From Eureka to K-Pos: Dynamic Positioning as a Highly Successful and Important Marine Control Technology

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Abstract: Dynamic positioning (DP) started out as an exotic control technology for geological core sampling in deep waters in the early 1960s. The technology gradually became more advanced during the 1970s, especially after it was introduced and applied in the offshore petroleum industry. Several British, French and US companies delivered DP systems during this period, and DP controllers were typically based on the PID principle. In 1977, the first DP system applying modern control theory in the form of a Kalman filter was delivered. This system was a collaborative effort between key companies, research institutes and universities in Norway, motivated by the discovery of oil and gas on the Norwegian continental shelf in 1969. A small group called Albatross had been established as part of the state-owned "modernization locomotive" Kongsberg Våpenfabrikk to industrialize and deliver the new DP system. Albatross DP rapidly gained popularity, and in 1980 all DP systems in the world were delivered by this small group situated in the small Norwegian inland town of Kongsberg. Since then, what has later become known as the Kongsberg DP has been able to maintain a majority share of an increasingly large DP market. Today, dynamic positioning technology has developed from scientific to industrial to mass-market applications, and has been a cornerstone of the offshore petroleum industry for more than four decades. This paper will present DP as an example of a highly successful and important marine control technology, and use the Kongsberg DP as a case study to illustrate key factors required to achieve commercial success for control applications. The paper is based on the book "The Jewel in the Crown: Kongsberg Dynamic Positioning Systems 1975 – 2015", which was released in June 2015.

Keywords: Dynamic positioning, Eureka, Howard Shatto, Jens Glad Balchen, Kalman filtering, Kongsberg Våpenfabrikk, Albatross, Green DP, K-Pos, K-Master

1. INTRODUCTION

On June 2nd 2015, King Harald V of Norway received a copy of the brand new book "The Jewel in the Crown" (Kvaal and Østby, 2015) at the maritime event Nor-Shipping. Work on the book was initiated in August 2011, financed by Kongsberg Maritime (KM). The book chronicles KM's role in the development of dynamic positioning (DP) technology. The main motivations behind the book project were:

- To document an important part of Norwegian and international technology history.
- To acknowledge and honor the work of those who contributed to the DP technology, which has made maritime operations safer and more efficient.
- To provide an excellent example of a successful application of modern cybernetics theory, which hopefully can inspire new generations of engineers to contribute to similar achievements in the future.

This paper is based on the book, which is available in both Norwegian and English language versions through the publisher Pax Forlag. The goal of the paper is to present DP as an example of a highly successful and important marine control technology, using the Kongsberg DP as a case study. Other recommended works on DP technology and history include (Morgan, 1978), (Faÿ, 1990) and (Bjørnstad, 2009).

2. DYNAMIC POSITIONING

2.1 What is dynamic positioning?

A dynamically positioned vessel automatically keeps its position exclusively by using active propellers and thrusters, with no anchoring involved, see Figure 1. The International Maritime Organization (IMO) defines a DP system as: "The complete installation necessary for dynamically positioning a vessel comprising the following sub-systems: Power system, thruster system, and DP control system" (IMO, 1994). The power system includes motors, generators, switchboards and a power distribution system. The thruster system includes thruster, propeller and rudder units, as well as their control electronics and cabling. Finally, the DP control system includes computer hardware and software, sensors, position references and operator interfaces. A DP system also necessitates a human DP operator (DPO). However, the term "DP system" is commonly used about the DP control system.

A DP vessel is mainly controlled in the 3 horizontal degrees of freedom (DOFs), which are surge, sway and yaw. Basic DP functionality includes manual control of thrusters, joystick control of thrusters, auto-position mode, auto-heading mode, autopilot mode and auto-track mode.

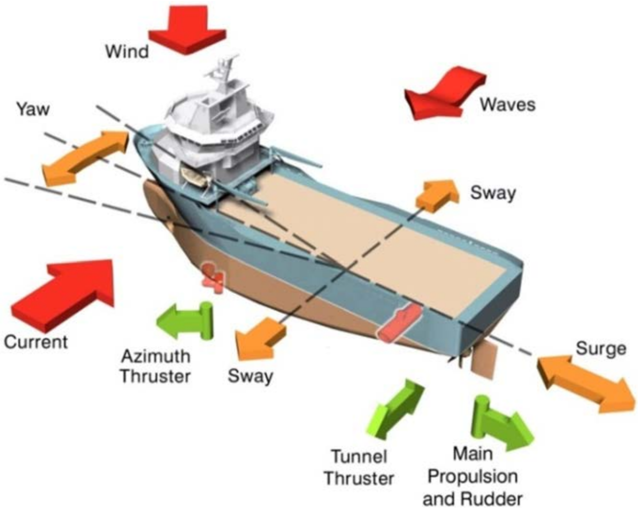


Fig. 1. In order to stay in position, a dynamically positioned vessel must automatically counteract environmental forces and moments from wind, waves and current by active use of its thrusters. Illustration courtesy of KM.

2.2 Origins of dynamic positioning

The first mention of DP seems to be in the novel «Propeller Island» by Jules Verne, which was first published in 1895 (Verne, 1895). This novel tells the tale of a group of wealthy people living on the huge artificial «Standard Island» which is positioned in the Pacific. An excerpt reads: "…it was not "moored" in the strict sense of the term. In other words, anchors were not used, as this would have been impossible at depths of one hundred meters or more. Thus, by means of the machines, which maneuver ahead and astern throughout its stay, it is kept in place, as immobile as the eight main islands of the Hawaiian Archipelago."

CUSS 1 was the first thruster-positioned vessel in the world. It was a marine barge rebuilt as a deep-water drilling vessel, owned by the CUSS consortium (Continental, Union, Shell and Superior Oil). CUSS 1 had four azimuth thrusters of 147 kW each (total of 588 kW), one in each corner of the vessel. Manual thruster control was performed by two operators, while the position references were visual by four surface buoys delineating a radius of 180 meters and a sonar screen displaying relative position to four deepwater buoys. Experimental drilling was successfully performed in March 1961 at a depth of 945 m outside of La Jolla, California. Later, CUSS 1 was able to collect core samples 200 m below the seabed at a depth of 4000 m by Guadalupe Island outside of Mexico, in order to investigate geological theories about the cause of earthquakes for «Project Mohole».

The first DP vessel in the world was the Eureka, a small drillship from 1961 which was owned by Shell and intended for deepwater coring, see Figure 2. Eureka had two azimuth thrusters of 147 and 294 kW (total of 441 kW), and it was originally planned to be manually controlled like CUSS 1. However, an automatic positioning control system was suggested and designed by the electrical engineer Howard Shatto, who is often referred to as the "Father of Dynamic Positioning". Shatto had recently been hired at Shell's R&D department for underwater technology in Long Beach outside Los Angeles, with experience from automation systems at a gas factory in New York. The Eureka DP system included a PID controller for each horizontal degree of freedom and had a taut wire position reference. The control unit was named «APE», which was an electro-mechanical unit patented by Shell, built by Hughes Aircraft and which represented the world's first thrust allocation functionality at sea.

Fig. 2. The Eureka (1961) was the world's first automatically positioned vessel. Picture courtesy of Howard Shatto.

In 1968, the deepwater coring giant Glomar Challenger was launched, initially operated by the Scripps Institution of Oceanography. Significantly larger than CUSS 1 and Eureka, it was capable of coring more than 1700 m below the seabed at depths of 7000 m. Glomar Challenger performed more than 600 coring missions in the Atlantic, the Pacific and the Indian Ocean. The drillship had a digital DP control system from Delco which was the first to utilize wave filtering for removing unwanted 1st-order wave-induced motion. It also had a new type of position reference: Short baseline (SBL) hydroacoustics, with one transmitter and three hydrophones below the hull and one transponder on the seabed.

Fig. 3. The SEDCO 445 (1971) was the world's first drillship designed for the petroleum industry.

A fundamental event happened in 1971 when the SEDCO 445 was launched, see Figure 3. This drillship was owned by Shell, with a length of 145 m and a weight of 17.500 tonnes. It had two main propellers and 11 tunnel thrusters, with a DP system delivered by Honeywell. The company's new Automatic Station Keeping (ASK) system introduced computer redundancy with one active and one passive control computer, guaranteeing 150 days of continuous operation. The redundant position reference system included taut wire, hydroacoustics and riser-angle measurement at the blowout preventer (BOP). SEDCO 445 was the world's first ship for drilling oil & gas wells, and signaled that DP was moving from science and geology to oil and industry.

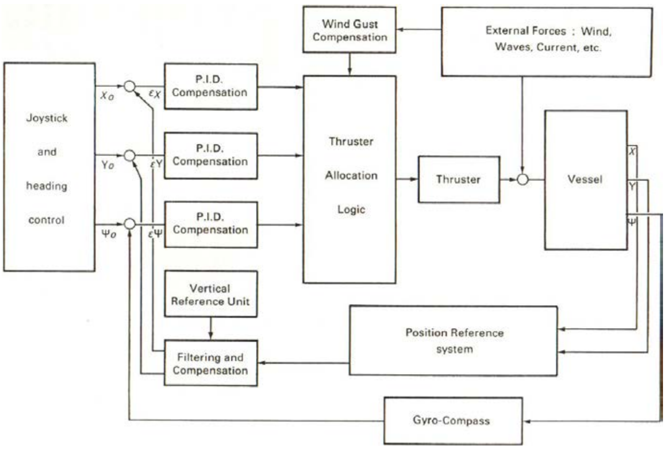


Fig. 4. The DP control system of the French research ship Térebél had a classical PID design (Harbonn, 1971).

In the 1970s, several companies delivered DP systems around the world, including Honeywell (USA), Delco (USA), General Electric Company (UK), CIT Alcatel (France) and Thomson-CSF (France). However, there were only 10 drilling vessels with DP in 1975, and just below 20 DP installations in the whole world. Hence, dynamic positioning still represented a niche market. All the DP systems at this time used a PID controller for each DOF, see Figure 4.

3. JENS GLAD BALCHEN, KONGSBERG VÅPENFABRIKK AND THE DYNPOS PROJECT

The Norwegian professor Jens Glad Balchen played a key role in promoting the use of modern control theory for DP systems, see Figure 5. A short DP-related timeline for Balchen is as follows:

- 1949: Graduates with a MSc in electrical engineering from the Norwegian Institute of Technology (NTH), which today is NTNU.
- 1951: Becomes familiar with real-time computers at MIT, participating in the Whirlwind project.
- 1954: Establishes the Department of Engineering Cybernetics at NTH and develops the analog computer DIANA.
- 1959: Learns about ship automation during a visit to California.
- 1961: Meets Rudolf Kalman at Berkeley during a US sabbatical and learns about the Kalman filter (Kalman, 1960).
- 1968: Meets a group of students working on the Glomar Challenger project and learns about dynamic positioning, during a sabbatical at the University of California, Santa Barbara (UCSB).
- 1969: Oil is discovered on the Norwegian continental shelf.
- 1971: Balchen contacts Kongsberg Våpenfabrikk for the first time...

Fig. 5. Jens Glad Balchen is recognized as the "Father of Engineering Cybernetics" in Norway. He built up the research and educational environments at NTH and SINTEF, and also initiated many cybernetics-based projects which later became industrial successes (Breivik and Sand, 2009). Picture courtesy of NTNU.

Kongsberg Våpenfabrikk (KV) was established in Kongsberg in 1814. It was a Norwegian «modernization locomotive» after the Second World War, involved in pretty much everything industrially important for Norway during the 1970s and 1980s, for both civilian and military applications, see Figure 6. Today, KV is known as Kongsberg Gruppen.

Kongsberg is a small, Norwegian inland town with about 25.000 inhabitants. It is located approximately 80 km southwest of Oslo, far from the sea and thus perhaps not the most likely candidate for a maritime success story. The town was founded in 1624 due to its large silver deposits, and is by many today called the high-tech capital of Norway.

A short timeline describing the interaction between Balchen and KV is as follows:

- 1971: Balchen initially contacts KV, equipped with knowledge about real-time computers, Kalman filtering and dynamic positioning. The business idea is to develop a better DP control system than the American, British and French companies deliver. Balchen argues that the state-owned company has a responsibility to develop new and more advanced technological solutions for the rough North Sea. However, KV sees no market and declines.

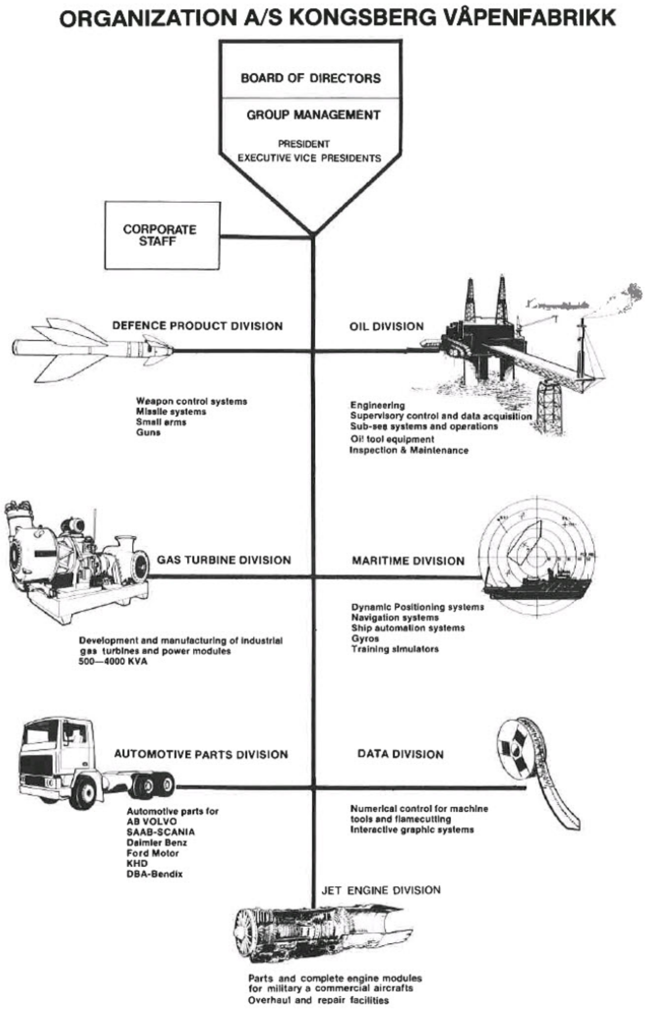


Fig. 6. In 1982, Kongsberg Våpenfabrikk was a state-owned and state-funded industrial locomotive in Norway, active in all high-tech fields relevant to the country. Illustration courtesy of Kongsberg Gruppen.

- 1973: Balchen contacts KV again, after the Norwegian Oil Directorate and Statoil have been established in 1972. The Norwegian ship-owner Stolt-Nielsen has recently ordered a Honeywell ASK system for his diving support vessel Seaway Falcon, which becomes the first DP-equipped vessel in Norway. KV delivers the control system for the vessel's water cannons. However, KV still sees no DP market, but is nevertheless involved in offshore projects with the Bergen-based research institute CMI, the marine electronics company Simrad and the shipbuilding company Aker. Balchen then intensifies research on DP control algorithms.

- 1974: KV suddenly invites CMI, Simrad and Balchen with colleagues from NTH and SINTEF. An agreement is made to start a Norwegian project on DP system development. The main motivation for KV is the hope of a contract with Stolt-Nielsen.

The main Balchen team at NTH and SINTEF consisted of Steinar Sælid and Nils Albert Jenssen, who were investigating DP estimation, control and thrust allocation algorithms based on Kalman filtering and optimal control theory. Several MSc theses were also written on the subject, the first arriving in 1974 (Auen, 1974), while Jenssen did the first Norwegian PhD thesis on dynamic positioning in 1981 (Jenssen, 1981). Both Sælid and Jenssen started working for KV in 1982, and while Jenssen in 2015 continues to play a central role for KM's DP product, Sælid moved on to create his own company Prediktor in 1995, which is currently developing an artificial pancreas.

3.1 The DYNPOS project

In September 1974, agreement was reached to start development of a Norwegian DP system. This was a national collaborative effort, where Simrad was tasked with providing a hydroacoustic position reference system, CMI tasked with simulating the effects of wind, waves and current on vessels at sea, NTH and SINTEF tasked with developing control algorithms and software, while KV was tasked with providing the control computer, system software and operator stations. The DYNPOS project was finally established on January 1, 1975. The project managers at KV were the soft-spoken Thor Skoland, who e.g. had experience from the fire control system MSI-80S for motor torpedo boats (MTBs), and the energetic Bjørn Barth Jacobsen, who had the attitude of «selling the skin before shooting the bear», while KV most often shot the bear before selling the skin, not seldom in vain. This dynamic duo led the project between 1975 and 1980.

During the summer of 1975, Skoland was allowed to inspect the Honeywell ASK system onboard the Seaway Falcon, which consisted of a DP control room behind the bridge and a slave monitor on the bridge without feedback to the controls. He was skeptical and thought the installation looked more like a computer room in a bank than a DP system for a ship. While the Honeywell solution seemed to be inspired by land-based industry, the KV project members had experience from U-boats and MTBs, which have limited space and operate in tough environments. Hence, the DYNPOS project aimed at developing a more tailor-made human-machine interface (HMI) better suited for maritime operations.

KV finally landed its first DP contract on November 22, 1975, valued at 5.3 million kroner (MNOK), with shipowner Jacob Stolt-Nielsen for the service rig Seaway Swan.

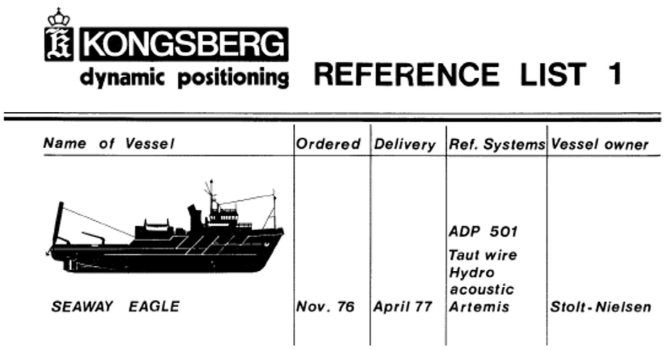
4. ALBATROSS DP

In 1976, the first Norwegian DP paper was presented at the IFAC/IFIP Symposium on Automation in Offshore Oil Field Operations in Bergen, Norway (Balchen et al., 1976). This paper is probably also the first to investigate Kalman filtering for dynamic positioning purposes. Specifically, it proposes an adaptive wave filter designed to estimate low and high frequency vessel motion components, where only the former is used for feedback control in order to reduce energy consumption and thruster wear and tear. The paper concludes as follows: "The simulations show that a control system based on Kalman filtering technique and optimal multivariable control theory may reduce thruster modulation significantly and give precise control."

Also in 1976, the DYNPOS project found out it needed a logo, to promote itself at trade shows and events. As a result, the project secretary came up with a proposal of an albatross, which was immediately accepted and later became a strong symbol for KV's DP activities, see Figure 7. In fact, the new DP product itself was named Albatross DP (ADP).

Fig. 7. The majestic albatross has long and slender wings which enable it to take advantage of the wind and glide for hours without a single wingbeat. Illustration courtesy of KM.

On the Norwegian Constitution Day May 17 in 1977, the first Albatross DP system was tested and approved onboard the diving support vessel Seaway Eagle, see Figure 8. The redundant position reference system included hydroacoustics from Simrad, taut wire and the microwave navigation system Artemis. The control computer was KV's own KS500. Much effort had also been put into making a user-friendly, simple and intuitive HMI with "one button for one function".



KONGSBERG dynamic positioning REFERENCE LIST 1

Name of Vessel	Ordered	Delivery	Ref. Systems	Vessel owner
SEAWAY EAGLE	Nov. 76	April 77	ADP 501 Taut wire Hydro acoustic Artemis	Stolt-Nielsen

Fig. 8. Seaway Eagle was the first vessel to be equipped with a DP control system based on Kalman filtering and optimal control theory. Illustration courtesy of KM.

A new milestone was reached in 1980, when the small Albatross group delivered all the DP systems in the world. Later that same year, over half of the world's DP systems were in fact ADP systems (42 out of 80). Subsequently, KV's DP business grew rapidly.

4.1 *A model-based DP system*

Also in 1980, the Norwegian cybernetics journal Modeling, Identification and Control (MIC) was founded with Jens Glad Balchen as its editor. In the first volume of MIC, a paper detailing the cybernetic algorithms behind the Albatross DP was published (Balchen et al., 1980). The paper starts with a rather technology-optimistic explanation for KV's DP initiative: "The known disadvantages of conventional DP-systems led the mechanical engineering and data technology company Kongsberg Våpenfabrik A/S of Norway to initiate the development of a DP-system based on the concept of modern control theory, such as Kalman filtering and optimal control."

The goal of a DP system is defined as follows: "A DP-system should be designed to keep the given vessel within specified position limits, with a minimum fuel consumption and with minimum wear and tear on the propulsion equipment. In addition, the DP-system should tolerate transient errors in the measurement system and also give an acceptable reaction in case of error in the propulsion system."

On experience with the Kalman filter: "As could be expected, the Kalman filter works extremely well. This has made it possible to utilize reference systems not previously used for dynamic positioning systems (...) A hydroacoustic reference system used in unfavourable conditions and in deep water often yields measurement signals with considerable disturbances. The efficient filtering of these signals has significantly reduced the thruster control excitations from measurement noise." A sketch is shown in Figure 9.

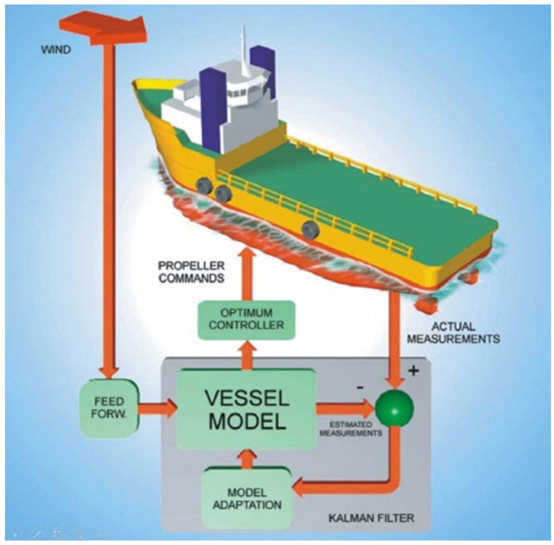


Fig. 9. The Kalman filter contains mathematical models of the low and high frequency vessel motions, which provide model-based filtering with reduced phase lag compared to conventional filters. In addition, the filter includes a current model to estimate unknown and environmental disturbance forces and moments, also known as "the Kongsberg current". Illustration courtesy of KM.

The paper concludes that: "Modern control theory has been successfully applied to the dynamic positioning problem. Operational experience has shown that the resulting system behaves in accordance with the expectations or even better in some aspects. The price to be paid is a more complicated software, increased computer capacity requirements and increased engineering effort in the specific system design. Recent experience has shown that the market is willing to pay for the extra advantages."

The Kalman filter also attained an almost magical quality in the sales work. Many anecdotes and stories exist about the filter, illustrating the imagination of the salesmen and the enthusiasm of the customers. One such story tells of a salesman who secured a contract by adding an extra Kalman filter free of charge. Another story tells of a manager who approved an invoice for purchasing liquor to clean the filter.

The new model-based DP system introduced by Balchen and co-workers had several advantages:

- Fusion of different sensors and position reference systems.
- Improved signal processing, including noise removal with minimum phase lag.
- Separation of vessel motion into low and high frequency components.
- Dead reckoning.
- Disturbance estimation.
- Error handling and fault tolerance.

The result was a more robust DP system which used less fuel and had less thruster wear and tear. After the commercial success with the new estimation and control algorithms, Balchen is rumored to jokingly have said: “There are only three people in the world who truly understand control engineering, and the other two are former students of mine.”

Figure 10 illustrates the signal flow in the Albatross DP system. Sensor measurements enter at the top, while thruster commands are issued at the bottom. In-between, a computer runs the cybernetic algorithms required for precise and robust positioning. As Balchen often emphasized: “The computer is the most important component in a cybernetic system.” (Breivik and Sand, 2009).

4.2 An example ADP configuration

Figure 11 illustrates the Wilchief diving support vessel, which could perform diving operations down to 350 m depth. Its Albatross DP system configuration was installed in 1983, see Figure 12. The particular configuration consisted of a redundant APD503 MK II system with two gyro compasses, two vertical reference units, two wind sensors and a redundant position reference system comprising two taut wires, two hydroacoustic systems from Simrad and one Artemis microwave navigation system. Note that the control computers were located in separate cabinets from the operator console. This console had two display panels, one control panel and one sensor panel. Colors were used to differentiate displayed data with respect to importance and priority. Wilchief had a diesel-electric power system with four main engines supplying a total of 10 MW, which roughly corresponds to the power used by 100 ordinary cars. Power was mainly consumed by the vessel’s two aft azimuth thrusters and four tunnel thrusters. An uninterruptible power supply provided power redundancy to the ADP system.

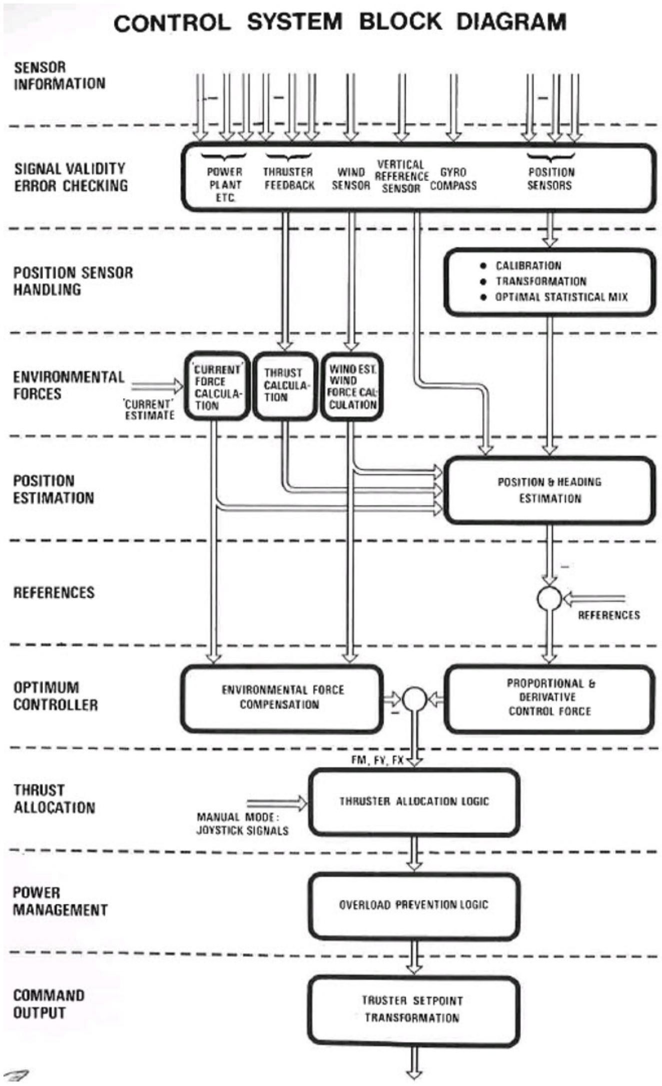


Fig. 10. The signal flow in the Albatross DP system, showing the main computer calculations required to stay safely and precisely in position. Illustration courtesy of KM.

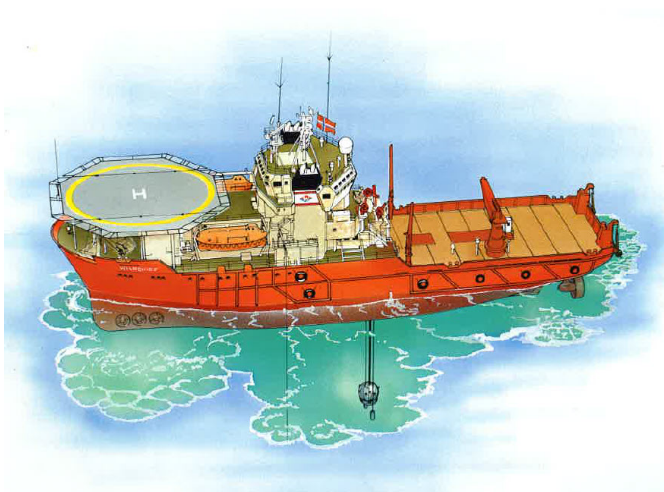


Fig. 11. An artist’s impression of the diving support vessel Wilchief, which could also perform installation and development work in addition to participating in fire-fighting operations. Illustration courtesy of KM.

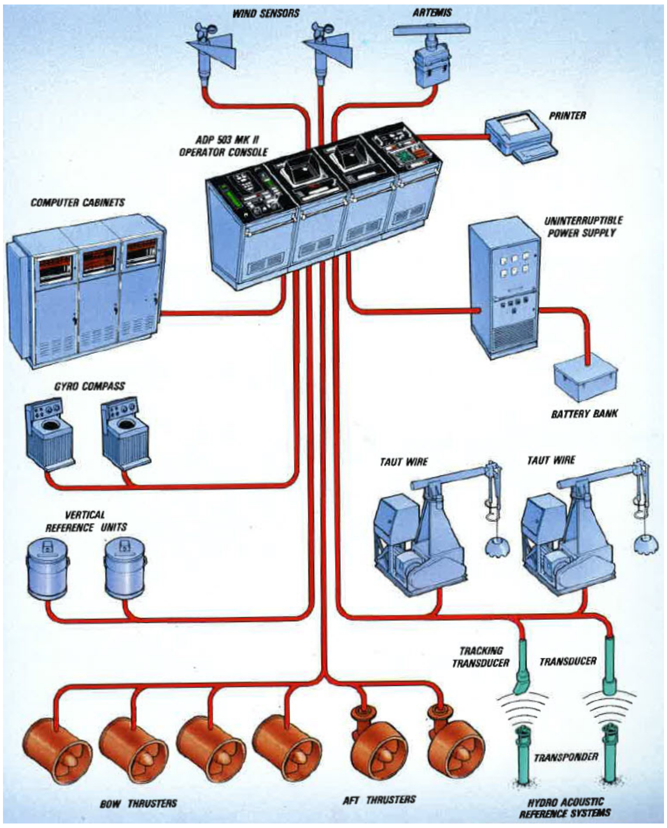


Fig. 12. The ADP configuration for the diving support vessel Wilchief. Illustration courtesy of KM.

4.3 *Theory Albatross*

In 1980, the KV Albatross group counted 60 employees. Due to the commercial success of their DP system, this number increased to 135 people by the end of 1982. The success was not only caused by new and advanced technology, but also by a distinct culture which was named "Theory Albatross" and structured into seven main rules for all employees to follow:

1. We live for, together with and by our customers.
2. We all have a leadership responsibility.
3. Good profitability is fundamental to our business.
4. We see possibilities instead of threats.
5. We want to be individualists.
6. We want specialist expertise.
7. Our quality is customer satisfaction.

This cultural foundation emphasized personal responsibility and a strong customer orientation for all employees, regardless of being software engineers, hardware engineers, test engineers, project engineers, service engineers, project managers, department managers, sales managers, illustrators, technical writers or secretaries. Figure 13 shows an old and wise guru giving advice to a youngster, in reality stating that "the mission of an albatross" is to help customers improve both their vessel and market positions.

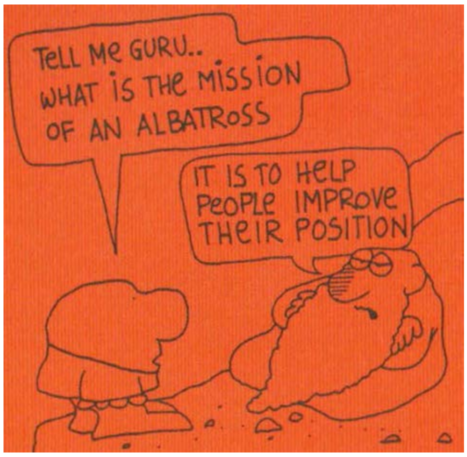


Fig. 13. Excerpt from a small pamphlet explaining the "Theory Albatross" culture. Illustration courtesy of KM.

5. KONGSBERG DP GENERATIONS

The Albatross DP technology continued to evolve, with smaller, faster, cheaper, better and more reliable components, as well as more advanced functionality. Figure 14 shows the main DP generations delivered from Kongsberg since 1977.

1977	ADP501 ADP502 ADP503	1 KS500 64k computer, HPR display 1 KS500 64k computer, display processor 3 KS500 64 k computers, 2 display processors
1979	ADP503 MkII ADP311	3 KS500 128k computers, 2 colour displays 1 KS500 128k computer, 1 colour display, 1 cabinet
1983	APM3000 ADP100	2 KS500 256k computers, 1 display 3 SBC1000, 1 display
1987	ADP703 rev. 0	9 SBC1000, voting, 2 displays
1990	ADP701 rev. 0 ADP700	2 SBC2000, 1 display 1 SBC2000 with joystick terminal
1992	ADP701 MkI & II ADP702 MkI & II ADP703 MkI & II STC	1 SBC3000, 1 display 2 SBC3000, 2 displays 3 SBC3000, 3 displays SBC3000 Thruster Control
1996	SDP11/12, 21/22, 31/32 SPM SJS01/SDP01 STC	SBC400 DP Controller and NT workstation SBC400 DP Controller and NT workstation Joystick/Compact DP (replace Robertson products) SBC400 Thruster Control and NT workstation
2001	SDP GreenDP (SDP11/12,21/22,31/32)	SBC500 DP Controller and NT workstation
2003	SDP/SDPM/SPM (SDP11/12,21/22,31/32)	SBC500 DP Controller and XP workstation
2004	SDP/SDPM/SPM (SDP11/12,21/22,31/32) cJoy cPos STC-400	RIO-based DP Controller and XP workstation RIO-based compact joystick system RIO-based compact DP system (equipment class 1) RIO-based Propulsion and Thruster Control System
2006	K-POS (DP11/12,21/22,31/32) K-Thrust	RIO-based DP Controller and XP workstation RIO-based Propulsion and Thruster Control System

Fig. 14. Brief overview of the main Kongsberg DP generations. Table courtesy of KM.

The early ADP50X and ADP311 systems used KV's KS500 computer, which had quite limited memory capacity. It was a Word-based computer, which means that 64kW in the table corresponds to 128kB. The Albatross group then developed their own single-board computer (SBC) in 1983 based on Intel's new x86 processor technology. It was first used in the compact ADP100 system. Simultaneously, the software was ported from Fortran to C. In 1987, the first triple-redundant

DP system was launched, namely the ADP703 rev. 0 with majority voting and Ethernet communication. Its control computers had also been moved inside the operator console.

The same year, Kongsberg Våpenfabrikk was forced to sell all its assets except the defense activities after the Norwegian government refused to continue servicing KV's huge debt, which had grown to become larger than the value of the company. Hence, the Albatross business was sold to Simrad and renamed Simrad Albatross in 1988.

In 1990, the SBC1000 was replaced by the new SBC2000 based on the Intel 80286 and used for the ADP701 rev. 0. Subsequently, 1992 saw the arrival of the ADP70X series with distinct redundancy levels and using the new SBC3000 computer. Two years later, in 1994, the IMO published its guidelines for vessels with DP systems, including the concept of equipment classes (IMO, 1994). Here, equipment class 1 has no redundancy and a loss of position may occur in the event of a single fault, class 2 has redundancy such that no single fault in an active component or system will cause loss of position, while class 3 additionally must handle both fire and flooding in any one compartment without losing position.

Also in 1994, Simrad started work on their new DP generation, which was launched in 1996 and named Simrad Dynamic Positioning (SDP). The graphical user interface became Windows-based and the control computers moved out of the operator console and into separate cabinets again. The naming convention became standardized, for easy recognition toward the new IMO guidelines: SDP11/12, SDP21/22 and SDP31/32. Here, the first number indicates a "single", "dual redundant" or "triple redundant" system, while the second number indicates whether the DP system is a "standalone" or "integrated" delivery. Figure 15 shows the separation between the PC-powered operator stations running Windows NT and the DP controller cabinet which interfaces the position references, sensors and thrusters while running real-time calculations on the new SBC400 computer.

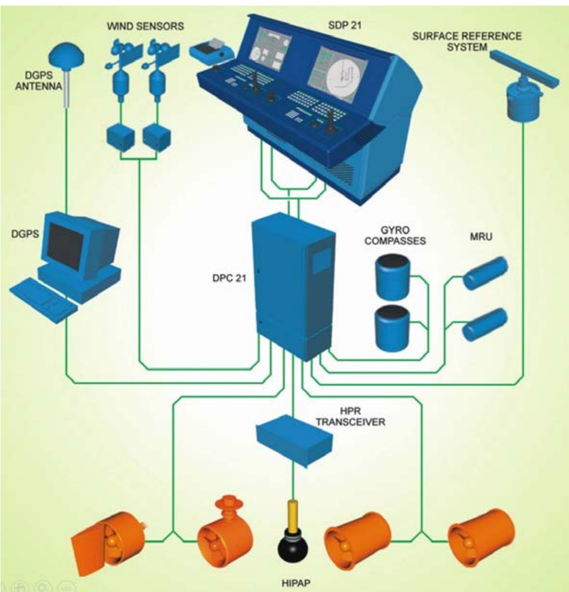


Fig. 15. The topology of an SDP21 dual redundant, standalone system. Illustration courtesy of KM.

During the early 1990s, there was a power struggle between Simrad and the remains of KV to become the leading Norwegian marine electronics company. The latter changed name to Kongsberg Gruppen in 1995 and managed to buy Simrad in 1996. The following year, the Albatross business became part of a new company called Kongsberg Simrad.

In 2001, Kongsberg Simrad launched a new and environmentally friendly DP functionality called "Green DP" (Hvamb, 2001). Figure 16 illustrates the concept, where an inner working area and an outer operational area are defined. The Green DP functionality employs nonlinear model predictive control (NMPC) to find out if the environmental disturbances will push the vessel outside its operational boundaries within a given time horizon, and calculates a corresponding smooth, minimum-power control effort to prevent this from happening. Green DP results in less fuel consumption and significantly lower power variations than traditional "bull's eye" positioning, and is utilized for non-critical standby operations for offshore vessels and electronic anchoring for cruise ships located close to coral reefs.

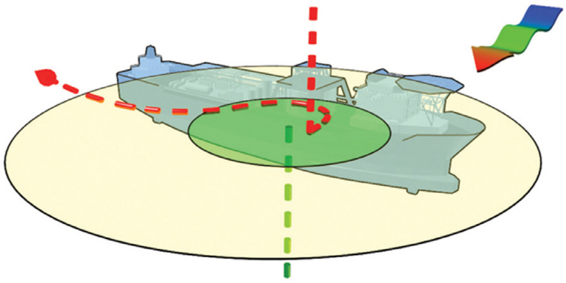


Fig. 16. Green DP: Operational boundaries and predicted trajectory. Illustration courtesy of KM.

The new and computationally intensive NMPC functionality also required a more powerful control computer, resulting in the SBC500, which was up to 100 times faster on floating-point operations than its predecessor.

Kongsberg Simrad disappeared when Kongsberg Maritime (KM) was established as a company in 2003. The Albatross business is currently part of KM's offshore division and the name is no longer in use. Three years later, in 2006, KM launched a new DP generation called K-Pos. The operator stations were redesigned, with a new graphical user interface, see Figure 17. New IO modules, cabinets and a new control computer RCU501 (remote control unit) were developed. Otherwise, the naming convention established with the SDP generation continued, resulting in K-Pos DP11/12, etc.

Fig. 17. K-Pos operator stations with flat screens, push buttons, lamps and joystick controls. Picture courtesy of KM.

In 2009, the multi-function operator chair K-Master was launched, see Figure 18. With origins from 2002 and the Simrad Maneuvering Control (SMC) console, the new chair was intended for the aft-bridge work environment and included functionality such as thruster control, joystick control, DP control, ship automation, conning display, chart radar, bridge-auxiliaries control, as well as integration of third-party systems. During its development, focus had been on user-centered design and improved situational awareness for the human operator, resulting in a common user interface for the different sub-systems. The goal was to change focus away from "boxes, systems and equipment" to information and operation, displaying the 20% of the functionality being used 80% of the time at the front.

Fig. 18. The K-Master chair won the Award for Design Excellence by the Norwegian Design Council in 2010. Picture courtesy of KM.

Hence, the DP system is just one of many vessel systems which can be controlled from a K-Master. However, DP has not yet been "swallowed up" as one of several components in a larger vessel automation system and continues to exist as a separate product. An important reason is that it is a safety-critical technology with strict redundancy demands.

DP system components such as thrusters and position references have also experienced significant progress since the 1970s. In particular, satellite navigation systems have become indispensable position reference systems for most DP vessels today. Figure 19 illustrates the richness in both global and local as well as surface and subsurface systems.

In 1995, a total of 50 DP systems were delivered from Kongsberg. This number increased significantly in the coming years, such that in 2012 almost 350 Kongsberg DP systems were delivered for installation around the world. Most of these installations were performed at ship yards in Asia, in particular China, Singapore, South Korea and India. Other significant yard locations included Norway, USA and Brazil. The DP systems are supported 24/7 by the KM customer support system "Follow the sun", where personnel work 8-hour shifts rotating between the main hubs in Kongsberg, New Orleans and Singapore.

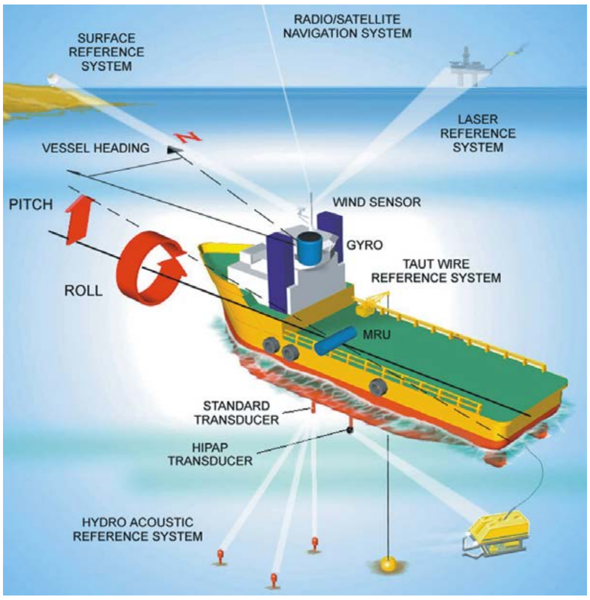


Fig. 19. A DP vessel can utilize several types of position reference systems for increased precision and robustness. Illustration courtesy of KM.

A curious testament to the user-friendliness and robustness of the Kongsberg DP systems is the story of an ADP311 which was delivered in 1980 with serial no. 17. In 2013, this system was still going strong and being used in Australia despite efforts by KM to get it replaced, being at that point probably the oldest operational DP system in the world.

At the end of 1999, the Albatross DP system came second in a vote among Norwegian engineers over the "Engineering Feat of the Century", a competition arranged by the leading engineering magazine Teknisk Ukeblad. Key criteria included technical boldness, imagination, innovation and social significance. The gigantic Troll A platform, the tallest structure ever moved, was voted number one.

Finally, Figure 20 shows a selection of facts related to the Kongsberg DP systems since 1975. While positioning accuracy and processor memory have increased, system prices and weight have decreased.

6. DYNAMIC POSITIONING EVERYWHERE

Today, thousands of vessels around the world rely on DP systems to do their job. These are vessels performing drilling, diving support, pipe and cable laying, offshore loading, heavy lift operations, anchor handling and tug supply (AHTS), inspection, maintenance and repair (IMR), trenching, dredging and rock dumping. Scientific research vessels, luxury yachts, cruise ships, crew boats, wind turbine service vessels, icebreakers, offshore rocket launchers, mine hunters and mobile loading platforms all require DP capabilities.

Figure 21 shows the IMR vessel Seven Viking, which is equipped with a heave-compensated crane, three ROVs and a dual redundant, standalone K-Pos DP21 system. Operational tasks include installation of subsea structures, maintenance and repair of subsea control systems, repair and replacement of riser systems and flowlines, as well as ROV inspections.

Facts	1975-1980	1980-1985	1985-1990	1990-1995	1995-2000	2000-2005	2005-
Accumulated number of vessels with Kongsberg DP systems	50	173	250	312	586	1169	4030
Dominant DP manufacturer	Honeywell/GEC	GEC/Kongsberg	Kongsberg	Kongsberg	Kongsberg	Kongsberg	Kongsberg
Most popular Kongsberg DP	Single ADP501/311	Double ADP503 and ADP311	ADP701 and ADP703	ADP701	SDP21	SDP21 with K-Pos DP21 taking over	K-Pos DP21
Typical station keeping accuracy	5 meters	5 meters	5 meters	3-5 meters	3 meters	3-2 meters	2 meters
Typical DP system price, including sensors and reference systems	15 mill NOK	10 mill NOK	8 mill NOK	8 mill NOK	8 mill NOK	7 mill NOK	6 mill NOK
Most common position reference systems	Tautwire, Hydroacoustics, Microwave systems	Tautwire, Hydroacoustics, Microwave systems, Radio navigation	Tautwire, Hydroacoustics, Microwave systems, Radio navigation	GPS introduced	Laser scanners introduced	GLONASS introduced	Inertial navigation sensors introduced
Applied hardware technology	ADP50x and ADP311 with KS500 mini-computer (bitslice) and random scan monochrome display	ADP503-ADP311 with KS500 and raster scan colour display. ADP 100 with SBC1000 (Intel 80186) and SBG1000 raster scan colour display	ADP503, ADP701 and ADP703 with SBC1000	ADP70X with SBC3000	SDP with SBC 400 and Windows® operating system	SDP (Green DP) with SBC500	K-Pos DP with RCU502 and RIO400
Processor memory for DP controller	128kB	192kB	512kB	8MB	16MB	32MB	64MB
Installed weight of DP system (ex HPR)	1000kg	1000kg	400kg	400kg	350kg	350kg	320kg

Fig. 20. Various Kongsberg DP facts since the beginning in 1975. Table from (Kvaal and Østby, 2015).

Such vessels become increasingly important as surface platforms are being replaced with subsea plants for petroleum production and processing.

Fig. 21. A workshorse of the North Sea: The IMR vessel Seven Viking, which received the prestigious award Ship of the Year 2013 by the Nordic shipping magazine Skipsrevyen. Picture courtesy of Per Eide Studio.

One of the world's largest DP vessels is the Pioneering Spirit, which is a platform installation, decommissioning and pipe-lay vessel, see Figure 22. It is 382 m long and has 12 thrusters, each of 5.5 MW (total of 61 MW). The DP system is a triple redundant, integrated K-Pos DP32.

One of the world's strangest DP vessels is the HiLoad DP unit, which basically is a mobile thruster unit which can connect to and provide additional propulsion or DP capabilities for rigs and ship-shaped vessels, see Figure 22. KM developed customized functionality for its DP system.

In addition to KM, current DP companies include Rolls-Royce Marine, GE Power Conversion, Wärtsila, Marine Technologies and Navis Engineering.

Fig. 22. Left: The ocean giant Pioneering Spirit. Picture courtesy of Allseas. Right: The HiLoad "clamp-on DP" unit. Picture courtesy of Remora.

Today, GPS-based automatic positioning systems also exist for small boats, courtesy of vendors like Mercury Marine and Volvo Penta. However, these do not offer the same reliability or functionality as industrial DP systems.

Current DP-related research challenges include how to obtain safe offshore operations in Arctic regions, where the conditions are icy, cold and dark. The recently completed project "Arctic DP: Safe and green dynamic positioning operations of offshore vessels in an Arctic environment" investigated various aspects of cold-climate DP operations and published the main findings in a special edition of the MIC journal, see (Skjetne et al., 2014).

7. CONCLUSIONS

Since its inception in the US in 1961, the use of DP technology has moved from science and geology to oil and industry to military and renewables. Simply put, offshore oil & gas activities and the resulting modern Norwegian welfare state had not been possible without DP vessels. Pushed by Jens Glad Balchen and supported by Jacob Stolt-Nielsen, Kongsberg Våpenfabrikk introduced the new Albatross DP system based on Kalman filtering and modern control theory in 1977, quickly becoming the leading DP supplier in the world from 1980 onwards. Since then, DP technology has continuously improved and DP systems have become smaller, cheaper, better and more reliable. Today, thousands of vessels around the world rely on dynamic positioning functionality to do their job, where advanced cybernetic algorithms beat at the heart of this functionality. A major focus is currently on human factors and improved situational awareness in order to prevent incidents. Summing up, the DP story is a story about people, technology and dedication.

Some lessons learned:

- A good technological idea is not enough for commercial success, you also need a market in need of your idea.
- It is an advantage to have a friendly but demanding home market filled with competent customers.
- The first customer is very important.
- Sometimes it can be better to sell the skin before shooting the bear.
- …and sometimes not.
- Understanding the market is essential.
- Listen to and collaborate with your customers and give them what they want.
- Empower each employee with both responsibility and authority…also known as "The Scandinavian model".
- Establish an excellent customer support system with 24/7 availability.

Key topics which have not been presented in this paper, but can be explored in the book: Albatross Integrated Multifunction (AIM); position mooring (POSMOOR); HMI developments; rules and regulations; documentation; operator training; «The Deepwater Project»; quality assurance by FAT/CAT/HIL-testing; sales & marketing strategies and activities; ...and much, much more.

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Fig. 23. Picture taken by the first author at a sea trial in a Norwegian fjord in April 2012 onboard a multi-purpose offshore vessel with 5 thrusters (11 MW) and K-Pos DP21.