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DYNAMIC POSITIONING, ITS APPLICATION TO OFFSHORE CRAFT

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SYNOPSIS

Dynamic Positioning is largely associated with offshore oil exploration activities. This paper identifies that the practicality of dynamically positioning a floating vessel had been demonstrated in other fields and vessels before the 'Glomar Challenger', the first dynamically position ship entered service.

The requirements for dynamic positioning are examined and the elements of the system described and references provided to background papers on the subject. It is suggested that precision of position keeping under stated environmental conditions is a function of the characteristics of the power and thrust generating systems which have more influence on performance than the position reference and control systems. Offshore operations are often limited by the ability of the crew to accept ship motions and these limits may be reached before maximum permitted deviation has occurred. It is suggested that there are significant differences between the systems arrangements and machinery installations of dynamically positioned drill ships, and those vessels which may be employed in support of activities relating to the development of offshore oilfields and exploitation of other marine resources.

INTRODUCTION

At the 1970 OTC Harbonn presented a paper [1] describing the system fitted on the 'Terebel' and defined Dynamic Positioning as "essentially a method for keeping a ship or floating platform above a preselected position on the surface of the sea by the exclusive means of variations of thrusters".

Five years later Van Calcar and Morgan [2] defined it as "the process of automatically controlling the vessel's thrusters and screws to maintain the vessel at a fixed position and heading and/or at a precise speed along a selected track".

These two definitions differ in two respects, Harbonn did not consider heading or motion. Van Calcar and Morgan considered both heading and track but described essentially applications to drillships in which control of these aspects are less vital, as the vessel is stationary and may rotate about the drill string.

The 'Terebel' was a research ship and its system employed analogue computing techniques, while the other paper describes digital solutions and applications to essentially a production operation namely offshore exploration drilling. It could be said that they represent firstly development of computers to meet a particular requirement, and secondly the application of computers to an additional task within existing operations.

They both describe how control systems can be developed to take account of the forces acting on a vessel and so control propulsion or thrust generating units to maintain a pre-determined position. Even prior to 1960 vessels existed which could be operated in a dynamically positioned mode, albeit for limited periods of time, under manual control and using visual reference systems. Examples of these types of operations being double ended ferries and crane barges particularly when fitted with cycloidal propulsion units at bow and stern.

The earliest automatic dynamic positioning system designed in the U.S. was fitted in the 'Eureka' in 1961 and other systems followed including the 'Terebel' system described by Harbonn. These systems were developed largely for marine research and coring operations which demanded that the vessel be held stationary for limited periods. Thus if reasonable ship/research productivity was to be achieved mooring conventionally with anchors had to be abandoned.

In the UK during the 1960s to meet the requirements of an offshore dredging operation demanding slow transits, Planning Associates (part of Decca Survey) proposed the 'Dynafix' system. This system employed a Sea-Fis position fixing system to drive a modified autopilot controlling the Voith Schneider propellers. The Dyna-Fix system was able to provide control of heading, 'across track' error, and speed, thus when the latter was zero the vessel was in fact dynamically positioned.

Tests of this system were carried out with the survey vessel 'Ruhrort' on the Rhine in 1967 and are described in [3] and in a paper by Bech and Saunders [4]. This paper also describes the development of the dredge and its associated equipment. Although this latter system was initiated to meet a transit operations requirement, the speed of transit was so low that conventional steering and propulsion systems could not provide the necessary control.

All these systems preceded that fitted in the 'Global Challenger' and were of the analogue type. The dredge described in [4] was never constructed but the system proposed was supplied into the Alcoa Seaprobe (Fig. 1) in 1971. This system is of interest as it is probably the most comprehensive analogue system fitted to date. Details of the vessel are provided in Table 1 together with other DP vessels. The 'Alcoa Seaprobe' is also unique being built of aluminium and fitted with Voith Schneider propellers. The simple installation of the analogue equipment is illustrated in Figs. 2 and 3.

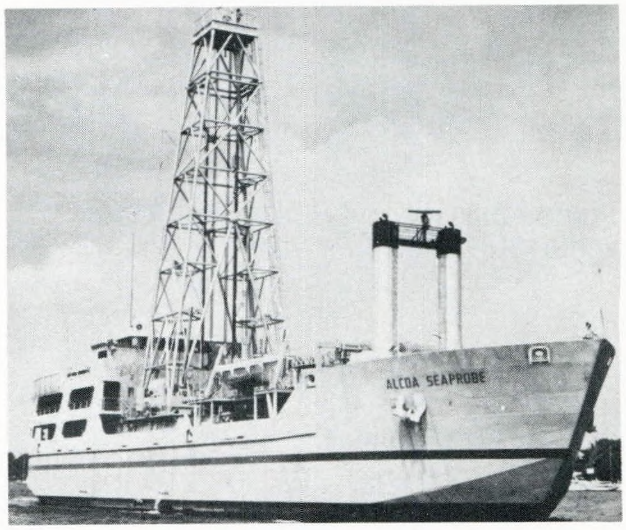

Fig. 1. 'Alcoa Seaprobe' Research and G.P. Vessel

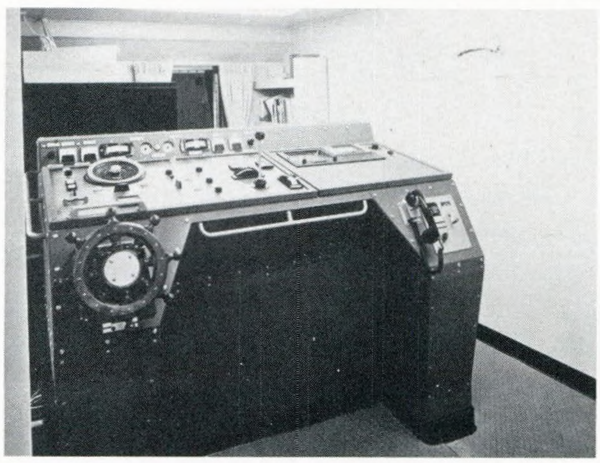

Fig. 2. 'Alcoa Seaprobe' D.P. Control Console

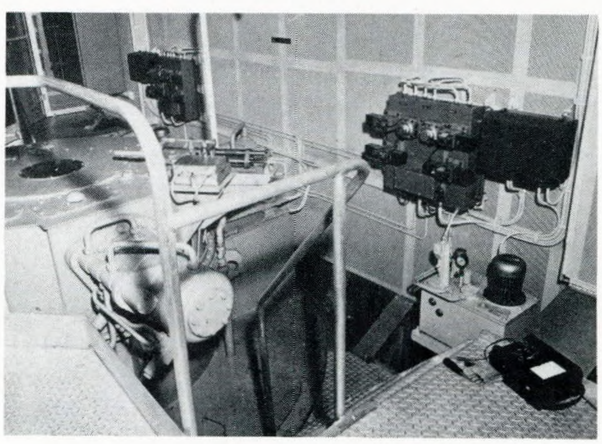

Fig. 3. 'Alcoa Seaprobe' Propeller Control Equipment

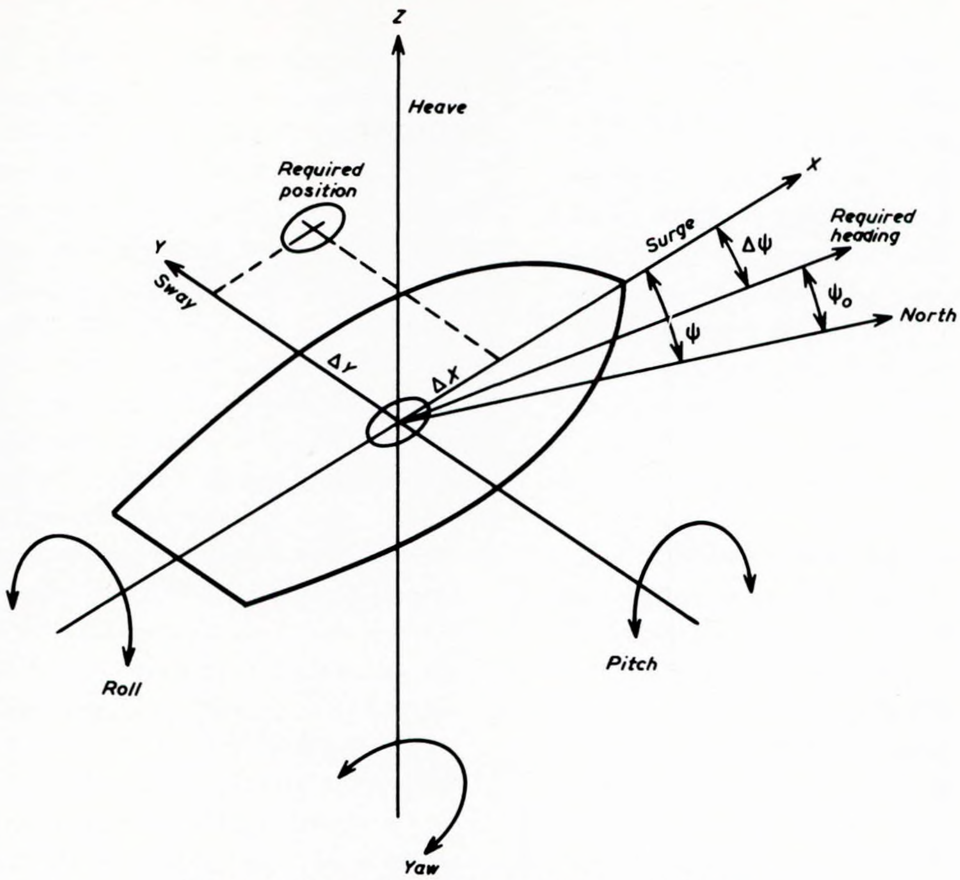

Fig. 4. Ship motions and position references

These installations proved that analogue techniques which had served the marine industry satisfactorily for many years in autopilots could be applied to the problems of position control. During the same period offshore exploration drilling rigs and drillships using conventional anchoring systems were using taut wire systems for position sensing and carried digital computers for geographical position fixing, well logging and other data processing tasks.

Once a requirement to drill beyond the 1000 foot line was identified, it became evident that drillships would require to rely upon some form of P.D. system. Since the digital processing load for this function is small and could be accommodated on the types of computers already carried aboard drillships, it was inevitable that digital techniques were employed.

Thus today there are two types of system operating analogue systems spawned essentially by mariners and marine requirements and digital systems developed by the oil industry contractors for oil exploration drilling.

It is not the purpose of this paper to distinguish between the merits or de-merits of these approaches but rather to comment upon some aspects of the problems of Dynamic Positioning identified in a number of papers by more able authors and related to service craft rather than drillships.

DYNAMIC POSITIONING - THE PROBLEM

Dynamic Positioning systems are concerned with providing thrust in appropriate quantity and direction to match the mean loads imposed on the vessel by environmental (and other) forces. The effect of environment forces upon the vessel is to induce motions in the vessel some of which cause positional errors or affect the accuracy of positional reference sensors fitted in the vessel; while the hull form and arrangements materially affect the response of the vessel to the environmental forces of wind and wave. Such forces induce the following motions in the ship, Surge, Sway or Drift, Heave, Yaw Pitch and Roll. These are illustrated in Fig. 4.

Ship Motions

Only sway and 'surge' affect position if the definition of dynamic positioning adopted by Harbonn is considered. Eda and Crane [5] show that surge has only minor effect upon the directional stability of ships. Sway (or drift) occurs because of the imbalance of wind and tidal forces acting upon the vessel and is usually associated with yaw (rotation about the vertical Z axis).

Yawing is induced by orbital motions of the water in the wave, differential static pressure on the hull because of shape (form) and the gyroscopic couple due to the imposition of rolling motion on the pitching ship.

Yaw is the most significant of the ship motions since correction requires the use of rudders (or other transverse thrust generating systems). Effective control of yaw demands prompt application of small quantities of transverse thrust since as yaw angle increases, the yaw momentum of the craft increases, so that greater vectored thrust is required to restore the ship's head.

The second definition of dynamic positioning postulates that the vessel may be moving at controlled speed upon the surface. It is useful to distinguish between course and track. Course is only concerned with direction, track is represented by a line drawn between two points on the earth's surface. At sea a vessel makes periodic changes of course to return to the required track plotted on the chart by the navigator. Autopilots control course/heading but any D.P. system has the potential of providing an auto-tracking facility when it is supplied with a series of position references along the desired track.

Environmental and Disturbing Forces

The action of wind and waves upon all surface craft creates disturbing forces which induce the motions previously described. These motions may affect the ability of the craft to maintain track or position. The major disturbing influence causing positional deviation is wind, which produces along and perpendicular to its average direction, force components of magnitude varying with the instantaneous wind speed. These components may be regarded as random variables with normal or Gaussian probability disturbances, the perpendicular component having zero mean. The frequency of these components however being generally low.

Small craft are more responsive to wind because of their low inertia and often high freeboard (the heights of deckhouse and superstructures does not reduce in proportion with the reduction in size of vessel). Wind thus has a major affect upon craft control strategy particularly in dynamic positioning and at low speeds when the rates of wind velocity to vessel speed may be high.

Wind gusts (and drift forces) have frequencies generally from 0 to 0.04 cps and those of wave induced ship motions are approximately in the range of 0.05 cps to 0.25 cps. This is covered in a joint paper [6] given at the 3rd Ship Control Systems Symposium. 'The automatic Position and Heading Control of a Drilling Vessel'. These disturbances produce an oscillatory motion and Eda and Crane [5] indicate these motions to be convergent up to wind to vessel speeds of 10:1 and divergent beyond this ratio (that is under Dynamic Positioning conditions).

The effect of various control characteristics on the dynamic performance of ships in wind is described in a comprehensive paper by Eda [7] and the use of data based on stored up drag coefficients is described in [2] which illustrates how the resulting forces and moments can be obtained when the aerodynamic characteristics of the vessel are known and when wind force and direction can be measured.

Wave forces are generally very large and readily exceed thruster capacity, indeed it is impossible to install adequate thruster power in any vessel to overcome all wave conditions. All vessels will therefore tend to oscillate with the wave motion. Wave motion does however effect the steering characteristics of ships and this is examined in a paper [5] by Eda and Crane.

Tidal changes of speed and direction are generally slow when compared with wind direction and wave forces and so current speed and direction can be considered constant over considerable periods of time.

Hydro-dynamic Aspects

A vessel held stationary at sea is subject to substantial forces and moments. These arise from the effect of currents, wave motion and wind upon the vessel. If appropriate thrust generating systems are to be fitted reasonable estimates of these forces and moments must be made. These are fully described in [8]. It is possible to use empirical data to deduce the forces and moments in the X and Y directions but since the forces and moments due to current vary according to the angle which the vessel makes to the current, the flow around a hull at an oblique angle is complex and the forces and moments can often only be estimated from extensive model tests. These values are further modified by changes in vessel dimensions and hull details such as appendages.

Wave motion creates oscillatory forces and moments corresponding to the passage of individual waves, which if regular, produce steady drift forces and moments (these vary slowly in time in an irregular wave train). When determining the sizes of the thrust generating units to be fitted it is necessary to distinguish between the steady and slowly oscillating elements.

In practice the wave train will not be regular so that it is necessary to establish an assumed wave energy spectrum related to the vessels anticipated operating conditions and to integrate the forces and moments accordingly.

In addition to these general considerations, the effect of tunnels, propellers and other items associated with the thrust generating systems must be considered. There are operational reasons which require thrusters to be fitted as deep as possible to prevent loss of power due to rolling, or creation of aeration or noise which will interfere with the operation of acoustic systems. Further the effect of current upon the operation of transverse thrust units has considerable effect upon their performance [9 and 10] and when multiple units are to be fitted their location relative to each other requires careful consideration if interaction between units are to be minimised.

In a similar manner wind forces and moments vary according to the wind direction relative to the vessel's heading, and very considerably according to the superstructure details and other items carried on deck.

The Control Problems

The controller must be designed or programmed to provide the requisite overall system performance and use the error signal to implement the desired control strategy. These signals must be combined and computed with ship parameters to the hull arrangements and other hydro-dynamic particulars to match the outputs of the thrust generating units to the disturbing forces.

As it is impracticable to counter the cyclical motion of the waves, the system must include filters to reduce wave induced noise. It is desirable for accurate positioning to have a system with high gain, but this will be more sensitive to noise and to the cyclical wave motions. A system with high gain will increase the amount of thruster modulation causing increased wear on these units and wasting fuel. If the band width of such a system is reduced its transient response and stability will deteriorate.

Although the system must ignore the cyclical forces of the waves it must discriminate and respond to all other ship responses. This objective is achieved by employing suitable filtering techniques and comparing the filtered output with the selected 'set point' to provide the error signal for processing into force commands.

Wind is the predominant disturbing force and the control system should provide active compensation by continuously monitoring direction and velocity and combining these with stored drag coefficients to compute estimates of wind forces and moments.

This output when suitably filtered can be combined with the basic outputs to provide compensatory thruster commands for wind gusts to be introduced before any significant positional duration has developed.

Finally the control system must distribute the thrust commands to each thruster or propeller in accord with the computed requirement at each instant in time. This section of the system must take account of the location, characteristics of and interaction between the various thrust generating units, and possibly the allocation of the total power available for positioning when this is restricted for operational or other considerations.

PRACTICAL D.P. SYSTEMS

The previous section outlined the problem, but in practice decisions relating to the type of vessel, thruster systems and control philosophy should vary according to the intended operational tasks. This section of the paper considers the elements of all dynamic systems and suggests that the full impact of operational requirements upon systems selection has not yet been realised.

The essentials of any Dynamic Positioning system are that it consists of:

- A position and heading reference system to provide errors in the alongship (X) direction, the athwartship (Y) direction, and heading (Ψ);
- A propulsion and thrust generating system to control surge, sway and yaw;
- An integrated control system for processing the positional errors into meaningful commands for control of the thrust generators.

These are illustrated in Figure 5.

POSITION REFERENCE SYSTEMS

For dynamic positioning purposes only those systems providing reasonable accuracy need be considered, although navigation systems such as Decca Navigator and Loran can provide satisfactory input when a large envelope of position can be tolerated. Systems may be configured in two ways. Those employing a short base line or direct measurement and those using long base lines and indirect measurement. Generally the former are vessel deployed and the latter usually dependent upon fixed stations remote from the operating areas.

Accuracy is dependent upon system resolution which is a function of wavelength. The accuracy of systems employing base stations varies according to:

- The wavelength of the system;
- The baseline length;
- The angle of cut, i.e. the position in the area covered by the system.

A longer baseline improving the angle of cut and in hyberbolic systems giving smaller lane expansions over a larger area. The offshore fix is inherently less accurate than a position fixed ashore, and the normal motions of the vessel do not assist the position fixing operation. The "absolute" accuracy of any system is concerned with the ability to relate a position reference to geographic or grid co-ordinates. In any offshore operation this may not be significant, since what is required is the relative accuracy (i.e. related to the base stations) and repeatability (the ability to return to the same spot within the "field or net" and to record similar position references). Offshore exploration drilling provides illustrations of these differences. The "set point" may be at fixed geographic co-ordinates on the earth's surface, e.g. when a drillship must return to a location of previous operations, or it may be a "relative position" when the actual geographic co-ordinates are not significant e.g. once a drill ship has moved to location it will locate the seabed well head by sonar or other means and then deploy a beacon from which it will hold station.

Position reference systems must therefore be able to determine the deviations from "set point" in respect of fixed co-ordinates and measure them to a specific accuracy. An ideal system would provide continuous precise information of the vessels position relative to "set point" of all ranges for 24 hours of every day in all weathers. No single system can meet all these requirements.

Short Base Line Systems

Taut Wire systems consist of stretching a wire under known tension between the vessel and the sea bed or other anchor point. Inclinometers attached to this wire can discriminate the angle made by the wire to the vertical in the X and Y planes. When the physical characteristics of the wire are known, the catenary may be deduced and the positional offset calculated.

Single Beacon Acoustic Systems employ a single beacon on the sea bed and an array of hydrophones in the vessel's hull. The accuracy of both these types of system is depth dependent and is about one per cent of water depth up to 300 metres. They have been used extensively in offshore ing activities and so the indicated accuracy enables a criteria to be established for other systems. This criteria is considered to be that position must be indicated to within 3 metres, and this enables other types of reference system to be identified.

Short Base Line - Active Ranging Systems

These range and bearing systems operate at radar frequencies and employ a scanner on the vessel and a single transponder fitted at a known

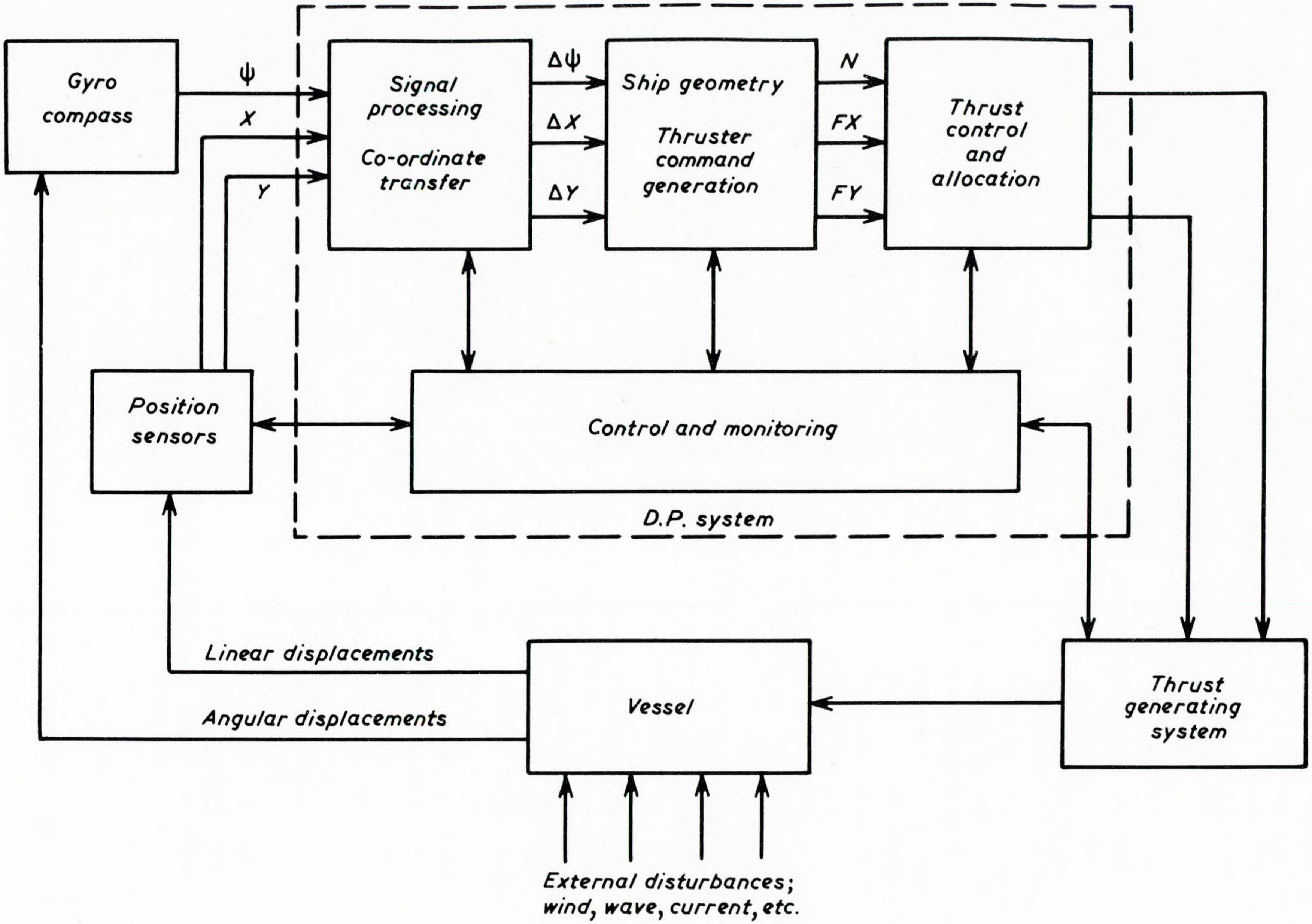

Fig. 5. Block diagram of D.P. system

fixed point to enable range and bearing to be determined and the vessels position to be deduced. Accuracies of about 1 metre are quoted but like single acoustic systems this is range dependent, the error being related to width of beam and can be stated as 1:10,000 i.e. 1 metre at 10 kilometres.

Long Base Line - Medium Range Radio Systems

These systems may operate at frequencies in the radio, radar and acoustic bands, and consist of receiving signals from transmitters at known positions transmitting in sequence. All these systems measure the time difference either, directly of the short pulses transmitted (Loran), or by comparison of the continuous wave signals (Decca). If acceptable levels of accuracy are to be obtained higher frequencies must be used such as Decca Hi-Fix (1-6 to 3 MHz) or systems based on pulsed transmissions Loran C or Pulse/8 (100 kHz). The latter systems have similar accuracy but are not affected by sky wave effects and so provide reliable coverage over the full 24 hours at ranges of over 100 miles.

Short Range Systems - X band and Acoustic

When opportunity exists for setting up stations within sight of the operating area it is practicable to use Mini Ranger or Trisponder type systems, which consist of three transmitter/receivers radiating low power X band microwave signals. The vessel carries the master unit which is fitted with a distance measuring unit. Such systems can provide position fixing to about 2 metres, but are restricted to "line of sight" operation and signals may be interfered with by moving items of equipment or ships structure. A useful review of radio positioning systems is given in a paper by C. Powell [11] and in [12]. Long base line acoustic systems employing a number of transponders are now being introduced and can operate over limited ranges (about 4/5 km) and provide similar accuracies to the X band radar transmissions. All acoustic systems are however subject to interruption by noise, air bubbles, variations in density or temperature layer effects in the water.

It is only in recent years that consideration has been given to the use of long base line systems for D.P. purposes. Although some of the radio systems have been employed for close control of vessels carrying out offshore survey and other tasks for over twenty years. The experience gained from such activities and practical tests and the use of auto-track-keeping equipment confirms that satisfactory performance for dynamic positioning control can be provided. It perhaps should be stated that the majority of such experience is out-with the oil industry.

THRUST GENERATING SYSTEMS

When a vessel is to operate in a dynamically positioned mode the vessel must be provided with a system to produce thrust not only in a longitudinal direction but also transversely at each end. The units at bow and stern being capable of working not only in unison to provide pure transverse motion (to oppose sway or drift) but also in opposition to give pure torque to combat the yaw motion of the vessel. The function of the control system being to combine the thrust produced in such a manner to counteract the external disturbing forces.

The oscillatory component of wave motion is very large and cannot be resisted by the dynamic positioning system. Thus as response to thruster commands is several times longer than the wave period, the vessel oscillates about a mean point varying with the frequency of the wave oscillation. Any attempt to counter this motion would merely cause unnecessary use of fuel and additional wear upon the thrust units.

The principal types of thrust producing units are:

(1) Screw propellers of thrusters;
(2) Cycloidal propellers (Voith Schneider Units);
(3) Pumps

Screw Propellers

These propellers may be uni-directional or reversible with fixed or controllable pitch blades and designed to run at constant or variable speed. They may be fitted on a fixed axis, that is as main screws and as thrusters arranged in a transverse direction, or be capable of being rotated about a vertical axis to provide thrust in any direction. The latter are generally termed 'Azimuth' type (Schottel) units.

Azimuth type units may be arranged to operate clear of the vessel's hull being usually fitted with a nozzle or shroud. They have been frequently used in conversions and may be arranged to retract into wells in the ships hull for making passage. They present particular control problems and as size increases the speed of azimuthing is reduced so that commanded changes of direction of thrust take longer to achieve. Solutions to the problem of azimuth units have been sought. In one early installation fitted with four rotatable units, the operating philosophy adopted required the thrust from all units to be directed towards the centre of the vessel to achieve equilibrium and only a single unit rotated to correct any positional displacement. It is perhaps significant that this arrangement was not proposed for a subsequent vessel for the same project.

The most common arrangement is to employ screw thrusters operating in tunnels at each end of the vessel. The following points must be considered if screw type units are to be employed.

1) The draft of the vessel determines the diameter of thruster which can be installed if the tunnels are to remain submerged in all operating sea states. Units fitted aft may present structural problems.
2) Multiple tunnels may have to be used to provide adequate thrust. Such arrangement requires careful design because of hull forms which can cause interaction between adjacent units and complicates the control logic.
3) Earlier installations presented problems of reliability and maintenance because they had been developed from bow thrusters which were essentially manoeuvring devices not intended to run continuously or to be subject to rapid cycling of thrust direction.
4) When rapid electric drive is employed the motor pod increases the propeller hub diameter and reduces the volume of thrust which can be produced for any given diameter.
5) When the blades are fixed the rev/min must be varied. This creates control problems and unless a "balanced" arrangement is employed the units must be capable of being reversed. These arrangements do not provide a very effective system because of the relatively long delay before full thrust is developed or direction reversed.
6) Geared "Z" drives and vertical electric motors have been employed which offer somewhat better propeller performance but are mechanically more complex.
7) The response of the screw to changes in commanded thrust is dependent upon the design of the unit; fixed pitch units being slower than controllable pitch propellers, but there is nevertheless a limit to the rate at which pitch may be changed and because any propeller must accelerate a considerable able mass of water to build up thrust. The representative response time for various types of propeller is indicated in Table III.

For dynamic positioning still water criteria used to specify bow thrust units must be ignored and very much higher powered units installed. Table IV taken from [10] indicates the attenuation of transverse thrust for a range of vessels.

Cycloidal Propellers

Voith Schneider units dominate this field and are unique in that they rotate on a vertical axis undirectionally at constant speed. Vertical blades of aerofoil section are fitted around the periphery of a rotor and these blades are oscillated about their own axis by linkages radiating from the pitch or "steering" centre. Thrust is therefore produced in any required direction by moving the 'pitch or steering' centre. When it coincides with the propeller axis zero thrust is produced, and only frictional power is absorbed. As the 'steering' centre is moved the direction of this movement and the quantity of thrust is proportional to its eccentricity. Control of the thrust is in accordance with Cartesian co-ordinates one alongships and the other athwartships. Their prime disadvantages being their relatively high cost, since they are complex mechanical assemblies, and their requirement for special hull forms to accommodate them. They have however operated at sea since 1931 and do possess unique advantages for dynamic positioning applications which include:

i) They can provide propulsion and positioning thrusts. Full power is available in any direction;
ii) They are not affected by currents;
iii) The transverse thrust is fully effective for steering at both zero and low speeds;
iv) The thrust diagram is virtually a circle

(there is no preferential direction of thrust);

v) Drive arrangements are simple and thrust response swift to commands as no mass water or machinery has to be accelerated;

vi) Fuel consumption is reduced when operating in a D.P. mode relative to other systems because little power is absorbed when 'idling' and the fast response reduces the total power required to restore equilibrium.

Pump Systems

Pump systems have been proposed and investigated for a number of applications but no actual installation Has been identified. In their paper [9] Chislett and Bjorheden concluded that if there were no factors limiting tunnel and jet diameter a small diameter high velocity "hard" jet would be best suited to low speed operation.

Pump systems would appear to offer little advantage over well designed screw systems for general commercial use. However there may be applications when hull form, noise, aeration and other considerations may make the use of pump systems attractive.

PRESENT DEVELOPMENT

Since the early 1960s nearly fifty vessels have been fitted with dynamic positioning systems. Most of these vessels have been drill ships or semi-submersible drilling rigs. A considerable number of papers have discussed drill ships and their systems but it is interesting to consider some of the other installations. Table I indicates a number of these units as well as a selected number of drill ships to show that a wide variety of ship types and sizes, machinery installations and control systems have been employed.

The vessels in Table I have been grouped as:

1) Vessel in service prior to the 'Glomar Challenger'
2) Drill ships
3) Modern utility vessels (displacement type)
4) A semi submersible support ship

This grouping is not as artificial as it may appear, since some of these vessels were examined by Sargent and Cowgill [14] in a paper on control system design for utility vessels. In this paper it is noted that the earlier vessels had considerably higher sway thrust/mass characteristics to those of later utility vessels, which were more related to the drill ships (about 0.3 metres/sec). This paper also concluded that if a vessel is to station in close proximity to fixed or floating platforms the ratio of sway thrust/mass should be about 0.6 metres/sec. and that larger propulsion capabilities will be required particularly when floating structures are to be serviced. It is significant that the earliest vessels employed relatively higher powered thrust systems than these currently being used in support vessels and the operational requirements of these vessels are considered in the following paragraphs.

Operational Considerations

The application of dynamic positioning to offshore drilling represents a very basic system in that:

i) Operations are carried out in deep open water
ii) The vessel may swing to meet wind and wave
iii) The positioning power usually represents only about 40 per cent of the total power available.
iv) Under worsening weather conditions, when drilling ceases additional power is available for positioning.
v) Break away is unlikely to hazard the ship or to damage other installations.
vi) The sensor systems are simple and are not subject to interference from other operations.
vii) The acoustic systems are operating in almost ideal depth 400-1000 ft (122 - 305m)
viii) Drilling is a "productive" operation each well occupying considerable periods of time (80-120 days).

The limiting factor in any dynamic positioning application will always be the capability of the thrust generating systems and their prime movers. There are however limits to the size of thrusters and power limits which can be fitted into any vessel.

The precision with which any vessel will maintain station under given environmental conditions is a function of the power of the thrust generating system and the time of response, assuming that the system is provided with adequate position reference signals. No system will perform satisfactorily if it does not receive continuously updated reference position references.

It can be broadly stated that when the operations to be carried out by a D.P. vessel permit the vessel's head to swing to meet the environmental forces considerably lower powered thrust units may be installed. If the operations demand that heading is constrained the power requirement may be doubled. Some operations impose additional drag upon the vessel and these forces would also require consideration in any design.

It is considered that, apart from size of unit, power requirements are depended upon whether heading is fixed or constrained and any additionally induced drag. Performance is also likely to be affected by the reliability of sensor systems and factors interfering with their satisfactory performance. An attempt is made in Table V to indicate these factors relating to certain operations.

GENERAL PURPOSE VESSELS

The authors of [14] noted the discrepancy in sway thrust/mass ratio, and concluded that a short base line system could be used for station keeping and that vessels with low wind drag and high mass (i.e. semi-submersibles) could meet this requirement, while displacement type vessels would be more suitable if the structure was floating.

It may be concluded that current utility vessels have developed from "drill ship" philosophy of control and powering, and to fulfil, if Table V is considered, the diving support role. The most onerous application is clearly when the vessel is to operate in close support of platforms. The requirement for such vessels are, considered to be:

1) The vessel must be of suitable hydrodynamic form with low wind drag characteristics;
2) Should have adequate thrust power delivered by duplicated thrust generating systems at bow and stern;
3) The control system must be provided with adequate redundancy to provide availability in excess of 95 per cent;
4) The system must be designed to degrade gracefully from fully automatic to manual modes without hazarding the vessel during this period;
5) The power generation systems or prime movers must be capable of coping reliably with widely varying demands for power under all circumstances;
6) Adequate sensor systems must be employed to provide continuous and accurate position references under all operating and emergency conditions;
7) All elements of the system must be provided with protection from any transient malfunction of any subsystem or other equipment.

The implication of these requirements are considerable and include:

Main Machinery Installations

The main machinery must cope with all normal ship operational services and with thruster loads which may vary from lying with thruster units idling at low pitch values, to conditions when all disturbing forces are abeam and full pitch is commanded on all thrusters.

Further the machinery must run continuously and reliably under the whole range of conditions indicated. Consideration at the design stage will require to include the total number of power units, their size and type.

It is also evident that the wide fluctuation in power demand will favour diesel electric installations and require examination of the benefits of various line voltage, power distribution and motor control systems.

The methods of control of start up and shut down of units must be examined since large power modulation may be required at short notice (less than 1 minute) as well as the relationship of non-positioning but essential services to thruster and other less essential demands for power.

Thruster Installation

Security of operation is paramount so it is necessary that the thruster system is duplicated at bow and stern. Failure of a single unit will only degrade the D.P. potential if two units are fitted.

When controllable pitch propellers are used these must be designed to accept frequent changes in commanded pitch both of quantity and direction over long periods of service. Normally C.P. propellers bow thrusters do not have to meet such demands, being designed primparily as manoeuvring devices, but if used without modification for D.P., installations high wear rates of mechanical parts and seals must be expected.

The Control System

Under the operational conditions envisaged the control system must be arranged to accept, in addition to positional error data, information relating to the failure of thrusters and, or lack of power due to breakdown or malfunction of main machinery units. The control system will require to be duplicated with adequate monitoring systems to detect and signal any malfunction. Both systems must be provided with guaranteed and protected power supplies in the event of ships mains failure. The equipment must be designed and protected against mechanical, vibratory, heat and electrical damage due to external influences or malfunctions.

More important although complex the systems operation must be intelligible to the operator so that he is fully aware of the logic and how it is arranged to degrade in emergency so that he may, when necessary, take any appropriate action.

Position Sensor Systems

When operating in support of a platform these systems will be subject to noise and interference. Thus single path transmissions from short base line systems cannot be relied upon at all time. It will be necessary therefore to provide duplicated primary sensors, and also duplicated back-up secondary systems. The benefits of employing an array of acoustic transponders or Trisponder type units are that groups of stations provide a multiplicity of paths, enabling the best possible fix to be maintained at all times despite changing patterns of interference. Complex signal processing and comparison procedures can provide reliable signals up-dated at a faster rate than the changes in thrust can be commanded.

Systems Engineering

The whole system must be reliably systems engineered not solely to provide reliable station keeping off the platform, but to display information relating to the current status of any sub- section to the particular tasks being undertaken. The peripheral equipment will therefore be considerable if adequate protection is to be provided to all sections by the integration of reliable alarms, protection systems, displays and recording equipment.

ECONOMIC CONSIDERATIONS

This brief examination indicates some of the factors involved in tackling the most onerous application. Although many papers have been presented on Dynamic Positioning, little reference is made in any of them to the "forgotten motion" of the ship - "heave".

Yet it is heave which usually causes operations to cease. In a paper on "Drillship Design" W.H. Jolles [15] indicates that drilling ceased when heave reached 7.5 ft (2.2m) and if B.O.P. stacks were being handled at 3.5 ft (1.09m) ! An acceptable level of 30 per cent sea sickness occurs when accelerations of 1.5 m/sec are reached.

Clearly if accelerations are to be reduced as sea state increase the size of vessel must be increased. Any increase in vessel size increases vessel costs, thus if high availability is demanded vessels must be larger and possibly of semi-submersible type.

When operating in a D.P. mode, machinery must run continuously so that fuel consumption is considerable. A drill ship may consume up to 15/20 tonnes of fuel per day when operating in a D.P. mode, but only 2 to 3 tonnes/day if dynamically moored, the cost savings under these conditions are considerable (over 4000 tonnes per annum).

The D.P. vessel is therefore expensive in first cost because of its special machinery arrangements, its size and the additional equipment which must be fitted. It will also be expensive to run. The effect of these costs must be that, Dynamic Positioning can only be justified if a high proportion of the vessels operating time demands D.P. position. (Drillships may operate 85 - 93 per cent of total time in the D.P. mode) or if the activities undertaken do not permit anchoring or demand D.P. operation for reasons of risk and only when these are sufficiently high. However Table V indicates that there are still considerable areas of maritime operation in which D.P. control can find application when economic criteria can be satisfied.

CONCLUSIONS

It is concluded that the type of system indicated above will be the exception rather than the rule, but as offshore installations will continue to increase so will demand for such units. Applications into drill ships will continue, but technological development of mooring wires, anchor systems and capstan winches with good dynamic characteristics may permit mooring in deeper water than presently possible.

It is difficult to envisage any D.P. vessel being built as a "ship of opportunity". When not operating in a D.P. mode such a vessel is carrying the premium cost of its thrust generating system and its associated power plant, and as Table I indicates even for the operations with 'free heading" this power may be equal to, if not exceed, that of conventional propulsion. It is perhaps unfortunate that few vessels other than ferries have been fitted with Voith Schneider units at bow and stern. Only these units are able to offer D.P. and conventional operation without penalty.

The challenge to the marine engineer lies in the design of reliable and flexible power generation, probably of diesel electric type, capable of accepting wide variations in demand over long periods of service. Improvement in the mechanical design of thruster units to provide improved availability, better thrust and improved noise characteristics would be beneficial, and might encourage ship control engineers to develop improved manoeuvring control systems for conventionally fitted vessels.

The naval architect must face the problems that working craft require different treatment to conventional cargo vessels and more attention must be paid to motion characteristics, better forms to reduce drag and cleaner design of upper works to reduce windage. Ultimately it is the "man on deck" who calls halt to operations, a situation only faced by those shipowners operating fishing and service craft.

Operators must face the problem that what is required is total system design and not designs of D.P. systems. Consideration of such minor factors as the location of cranes relative to the orientation of the platform and prevailing environmental conditions could materially alleviate the demands on the support craft and improve their utilization. Improved detail design arrangements of structures could considerably reduce the requirement for close support diving from D.P. vessels. Modification to equipment will often improve vessel utilization and it is significant that diving systems are being introduced with full heave compensation.

Regretably it appears that few oil companies, ship owners and constructors have organisational arrangement to exploit a fully effective systems engineering approach, consequently present tonnage and many future units may be less economic than they might have been.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Harbonn 1971 "The Terebel Dynamic Positioning System" OTC 1499.

(2) Van Calcar, H. and Morgan, M.J., 1975 "Dynamic Positioning Today" Oceanology International.

(3) "Dynamic Positioning of Offshore Mining Equipment" 1967 Mining Magazine Vol. 117 No. 4.

(4) Saunders, D.W. and Bech, M. 1969 "Automation in Offshore Prospecting and Mining" Oceanology International.

(5) Eda, H. and Crane, C.L. 1965 "Steering Characteristics of Ships in Calm Water and Waves" Trans. SNAME.

(6) Brink, A.W. Van de Brug, J.B. Ton, C. Wahab, R. Van Wijk, W.R. The Automatic Position and Heading Control of a Drilling Vessel 3rd Ship Control Symposium Paper IV 32.

(7) Eda, H. 1968 Low Speed Controllability of Ships in Wind. Trans. SNAME.

(8) English, J.W. and Wise, D.A. 1975 "Hydrodynamic Aspects of Dynamic Positioning". Trans. NEVIES, December.

(9) Chislett, M.S. and Bjorheden, O. 1966 Influence of Ship Speed on the Effectiveness of Lateral Thrust Units 11th International towing tank Conference

(10) Ridley, D.E. 1971 "Observations on the Effect of Vessel Speed on Bow Thruster Performance" - Marine Technology January.

(11) Powell, C. 1973 An Informal Review of Shore Based Radio Position Fixing Systems - Hydrographic Society and SUT Sept.

(12) "Sea Surveying" Edited by A.E. Ingham.

(13) McClure, A.C. and Schneider, W.P. 1977 "Planning for Dynamic Positioning" Petroleum Engineer May.

(14) Sargent, J.S. and Cowgill, P.N. 1976 "Design Considerations for Dynamically Positioned Utility Vessels" OTC 2633.

(15) Joller, W.H. 1976 "Design Criteria for Drill Ships" 2nd International Offshore Craft Conference.

TABLE I

GROUP	VESSEL	YEAR	DIMENSIONS			DISP	THRUSTER SYSTEM					CONTROL SYSTEM	OPERATION
			LBP(M)	B(M)	D(M)	(TONS)	X(HP)	Y(HP)	DRIVE	TYPE	PITCH		
1	EUREKA	1961	41.5	11.0	2.0	410	800	800	A/C	AZIM	FIXED	ANAL	RESEARCH
	TEREBEL	1964	52.1	13.6	2.1	1030	1200	1200	DIESEL	AZIM	FIXED	ANAL	RESEARCH
	NAUBUC	1968	45.7	10.4	3.1	850	4800	4800	DIESEL	AZIM	FIXED	DIGIT	CABLE LAYING
	ALCOA SEAPROBE	1970	74.0	15.2	2.4	1700	2120	2120	A/C	V.S.	VAR.	ANAL	RESEARCH
2	GLOMAR CHALLENGER	1970	121.5	19.75	8.35	10,500	4500	3200	AC	X-Y	FIXED	DIGIT	DRILLSHIP
	SAIPEM DUE	1973	122.5	21.34	6.36	13,000	7000	7000	AC	V.S.	VAR.	DIGIT	DRILLSHIP
	WIMPEY SEALAB	1974	99.1	15.2	5.5	5674	2700	4000	AC	AZIM	VAR.	DIGIT	DRILLSHIP
	DISCOVERER SEVEN SEAS	1976	162.8	24.4	7.3	20,560	8000	15000	AC	X-Y	FIXED	DIGIT	DRILLSHIP
3	ARCTIC SURVEYOR	1974	79.0	12.0	3.7	2274	2000	1200	DIES/AC	X-Y	VAR.	DIGIT	DIVING SUPPORT
	SEAWAY FALCON	1975	80.0	16.0	4.3	3650	2000	1950	DIES/AC	X-Y	VAR.	DIGIT	UTILITY
	KATTENTURM	1976	52.7	11.0	3.9	1569	1930	1026	DIESEL	AZIM	VAR.	DIGIT	DIVING SUPPORT
4	UNCLE JOHN	1977	77.0	52.5	15.5	9000	6000	6000	AC	X-Y	VAR.	DIGIT	UTILITY

TABLE II

RADIO POSITION REFERENCE SYSTEMS

SYSTEM LONG/MED.RANGE	FREQUENCY kHz	WAVE LENGTH M	LANE WIDTH M	RESOL^n M	NOM RANGE km
Hi-Fix Sea-Fix	1600-3000	150	75	0.75	40-360
Raydist	1600-4000	75-180	37-90	0.4-0.9	120-400
Toran	1600-3800	80-180	40-90	0.4-0.9	50-750
Lambda	100-200	560-840	280 & 420	2.8/4.2	400-800
Loran C	100	3000	1500	30	2000
Omega	10-14	30,000	15,000	150	8000
Short Range	MHz	WAVE LENGTH M	NOM ACCUR^V M	RESOL^n M	NOM RANGE km
Hydrodist	2800-3200	0.1	$\pm$ 1.5	1.0	40
Tellurometer	2800-3200	0.1	$\pm$ 1.0	0.1	50
Autotape/DM40	2900-3100	0.1	0.5	0.1	100
Trisponder	9200-9500	0.03	$\pm$ 3	10 or 1	75
Ralog 10	34.3 and 68.6	4.5	1:1000	0.1	5

TABLE III

THRUST GENERATING UNITS – RESPONSE TIMES.

1 TYPE	2 RANGE (h.p.)	3 RESPONSE TIME (SEC)
C.P. SCREWS	up to 1000 1000 to 3000	3 to 5 5 to 7
AZIMUTHING UNITS	up to 1000 1000 to 2500	7 to 10 10 to 13
VOITH SCHNEIDER UNITS	700 to 3000	1 to 3
PUMP SYSTEMS	500 to 1200	5 to 7

Col 3 – indicates approximate time required to generate commanded thrust.

TABLE IV % EFFECTIVENESS OF BOW THRUSTER WITH AHEAD SPEED

SHIP TYPE	BUOY TENDER	PERRY	TANKER	BULK CARRIER	TANKER	TANKER	TANKER
LBP (FT)	170	420	510	586	600	600	800
SPEED (K)							
O	100	100	100	100	100	100	100
1.2					92		
1.6						79	
1.75	46						
2.0			66				
2.4					618.60		
2.5							73
3.0		60					
3.5			49				
3.6					52		
4.8					58		

FROM 'OBSERVATIONS ON EFFECT OF VESSEL SPEED ON BOW THRUSTER PERFORMANCE'
D.E. RIDLEY MARINE TECHNOLOGY, JAN. '71

TABLE V
OFFSHORE OPERATIONS – DRAG AND INTERFERENCE

OPERATION	SHIP'S HEAD CONDITION	ADDITIONAL DRAG	POSSIBLE INTERFERENCE
DRILLING	FREE	DRILL STRING	NOISE* MUD LEAKS
CORING	FREE	DRILL STRING	NOISE
SURVEYING	FREE/CONS-TRAINED	–	–
CABLE LAYING	CONSTRAINED	CABLE DRAG	NOISE*
DREDGING	FREE/CONS-TRAINED	DREDGE HEAD DRAG LADDER/ PIPE ETC	NOISE*
DIVING (GENERAL)	FREE	–	AERATION
DIVING (EMERGENCY)	FREE	–	AERATION, MUD/GAS LEAKS, NOISE
PLATFORM SUPPORT	CONSTRAINED	–	AERATION, MUD/GAS LEAKS, NOISE, ACOUSTIC REFLECTIONS, CRANE MOVEMENTS, HELICOPTER MOVEMENTS

* SELF GENERATED BY OPERATIONS

DISCUSSION

MR D J GIBBONS FIMarE expressed his appreciation to Mr Mearns for his excellent paper on Dynamic Positioning, saying that he was sure that this paper would form an excellent basis for technical appreciation and discussion, and summarised without elaborate control theory many of the factors that must be taken into account by owners and shipyards in specifying and selecting a dynamic positioning system.

There was no doubt that the range of ship applications for dynamic positioning was increasing, and that advances in ship specialization and system design would encourage the process. In his paper Mr Mearns had described the historical origins up to the present time and referred to the selection of vessel, thruster system and control philosophy as being dependent upon the intended operational task. Mr Gibbons fully agreed and thought that this was perhaps more relevant to a new construction vessel than a conversion, where some parameters would have already been given.

The author had stated in his paper that the control systems would require to be duplicated, together with duplication in sensor systems and partial redundancy in thruster systems; all this to achieve an availability of 95%. Mr Gibbons would suggest that with such a system an availability greater than 99% should be achieved, and it might well be that for a 95% availability, which would be suitable for some applications, a much simpler and less costly system would suffice. Was the author able to advise the reliability data which might be considered for all the elements in the D-P system so that an appropriate overall system might be specified for the intended duty and availability.

Another area of concern was the sensor systems upon which all control depended. There were the separate problems of accuracy and repeatability. Would Mr Mearns amplify his comments in this area with respect to the various systems described, and also indicate the variations in positional reference which could be expected with deviation for the nominal reference position. Recommendations were made for duplication in both primary and secondary reference systems. Was this philosophy warranted on economic grounds, or were there advantages to be gained by single secondary and tertiary systems.

MR G HESLAM's comments referred not to the components on the electric side of the Dynamic Positioning System but to the propulsion units necessary to obtain this positioning.

In the paper the author had referred to "reduced volume of thrust" in some tunnel thrusters because of the large pod. Later on he had referred to cycloidal units as being able to offer "D.P. and conventional operation" without penalty, i.e. main propulsion. He had also mentioned "low power requirements of cycloidal propellers at zero thrust, hence low fuel consumption overall". It was common knowledge that all controllable pitch propellers, whether thrusters or conventional, had a low power requirement at zero thrust.

In view of the foregoing three points, which all concerned the question of efficiency, could the author comment on the relative efficiencies of the units mentioned by quoting typical thrust per 100 hp for tunnel thrusters, Azimuth C P Propellers in nozzles, and cycloidal units, together with comparable free-going efficiencies for the two latter systems.

In this respect, could the author expand on his statement "no mass water ... has to be accelerated". Mr Heslam did not see how a cycloidal propeller differed from conventional propellers in this respect as no movement was possible without moving water.

In the author's reference to conventional thrusters in tunnels, referring to a slide of this type of unit, Mr Mearns created the impression that such a unit must at least be duplicated in case of breakdown, which might lead the uninitiated to assume that with a cycloidal type this was not necessary.

He agreed with the author's comments regarding the importance of improved noise characteristics in thruster and in this connection would draw his attention to the skewed-blade designs carried out and available for this very purpose.

MR PAUL A BRUNSELL thanked Mr Mearns for his interesting paper saying that as someone not well-versed in the control side of D P systems he had found the description of the overall problem and the discussion of various reference systems, thrust systems and control systems to be very informative.

His firm had been directly involved with the White Gill Bow Thruster manufactured by Elliott Turbomachinery Ltd of Cowes and had recently commissioned a diving support vessel, the "OIL ENDEAVOUR", with two White Gill Thrusters and a D P system supplied by GEC. Mr Mearns had noted that there were no actual installations of pump systems in dynamically positioned vessels but, as the White Gill was basically a pump system this was no longer the case. In fact, shortly, the "STAR CANOPUS" would also come into service with a D P system using White Gill Thrusters.

Most people were familiar with the standard White Gill Thruster units but it was of interest to describe the new T-3 concept since it was introduced in the Spring of 1977 and the "OIL ENDEAVOUR" utilized two T-3 units, one forward and one aft.

The T-3 differed from earlier designs by being arranged on a single vertical axis and by drawing-in water low down from the sides giving appreciable savings in hull space and in unit cost (see Figure 6). All the operational advantages of the original White Gill thruster were retained, the rotatable discharge in the ship's bottom providing thrust at any desired angle through 360 degrees. It could be used as an emergency propulsion unit in the event of main engine failure.

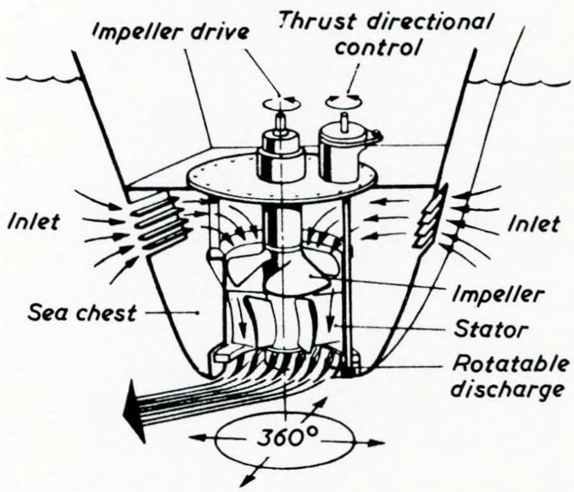

Figure 6

The two side inlets, mounted directly in the ship's plating, supplied a plenum chamber or sea chest, in which the steel impeller was mounted in top and bottom taper-roller bearings. A cast steel stator assembly was immediately below the impeller, and the deflector or discharge nozzle was flush-mounted in the ship's bottom skin.

As Mr Mearns and several of the discussers had pointed out, there were a number of advantages and disadvantages associated with each type of thruster system and, in particular, reference had been made to the requirement for simplicity, ease of maintenance, continuous thrust regardless of the effect of ship motions and the thrust effect at forward ship speed or in currents. It was felt that one of the major reasons for the wide use of White Gill units, particularly in North Sea offshore oil operations, was that the unit had favourable characteristics with regard to all of the above points.

In particular, because the unit was located in the bottom of the ship, it was not appreciably affected by pitching and/or rolling. Also, because the thrust jet was fairly high speed (20-25 kn) and emerged at an angle of about 25 degrees down from the horizontal, the thrust could be maintained at forward speed. In this regard they had done sea trials where they had used the White Gill unit to steer the vessel at speeds of 8 - 10 kn. In doing this they had locked the rudder at zero angle and manoeuvred the ship with the White Gill unit only.

With regard to maintenance and simplicity, the White Gill unit, utilizing primarily meehanite and stainless steel castings in the critical areas, was of such a rugged construction that there had been very few operational problems and a very small number of spares supplied. Since the impeller was fixed pitch and the main mechanical bearings were arranged to allow easy access, the unit had been found to be extremely simple to maintain. Of course, in a dynamic positioning application the demand in terms of operating hours on the unit would be considerably greater than past manual installations and it would be necessary to wait some time before being able to comment with certainty.

Of course, the White Gill unit had the disadvantage of providing less thrust per unit hp than, for example, a ducted propeller or tunnel type thruster. On the other hand, the company's prediction of the performance of the T-3 White Gill units on the "OIL ENDEAVOUR" was something in the order of 7 to 7.5 tons of thrust per unit at about 1000 hp and 8 to 8.5 tons of thrust per unit at 1200 hp.

Bollard pull measurements on the "OIL ENDEAVOUR", both fore and aft and athwartships, indicated approximately 8 to 8.5 tons of thrust at 1000 hp and between 10 and 11 tons of thrust at 1200 hp. They had not yet published these figures because they were still checking their calculations and also intended to check the T-3 unit presently in service on "Intersub V". Nevertheless, he mentioned the above because the measurements were made a number of times and the measuring equipment had been tested for accuracy.

Speed runs, using the units of the "OIL ENDEAVOUR" and the single T-3 unit on the "Intersub V" with thrust directed aft, resulted in speeds of between 7 - 7.5 kn with the main engines not operating. Since the unit was designed for virtually continuous operation as in a DP system, it suggested that perhaps in the future it might be possible to install Gill units as a combination main propulsion and dynamic positioning thrust system; as a main propulsion system the units would be inefficient if higher speeds were required, but if operating speeds of approximately 10 kn were acceptable this could be a possibility.

One last point: There had been mention of noise level and its effect on acoustic positioning systems. As White Gill units were used on fishing vessels using fish-finding sonar and on other types of vessel where hydrodynamic noise was a problem, the company had tried their best to investigate this point. They had discovered that the Navy had done tests on a research vessel using underwater microphones both below and to the side of the ship and were able to obtain a report which indicated noise level in "micropascals" for different frequency band widths. Having no idea what these readings meant we contacted the Institute of Oceanographic Sciences and managed to locate a theoretical chap who described the noise question in such detail that we were even more confused than when we started. At the conclusion of a long discussion we asked if in fact Gill units could be considered as "hydrodynamically quiet or noisy". The reply to this was that he was really not in a position to say! In seriousness, the company believed that the Gill unit was relatively quiet as regards hydrodynamic noise but it was certainly an area where there was not a great deal of information, and also an area where the company did not have very much expertize.

He apologised for making what appeared to be a sales pitch for White Gill Thrusters. He felt, however, that as the T-3 unit was very new and as the performance of the "OIL ENDEAVOUR" appeared to be quite good, the above would be of interest to those concerned with dynamic positioning.

MR TORE DALVAG thought that the part of this paper describing the control systems and feed back problems of dynamic positioning was well presented and gave a lot of valuable information on the subject. All he missed was some basic data concerning the acoustic positioning systems such as used frequencies and levels of tolerable background noise.

The part of the paper concerning thrust generating systems had a certain tendency towards the cycloidal propellers. He would like to correct this by the following remarks.

In the paper the author had stated that as the size of an azimuth unit (rotatable thruster) was increased, the response to commands of directions of thrust would slow down. This was mainly caused by the increase in inertia of water, and would therefore affect any type of thruster.

The complications with interaction were appearing in every installation in one way or another. The minimum interaction was normally considered to appear for a rotatable thruster installation with regard to its location beneath the hull.

Could the author expand on Table III; regarding the size of most of the numbers they indicated the time from zero thrust to maximum thrust or a 180° turn of an azimuth unit. However, if normal engines were providing the power, they would be overloaded at too rapid manoeuvres, due to the inertia of water to be accelerated making manoeuvring time from zero to full thrust around 5 sec. and upwards more realistic.

However, in normal positioning work, abrupt thrust alterations in the order of 100% were indeed not required, but rather small adjustments in the order of 10% - 20% of full thrust of a frequency of one impulse every 3rd to 4th second. With a screw propeller thruster of controllable pitch type these thrust adjustments were achieved almost instantaneously, or within times in the order of ½ to 1 second. This made the controllable pitch type of thruster superior to most other types for dynamic positioning purposes.

In the section describing the cycloidal propellers the complexity of the mechanical assembly was brought up and one must put a question mark here for the reliability of such a complex mechanical assembly.

The items i) ii) iii) and iv) under the heading Cycloidal Propellers aimed at describing the advantages of a cycloidal propeller in comparison with other types of thrusters. However, several of the statements made were far from correct and therefore misleading. Firstly, one fundamental difference between a cycloidal propeller and a screw propeller was its effectiveness. This concerned the free running propulsive efficiency as well as the bollard pull performance. Thus, for a certain power and shaft speed, a screw propeller type of thruster fitted with a nozzle would provide up to 50% more thrust than a corresponding cycloidal propeller. This must be of the utmost importance to the owner who had to pay the bill for the machinery investment and the fuel consumption.

As to the possibilities of directing the thrust, it was true that a fixed Y-thruster could generate thrust in one direction only. But, for many applications, the fixed type Y-thrusters in combination with controllable pitch type main propellers formed an adequate solution to the positioning problem. With a rotatable type of screw propeller thruster, the thrust was available in any direction.

As to the influence from the current, little had been published in terms of test results for cycloidal propellers. For the built in type of tunnel thrusters it was known that a certain reduction in the effectiveness might occur in a head current due to unfavourable interaction between the propeller jet and the hull. In certain cases, however, this interaction might be beneficial and might even bring about increased yawing moments due to a certain behaviour (deflection) of the jet. In short, no general rule was applicable but each case had to be studied individually in order to get detailed knowledge.

For a rotatable type of thruster, a considerable amplification of the thrust was achieved when the unit operated at large drift angles (in the order of 90^{o}) due to a dynamic lift acting on nozzle and struts in the oblique flow. This should make the rotatable type of thruster even more attractive for certain applications.

The item v) of the same subject was misleading, since any type of thruster must accelerate water to provide a thrust.

Item vi) was most confusing. The response to an order was normally limited by the engines and not the propulsion unit (see above). At idling condition, a controllable pitch propeller having symmetrical and flat blades in a nozzle, would most certainly absorb the same or less power than the cycloidal propeller. On this item he would appreciate some comparative data for a cycloidal propeller.

At the end of this paper Mr Mearns regretted that few vessels other than ferries had been fitted with cycloidal propellers. However, considering maintenance, reliability, thrust per horse power and costs, one could only suggest a positioning system consisting of controllable pitch propellers in nozzles aft, in combination with transverse thrusters (bow thrusters) fitted with controllable pitch propellers strategically placed along the vessel or alternatively, a system of rotatable type cpp thrusters.

Particularly if a heading against wind, waves or current was required, this system would give maximum thrust at minimum power and investment.

MR J NEUMANN BSc FIMarE referred to the joystick controls for the Dynamic Positioning System shown by Mr Mearns during the presentation of his paper. It was evident that the requirements of the Dynamic Positioning System were most exacting, requiring measurement of position and heading, comparison with desired values, calculation of appropriate corrective action and ordering thereof from the available machinery. Mr Neumann said that he had expected that "the computer" would be made responsible for these various actions, on the assumption that a human operator would not be quick enough/clever enough to carry them out. Evidently he was mistaken, and he would value the author's further remarks on the matter.

Mr Neumann referred to the "rotating cylinder rudder" principle of obtaining transverse thrust, whereby a vertically orientated cylinder was arranged at the leading edge of the rudder and, when required, caused to rotate clockwise when the rudder was to port and anticlockwise when the rudder was to starboard. By this means it was possible to use, without flow separation, rudder angles up to 90^{o}, and to obtain very large transverse forces which indeed were able virtually to spin the ship about its own axis. Mr Neumann wondered to what extent it was practicable to give consideration to the "rotating cylinder rudder" as a means of provision of transverse thrust in some of the vessels under discussion.

MR G E WOODLIFF FIMarE congratulated Mr Mearns on producing a paper which, being of the 'integrating' type, covered the whole field of dynamic positioning. However, because this paper was in the nature of a survey of the field, it must inevitably lag behind current developments. To illustrate how DP control had advanced, Mr Woodliff would suggest that the publication by DNV of the document 'Tentative Rules for the Construction of and Classification of Dynamic Positioning Systems for Ships and Mobile Offshore Units 1977' did illustrate that it had now become a recognized and accepted technique for many diverse purposes. There were a number of points on which he would like to comment in this connection.

Precision of Station Keeping:

If precision of station keeping was considered in normal, as opposed to extreme, environmental conditions he believed that the position reference and control systems had probably more significance than the power and thruster systems.

Ability to Operate:

While offshore operations would always be limited by the ability of the personnel and and ships equipment to accept ship motion, considerable advances had been made in recent times. An example of this was the dynamically positioned semi-submersible diving support vessel "UNCLE JOHN". Not only was the vessel itself designed to be more suitable for the environment but the sub-surface bell launching system eliminated a major hazard since the bell was no longer tossed around as it was launched through the swell.

Analogue/Digital Techniques:

Although analogue techniques were used successfully for earlier dynamic positioning systems, such circuits were much more susceptible to drift and pick up compared with digital systems. Additionally, systems currently being supplied had many more sophisticated features - such as a wider range of position fixing devices - which could not be successfully catered for with analogue principles.

Range of Currents in the North Sea:

Mr Woodliff believed that recent experience had indicated that a wide range of currents could be encountered in the North Sea and the forces involved were very significant when considering the power requirements and control requirements.

Measurement Systems:

1) Taut Wire Systems:
   Two systems could be offered with rope tensions of either 1 or .25 tonnes, the dead weight on the seabed being 2 tonnes or 500 kgs, with appropriate sizes for the rope, winch and other mechanical parts. The tension control must be more accurate for the light weight system to minimize errors due to the catenary effect, each equipment had the advantage of compactness and lower prime cost, and reduced the problem of handling the dead weight when it was brought inboard.

2) Acoustic Systems:
The effect of interruptions due to air bubbles and noise etc could be minimized by the provision of additional hydrophones, and better acoustic processing to reject inconsistent and doubtful data.

3) Accuracy of Measurement:
The accuracy of taut wire and acoustic systems was depth dependent but, particularly for acoustic systems, repeatability rather than accuracy, was the significant criterion. When a ship was on DP control, movement occurred due to sea forces, and the system operated to bring the ship back on station; it was really repeatability of measurement which was important under these circumstances.

4) Radio System:
Although long base line radio systems had certain attractions, they had a limitation since they required two or three remote stations. In many operational areas this was a distinct disadvantage in comparison with range/bearing systems, which required only one remote beacon.

5) Thrusters and Drives:
There were a number of DP ships in service with fixed pitch variable speed propellers driven by thyristor fed DC motors. In general quite modest rates of change of thrust, in the order of 15% per sec, were acceptable since there were many complex constraints elsewhere in the system - for example in the wave filter circuits and in the forcing margins, (ie the thrust available being the difference between that required to balance the maximum environmental forces and the maximum which could be developed) and these factors did tend to limit the maximum acceleration of the ship.

However, the aspect which must be watched was that for DP control thrust changes were constantly being output from the computer and this duty was more severe than for a conventional manoeuvring thruster. This factor must be borne in mind when equipment was designed/selected.

One of the major problems in converting ships for DP control was the provision of suitable thrusters, for example, it was often difficult to accommodate tunnel thrusters. Pump systems of a well known British make were proving particularly attractive from the installation viewpoint and the writer was personally aware of two ships currently being fitted with DP control with such devices.

6) Determination of Power Requirements:
In general, the criteria for the power requirements of a DP ship were determined purely by the environmental conditions plus a suitable control margin. The ship owner usually specified wind, waves and current and whether the heading was free or constrained, and this information, together with the ships profile, provided the basic data for the thrust power requirements.

7) Availability:
Systems availability in the order of 95% would give an unacceptable down time to say 15 days per annum. A usual design criterion for a fully redundant duplex system was 99.99% with MTBF measured in years.

Guaranteed power supplies with battery back up tended to be large and expensive. A complete power failure was unlikely and would render the thrusters inoperative. An alternative approach to the provision of a guaranteed power supply was to provide feeds to the computer from the main and standby power systems and to ensure the control system/computer would shut down in an orderly manner, i.e. without program loss, and would restart in a similar manner when the supply was restored.

8) Use of DP Controlled Ships:

The authors' comments regarding the use of DP ships were very relevant when operating adjacent to an offshore production platform, as anchoring was not permitted due to the presence of pipelines on the seabed. Often however the time at a particular location was so short that the time spent in laying anchors would be unjustified.

Steerable thrusters also had the same ability as Voith Schneider units to provide DP and conventional operation and they had a similar disadvantage i i.e. they increased the vessels draft. The thrust from both types of unit "vectors" and often this was considered to be a major disadvantage for diving purposes; this problem was avoided by non-steerable units.

The author did not refer to joystick control which could be considered an essential part of DP control and was currently being supplied in various forms - as an integral part of DP systems, as a separate emergency control for DP ships, or as a positioning control for non DP ships. These systems could be mini-computer (using the DP computer) or micro processor based and, broadly speaking, thrust was proportional to joystick position and deflection with ships heading either automatically maintained or manually adjusted by a turning control adjacent to the joystick.

Mr Woodliff would like to point out a slight error in Table I. Wimpey Sealab had 4 steerable thrusters of 1000 hp each and the main propulsion of 2700 hp was not used for DP purposes.

9) Recent Configurations:

Equipment had recently been supplied for three diving support ships; the list of equipment involved illustrated the wide diversity of hardware and control problems. The equipment included :-

i) Short Base Line Acoustic System (4 hydrophones);
Range/bearing Radio System;
Toughened Mini-computer for Joystick System;
Toughened Mini-computer for DP System;
2 pump type thrusters diesel driven (variable speed);
1 variable pitch tunnel thruster, diesel driven, combinator control.

ii) Ultra-short Base Line Acoustic System (hydrophones in single head);
Range/Bearing Radio System;
Heavy Weight Taut Wire System;
Toughened Mini-Computer for DP System;
Micro processor for Emergency Joystick Control;
2 pump type thrusters, diesel driven (variable speed);
1 Variable Pitch Tunnel Thruster, AC motor driven;
2 Main Propellers, diesel driven with combinator control.

iii) Ultra-short Base Line Acoustic System (hydrophones in single head);
Light Weight Taut Wire System;
Toughened Mini-computer for DP systems and Joystick;
2 Variable Pitch Tunnel Thrusters, diesel driven;
1 Steerable Thruster, diesel driven, variable speed;
2 Variable pitch main propellers, diesel driven.

MR R C WOPLING said that the paper gave a good review of the state of the art in this field and it was right that the author should stress the need for study in and improvement of power generators and thruster design.

The power system and its reliability, economy and flexibility were important, especially for DP systems on service crafts. The revival of the interest in diesel electric propulsion was a sign of progress in this field and in this respect the new supply vessel built by Halter Marine Services, and the papers of H W O'Brien [(1)] and A vd Made [(2)] showed a way to interesting possibilities.

The combination of diesel electric propulsion with dc motors and azimuthing thrusters used both for propulsion and DP was interesting because of the total reduction of installed power up to 30% compared with a X - Y nozzle thruster system, and even more in comparison with a system of tunnel thrusters and main propellers.[(3) and (4)]

Since the author had rightly stressed the need for fuel saving, it was not quite realistic to stress the advantage of the cycloidal propeller without mentioning the relative low thrust/power ratio of the propeller, and the unfavourable efficiency at higher speeds of advance in comparison with the conventional propeller. Azimuthing thrusters with conventional propellers allowed application of nozzles, which increased the thrust/power ratio dramatically up to 175 - 185 kN/kW, in bollard pull condition, while for the cycloidal 145 Kn/kW was quite a realistic figure.

As with other thrusters, the cycloidal propeller thrust was also affected by current, ie the thrust reduces with approximately 7% in a three knots current.

In transit mode the loss of propulsion efficiency of the cycloidal propeller amounted to approximately 30% in comparison with the conventional propeller system without nozzle[(5)].

With respect to fuel economy it was of interest to know the power absorbtion of the cycloidal in idling condition. It was realized that this was one of the disadvantages of the CP propeller which could have a large influence on the total fuel economy of DP systems[(6)].

The power absorbtion of a CP propeller when idling, amounted to approximately 15% to 18% of the normal installed motor power. This was mainly due to the friction of the blades in zero thrust condition, which must be of the same order of magnitude for the cycloidal propeller.

In this respect it was worthwhile to consider that the fixed pitch propeller absorbed only 6% of the maximum power at an idle rev/min of one third of the maximum.

The thruster could be switched off and on without peaks in power system, when driven by a dc motor, whereas switching off and on of ac motors caused problems because of high starting current.

Table III, showing the response time of several thrust generating systems, required some explanation. (It was understood that response time was defined as the time which was needed for building up thrust from zero to maximum).

There was no principal difference in generating thrust from the hydrodynamical point of view.

All propulsion devices had to accelerate the same amount of water when producing an equal amount of thrust, and suffered from the same thrust delay because of unstable flow phenomen around the propeller blades when building up the thrust.

It was obvious that in the fixed pitch propeller system the propeller shaft must be accelerated also, which increased the response time. For the rest it was more a question of how fast the mechanism of pitch and speed changes worked in combination with the drive engine, and how fast the thrust delay from unstable flow was overcome.

The azimuthing thrusters (as mentioned in the Table "azimuthing thrusters") were built for powers up to 3000 kW and in the future thrusters up to 4500 kW would be available.

Although the response time of the thruster was important for the stability of the ship control system, it was not as important as indicated by the author.

The application of wind sensors in the majority of DP systems was a very effective tool to decrease the time delay of the system, which decreases the need for a fast response time.

Moreover it had been learned from the company's experience that a thrust reverse time, that is 180° change in direction of 10 to 15 sec was quite acceptable and met the needs of a control system.

Since noise was also mentioned it should be realized that it was important to differentiate between inboard noise and underwater noise. The first could be so high that it became unacceptable if accommodation was close to the thruster position. Underwater noise was mainly noise from cavitation and here the shrouded propeller offered better possibility to reduce noise. From experience with thrusters supplied for mine hunting vessels the company knew that mechanical noise was no problem if in the design stage this aspect was taken into account.

The conclusion was justified that the unique advantages of the cycloidal propeller, as described, were not the sole proprietary of this type of propeller.

Since these advantages were the same, the remaining difference, that is better thrust/power ratio of the azimuthing unit with shrouded propeller, put a large weight on the balance in favour of the latter.

Table I was somewhat misleading or, at least, not up to date. The "SAIPEM DUE" was originally fitted with Voith Schneider cycloidal propellers but it was understood that after a conversion some time ago this ship was now also fitted with azimuthing thrusters.

If, in the same Table I, ac in the column drive stands for ac drive motors for thrusters, it should be pointed out that the main propulsion motors and thruster motors of the "GLOMAR CHALLENGER" were thyristor controlled dc motors. This was also the case on the new DP drillship of Global Marine.

REFERENCES:

1) O'Brien jr Harvey W - 1977 "SCR controlled electric propulsion system" Gulf Section SNAME

2) v d Made A - 1977 "Some thoughts on a tractor-tug supply vessel" 5th Int Aug convention - Rotterdam

3) Andenaes O - 1976 "Alternative Thruster Systems" Det Norske Veritas Det Norske Veritas "Safety and Reliability of Dynamic Positioning Systems"

4) v Leest H and Bussemaker O - 1976 "The performance and characteristics of thrusters" Offshore South East Asia Conference

5) v Manen J D - "Results of systematic tests with vertical axes propellers" I S P nr 235-b

6) v d Made A and Bussemaker O - "Thrusters for dynamic positioning" 2nd Int Offshore Craft Conference

AUTHOR's REPLY

MR MEARNS thanked Mr Gibbons for his remarks and observations particularly relating to increasing applications of DP operational tasks and specialization of vessels. These views were confirmed by other contributors, which in his view, indicated that alternative systems concepts would be developed to meet those needs and use the equipment now becoming available.

He was sorry if his mention of availability in excess of 95% gave the impression of being related to any particular configuration of equipment. This value had been selected since it related to the requirements of most charter parties for vessels used in offshore tasks which permitted one or two day/month downtime for maintenance. As both Mr Gibbons and Mr Woodliff had mentioned such systems would provide availabilities above 99%.

Mr Gibbons had asked him to specify what reliability data should be considered for a DP system. The first requirement was to establish acceptable data bases from which to calculate reliability. Such data existed or could be developed for most of the electronic and control elements, as well as for such items as gyro compasses, hydraulic actuators and valves, and these permitted MTBFs to be established when high security of operation was required. It might be necessary to extend such calculations to cover thruster systems as well as main power plant and auxiliary services. To the authors knowledge no system had been evaluated in this way, but the operational risks involved in some offshore tasks might justify a complete systems approach. In conventional ships downtime frequently arose from failures of systems not related to main machinery e.g.air conditioning systems etc.

The benefits of duplicated primary/secondary systems vis-a-vis the use of single secondary and tertiary systems, raised another aspect of DP systems in which no ideal system might be specified. Clearly assuming that the systems had equal stability and resolution, but not necessarily the same absolute accuracy, then a configuration of three systems would satisfy many operational requirements. However, when the task demanded immediate intervention on arrival a duplicated system should be employed. When intervention could be delayed to repair the primary system or "survey" in the secondary system a configuration of three systems would suffice. The importance of specifying the task could not be ignored when selecting a systems configuration.

Repeatability figures were based upon statistical estimates of the stability of the pattern to be expected at a "disciplined geographic point", it might be considered similar to the concept of "fall of shot" used in artillery. Figures quoted by manufacturers related to results expected from correctly installed equipment, at a fixed point within a specified area of the field pattern and using standard processed outputs.

Improvement could be obtained by using computer techniques of prediction from consideration of short terms deviations. This might account for discrepancies of repeatability figures for "similar" equipment quoted by suppliers of equipment and manufacturers of positioning systems.

Repeatability was sensitive to:
1) position of the receiver in the field;
2) the installation;
3) motion.

All systems were sensitive to motion, thus repeatability deteriorated in a moving vessel compared with fixed installations; this applied even to sophisticated doppler satellite systems.

Repeatability could only be maintained within a particular value over large areas if a number of stations were deployed, e.g. repeatability of Loran type Pulse 8 systems of better than 50 metres could be obtained over the area of the North Sea from Yarmouth to 62° North. (This meant that it was possible to return to within 50 metres of any geographically defined point within this total area).

Accuracy could only be specified against particular standards and conditions. Both types of medium range radio systems (Pulsed-Loran or time difference Hi-Fix) would provide accuracies at a fixed station of better than nine metres at ranges up to 100 km under normal operating conditions if equipment was properly installed (this implied that readings at any point would consistently be within + four metres of each other). More important the quoted accuracy of any system should be based on results obtained at the time of observation and not at a later time after subsequent appraisal or processing of received data. It was easy to "improve after the event".

Finally, it was generally true that the more signal paths considered the better would be figures of repeatability and accuracy, since those systems involved consideration of a larger statistical population. Single beacon systems provided range and bearing but not position, indeed to fully define position three independent signal paths were required.

Joystick control had been mentioned by Mr Neumann and explained by Mr Woodliff. Such systems were well established from experience in the earliest systems. Mr Mearns would suggest that it could be argued that, if a system did not enable the ship's position to be held to the operational limits, albeit for a limited period, under manual control, it was unlikely that any auto-control systems would achieve improved performance.

The rotating cylinder rudder mentioned by Mr Neumann was one of a number of unconventional steering systems designed to improve handling at low speeds. Dynamic positioning might be considered to be auto-track-keeping at zero speed, so that such systems would find application in conjunction with bow thruster or other units for such tasks demanding less precise positioning (i.e. hovering), and which were of such short duration that anchoring could not be justified. (A point also mentioned by Mr Woodliff). One could foresee a new generation of vessels with improved handling systems operating under manual control, from sophisticated positional displays, without the complications and costs of full DP systems.

The author was grateful for Mr Woodliff's contribution and would respond to some of the points he made. He had raised the question of relative significance of position reference and control systems to the power and thruster systems. It must be borne in mind that in support craft one is concerned more with the disaster or extreme environmental situation than with normal environmental conditions.

Extreme disturbing forces might be generated by failure of equipment used in operational tasks, e.g. "snagged" lines, inadequate clearance for lifting and collision situations.

Mr Woodliff had also queried the effectiveness of the short base line, single transponder systems. It must be accepted that those did not require the deployment of a number of remote units and that they were cheaper, but they offered only a single, or two very adjacent, paths for the signal and when there was any signal loss the risks were considerably increased compared with systems providing the facility to select signals from a number of remotes. This aspect often appeared to be neglected by both ship and oil operators, although in close operations any signal loss could be disastrous and costs of failure high.

On the benefits of analogue/digital systems: the only point Mr Mearns had hoped to make was that analogue systems had proved adequate for ship control systems, and were comprehensible to ship masters and operators. Digital systems had been employed because many DP vessels demanded sophisticated displays, and other control functions which could be conveniently handled digitally, and not because digital processing was required for ship control purposes.

Mr Woodliff's comments on taut wire systems were informative and interesting but it had not been his own experience that they were significantly cheaper than some other systems.

He supported Mr Woodliff's remarks on guaranteed power supplies, but when a "secure" system was required the cost of such systems would not be significant in the total systems cost, since such costs must include the reference system, control equipment, thrust generators, and power equipment with its associated control gear.

Mr Heslam had requested a comparison of the effectiveness of various types of thrust units. The following Table VI had been abstracted from various manufacturers' literature based on 100 hp and comparable powers of units, i.e. up to 2000 hp.

TABLE VI

Azimuthing Thrusters with nozzle		1350 kps
Thruster in Tunnel	'A'	1200
Thruster in Tunnel	'B'	1180
Thruster in Tunnel	'C'	1140
Cycloidal unit		1050
Pump		850

In order to determine the thrust required three of the manufacturers of the units indicated above provided tables of thrust/unit area below and above the waterline. (see Table VII).

TABLE VII

All values in kg/m^2	Area above water line			Area below water line		
Ferries and Passenger Ship	4-8	3-6	3-8	10-15	10-15	8-14
Tugs and Supply Vessels	5-8	5-8	3-7	6-11	5-10	5-9
Tankers, Bulkers and General Cargo	4-8	3-6	3-6	5-8	5-10	4-7
Fishing Vessels	5-10		3-8	8-14		8-12

Consideration of the values indicated, with the range of thrust outputs, could only convince any designer and naval architect that "you pay your money and take your choice" particularly when unbiased or objective feedback of operational performance was not available.

He thanked Mr Heslam for his request since it provided the opportunity to put the record straight and to deal with thruster systems in general.

A number of contributors had raised points relating to the performance, benefits and characteristics of particular types of thrust generating systems. Unfortunately limitation of time and space did not always permit such statements to be read in context and they might often relate to specific narrow applications/considerations or particular operating conditions. Indeed it might sometimes appear that different physical laws of nature applied to units of similar type! Mr Mearns proposed therefore to make some general observations on propellers, although the interest generated at the meeting would suggest that a paper by an author more able to provide an objective review of this field would attract considerable support.

The thrust/power ratio of all types of propulsors was related to their swept area, thus lower load per unit of area gave higher thrust per unit of power. Increase of size with the same power input would improve thrust/power ratio of any type of unit.

Most CP propellers had helical blades and when providing zero thrust, part of the blading was generating thrust ahead and part astern. A significant percentage of power was absorbed when idling (Mr Wopling had kindly provided values). Although this did not occur with cycloidal units, power was still required to overcome mechanical and hydraulic friction, and these losses might be as high as 15% of total power. In azimuthing systems, losses of a similar nature also arose due to frictioned losses due to drive configurations.

Units of propeller type could only produce equal thrust in each direction when blades of lenticular section were fitted. Such sections were considerably less efficient than aerofoils so that thrusters fitted with such blading had poorer thrust output than that of conventional propellers of similar size running ahead.

Under conditions of constant pitch the power absorbed by any propeller varied according to the cube of the rev/min. Thus, equating low power absorbed at reduced propeller revolutions had little significance for comparison purposes.

A screw propeller blade was an aerofoil and generated lift, part of this arising from suction on one face and part due to pressure on the other. Cycloidal units operated at considerably lower rev/min than screw thrusters, thus the acceleration of water through the propeller disc was much greater than that in the cycloidal unit. Further this "acceleration stream" was established some distance ahead of the screw, and this "cylinder" of water must be decelerated, stopped and accelerated when direction was reversed. The effect of a tunnel and to a lesser extent a nozzle was to accentuate this effect by more firmly establishing this "cylinder of water".

The response time of all systems was dependent upon the total mass of water and inertia of mooring parts which must be decelerated, stopped and accelerated. The larger the total of these masses (which includes prime movers) the poorer the response. Systems employing constant running units always had advantage over systems of similar power which involved reversing engines and motors. Good system design might ensure that such accelerations occurred in the optimum manner but they could not reduce the effects of constants of the physical laws of nature.

Screw propellers were essentially fans, while cycloidal propellers operated like impellers in centrifugal pumps - water being drawn vertically into the eye of the propeller and discharged in the direction according to the pitch setting. The volume of water that had to be accelerated was considerably less than with fan type units when a change of direction was commanded.

Ship draft and immersion requirements placed limitations on any transverse thruster unit, thus to be attractive they must have good ratio of power/volume. This could only be achieved by operating at relatively high speeds and high blade loadings (conditions conducive to cavitation and vibration). These limitations were not so relevant to cycloidal units since the length of blade was the critical dimension which must be related to ship draft and not diameter. These units did however require modified hull forms.

He was grateful for Mr Brunsell's contribution which complimented his own few remarks about pump systems. He was pleased to note that installations were entering service and looked forward to hearing of their operational performance. Although Mr Brunsell had mentioned the lower power output the Tables would indicate this not to be a serious disadvantage for some applications.

Mr Dalvag had asked a question concerning the frequencies of acoustic systems. Such systems demanded selection of frequencies outside those of machinery, propeller or other equipment or operation generated noise. The majority of this noise arose between 15 and 50 kHz. There were currently two groups of systems in service. Those operating in the lower frequencies offering moderate range and lower resolution, while those using higher frequencies had higher resolution but limited range. Systems operating in other frequencies had been developed and would be developed to meet particular operational requirements of range, or to overcome particular noise spectra, the probable noise spectra of surface vessels was becoming established but those of submersibles, and operations such as pipe laying and sub-sea equipment, might demand systems employing other frequencies.

Mr Wopling's remark concerning the "SIAPEM DUE" might be construed to imply that azimuthing thrusters were preferred to cycloidal units. One cycloidal unit of the pair fitted at the fore end of the vessel had been replaced by an azimuthing unit, because operational experience required additional power to maintain head and only an azimuthing unit could be fitted in the space available without major structural modifications. It was understood that consideration was being given to fitting three bow units of cycloidal type in a proposed newbuilding for these owners.

There were "horses for courses" and in offshore operations some courses could be identified and some horses had entered the field. As offshore operations developed other "courses" would appear for other horses to run, At present it was not possible to tip a winner either from past form, breeding or stamina. The shipowner or operator must therefore select the most appropriate reference, control and thruster system to suit his operational intentions. The premium costs of faulty selection or specification of operational tasks could be and would, continue to be high.