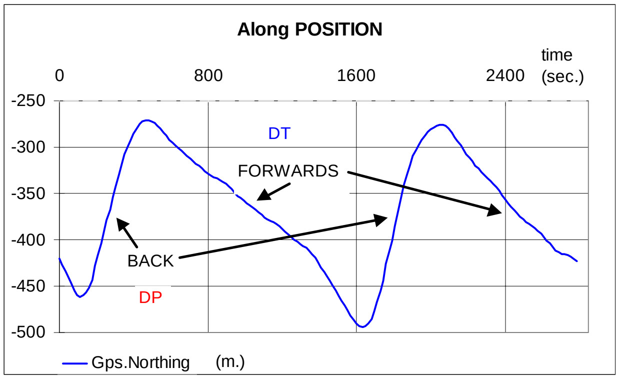


Figure 2; Back and forth tracks: along position

Accuracy
The accuracy of both the DT and DP modes is expressed in Figure 3. At the start of the DP-mode, when the 'along-error' (i.e. distance to desired DP point) is large, the 'cross track error' is larger than at the start of the DT mode. This is because in DP mode, priority is given to the 'along-error' if that is much larger than the cross-track error.

Return to Session Directory ►

Also, sailing in reverse is more troublesome than sailing forward. The accuracy of the DP mode approaches that of the DT mode when close to the desired DP position (i.e. at the starting point for the next track). The forward accuracy (in the DT mode) is better than 2 m. More about this operational use is described in ref. [5].

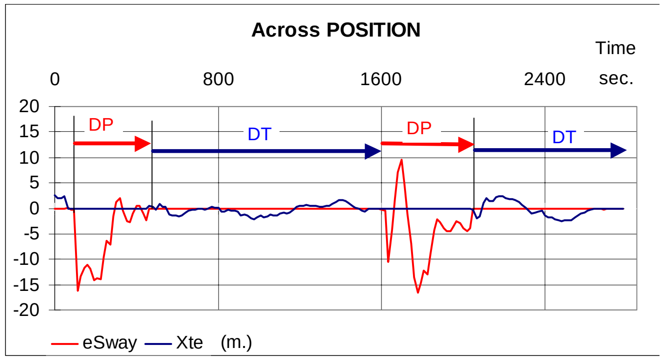


Figure 3; accuracy of the DP/DT system

Problem 2: improving the control algorithms

One of the major jobs of the DpDt System is track keeping while dredging. One has to realize that during this process large forces will be encountered caused by the dredge head pull (as in figures 1 to 3). This dredging force may be as large as 100% of the total propulsion power, while only 5 to 10 % propulsion is required for maintaining a speed of 2 to 3 knots without dredging. This means that 10 times more power may be required for compensating the dredging force than for overcoming the water resistance.
So, obtaining accurate track keeping performances requires measurement of the tension in the suction tubes. Subsequently, the DpDt System uses this measurement to immediately compensate the dredging force (by properly actuating propellers, rudders and bow thruster) before track deviations are even measured. This greatly enhances potential track keeping accuracy.

Unfortunately, the tension in the suction tube is not only very large (the largest force acting upon the vessel) but also very hard to assess. Often the force is measured in the two pins of the upper hinge of the suction tube. However this measured force is not the actual pulling force acting upon the dredge head.
To calculate this real pulling force, all kind of compensations should be made, e.g. for the weight of the suction tube, the mass of the dredged mixture, the tensions in the hoisting wires, the vacuum in the suction tube which pulls the hinges together, etc. (see figure 4).

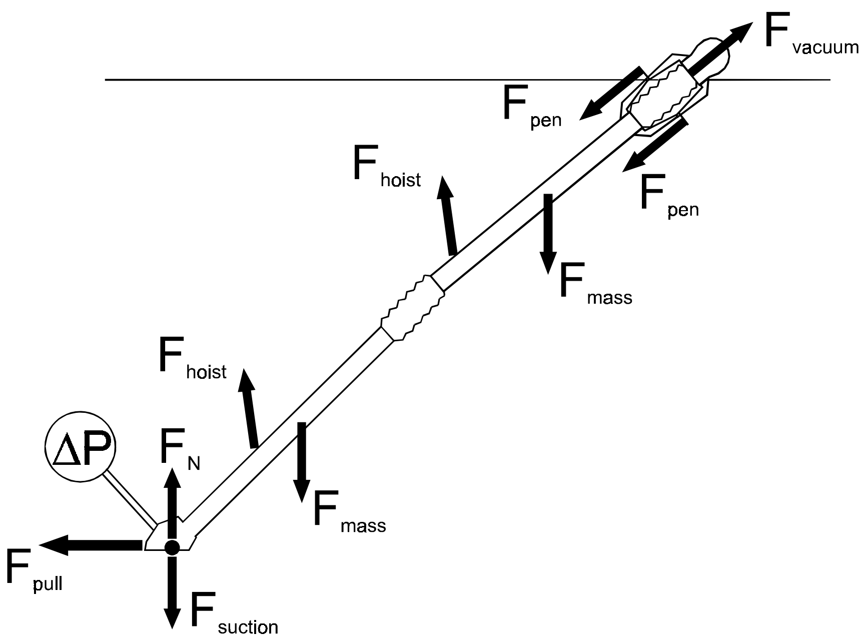


Figure 4: Forces acting on suction tube.

All these compensations make the tension measurement vulnerable for sensor errors. Regular calibration may help, but the vulnerability of the sensors themselves is the biggest problem.
Operating in an extremely hostile environment, the “Mean Time Between Repair” is quite short. As a consequence, these expensive sensors have to be replaced regularly.

Current and dredge head force estimation

The solution was found by combining advanced, model based, filtering and adaptation of the impact of dredging forces. A so-called 'Kalman filter' uses accurately modeled dynamics of the ship and the impact of the actuators and of the wind to estimate the motion of the ship. This estimate is compared with measured position, speed and heading. Any differences can only be caused by model errors, by the current or by the dredging forces.
A patented adaptation algorithm can make distinction whether these differences are caused by calibration errors of the dredging forces or by varying water current. This is possible because the dredging forces changes rapidly and thus causes fast changing differences when calibration is needed, while current deviations cause slowly varying differences.
Ref. [1] shows what high accuracy can be obtained by this improved algorithm.

New measurement principle

Automatic calibration does not solve the vulnerability of the tension measurements. A new measurement principle, using the differential pressure over the dredge head, does. The principle can be explained from the following figure:

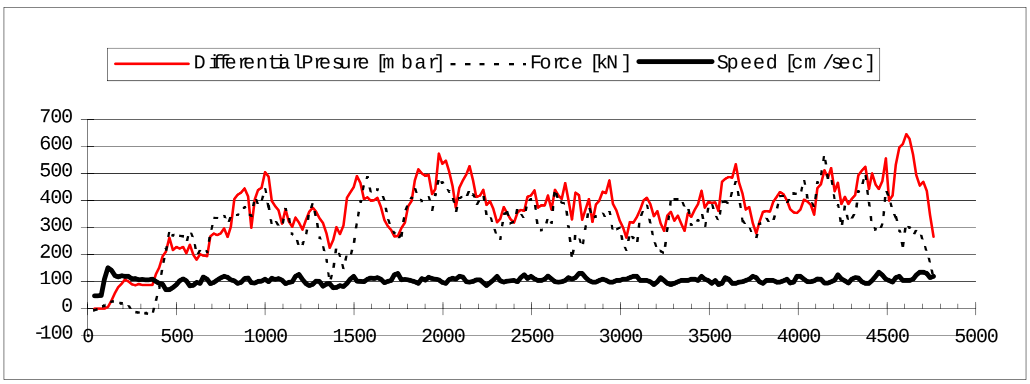


Figure 5: relation between differential pressure and dredge head pull (time-scale = 5000 sec.).

It shows the relation between the differential pressure and the dredge head pull as measured during a particular experiment.
At first glance, the signals look alike. Upon more detailed investigation, it appears that their relationship varies due to variations in soil condition, use of jet-water, pumping speed, conditions of dredge-head-teeth, etc. That's why hardly anyone thought it feasible to use this pressure difference instead of the dredge head pull.
However, due to the automatic and continuous calibration of the suction tube tension described above, it appears that even such a wildly fluctuating signal as the differential pressure may replace the tension sensors (see also ref[2]). Trials have been conducted with either using dredge head pull measurements or with using the (scaled) differential pressure as inputs of the automatic calibration algorithm. If there were any differences, they were in favor of the new approach (due to the vulnerability of the dredge head pull sensors).

Problem 3: 'Plug and Play' Installation

In order to achieve the accuracy requirements that the dredging industry poses to DP and DT operations, the design phase always includes an extensive study towards the potential of a ship, given her actuator properties.

This study (conducted by IHC Gusto Engineering) not only provides insight in the ship's potential (important for the dredging company), it also results in the parameters of a mathematical model of ship hydrodynamics and of its actuators.
Those same models are at the heart of the control algorithms mentioned above. The parameters of these models are used inside the DpDt System to calculate automatically the optimal settings of the control algorithms. These calculations are performed online in the DpDt System, because the hydrodynamic parameters change by changing circumstances (depth, trim, list, etc).
So, in theory, an optimal tuned system is obtained.
In practice, this 'Plug and Play' concept had to be demonstrated; first only for a Dt-system, on board of the Pearl River (ref. [1]), later in 1999 with the first new DpDt systems completed, on board the Queen of Penta Ocean, the Lange Wapper and the Nile River(ref [4]).

With these first systems installed, one may conclude that the Plug and Play concept is feasible. It is indeed possible to put DpDt systems into operation within the normal time span allotted for sea trials on hopper dredgers equipped without a DpDt System (usually three days). In each case, tests were conducted to validate

- the properties of ship and actuators,
- the proper connection of all interfaces
- the proper operation of all connected systems
- and off course the optimal working of all Dp en Dt modes.

In each case, a subsequent successful completion of the acceptance trials made additional fine-tuning of the control algorithms superfluous.

Conclusions

Designing a DpDt system for dredging vessels is not an easy task. As discussed above, the control problem, although difficult enough to solve, is only part of the problem. It is even more important to stimulate the operator to use the system.
A joint effort of three companies has finally resulted in a system with the desired properties.

- A **new sensing technology** in combination with sophisticated, model based, filtering and continuous calibration techniques enable the DpDt system to outperform the Human operator in most conditions.
- A **new Human Interface design**, based on extensive feedback from experienced operators, has proven its merits in practice. Even without instruction, operators required little encouragement to use the system. However, it took a three-day's training course several months later to encourage operators to address the more advanced functions of the system. Since then, the system has already been used in ways that were not foreseen by the designers (ref [5]).
- For each vessel a hydrodynamic study provides all ships' parameters that are used for online and automatically calculation of the controller settings of the DpDt algorithms. Practice has shown, that this procedure is so accurate, that no fine-tuning is required on board.
  This **"Plug & Play" property** means that ship owner and shipyard save days of sea trials.

Of course, the problems mentioned are unique for Hopper Dredgers. However, with exception of the new sensing technology, the solutions presented are not unique for Hopper Dredgers. This explains why also several other types of ships have been equipped successfully with versions of this same DpDt system; in some cases with less functionality (such as no DP-auto), in other cases with other functionality (such as Roll stabilization). In all cases, substantial benefits have been demonstrated in terms of sea trials and of operability.

References:

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