Trans IMarE, Vol 101, pp 151–159

Automatic draught gauge system

Andrew Coyston, CEng MIEE
Dive Time Systems Ltd

SYNOPSIS

This paper sets out the principles behind the development of an automatic draught gauge for use on ro-ro ferries. The methods of manually reading the draught marks are explored showing how errors can arise from their use. The paper gives a full description of the automatic draught gauge system's components and their functions. It covers the reasons behind the strict installation rules, as well as listing the problems that have been encountered and their solutions. Plate 1 shows the display panel of such a system.

INTRODUCTION

One of the recommendations of the formal investigation into the loss of the MV *Herald of Free Enterprise* was that draught gauges or indicators should be a requirement for ro-ro passenger ferries. It is now a statutory requirement for certain UK ro-ro passenger ferries to be fitted from May 1st 1989 with an automatic draught gauge as described in the Statutory Instrument 1989/100. The Department of Transport Merchant Shipping Notice No M 1366 describes the standard for such gauges. In November 1988 the SOLAS 74 Convention was amended (Chapter II–1, regulation 8, paragraph 7-3), recommending the fitting of 2-point automatic draught gauges.

A draught gauge system has been developed that meets the Department of Transport standards. The system was examined in October 1987, received a Letter of Acceptance in that month and a Certificate of Inspection and Tests in April 1988, from the Department of Transport Marine Directorate Passenger Ship Subdivision Section.

Their first system was installed on the *Pride of Dover* in June 1987 and had two totally independent measuring and display points. Six more systems with four measuring points and composite readouts have been in service on ro-ro ferries for over 8 months. The first of these was installed in November 1987. Since December 1988 another eight systems have been installed with preparations in hand for a further 25.

This paper records some of the problems involved in the manual reading of draught marks and the improvement in accuracy that can be obtained with the automatic gauge. Technical operation of the gauge is discussed in detail together with problems encountered in installation and use.

Andrew Coyston served an apprenticeship with Hawker Siddeley Dynamics Ltd at Hatfield. He subsequently gained experience in a number of companies working on electronic design of stage lighting controls, power supplies, timers and gas detectors before settling as a designer and later as Technical Manager of a digital instrumentation manufacturer. He set up on his own 3 years ago as a freelance electronics designer and in addition to developing the ships draught gauge he has been involved in projects using computers in measuring systems for flour flow, train speed and diving.

Plate 1: Reading from an automatic draught gauge
More information is now displayed in the same space.

READING OF DRAUGHT MARKS ON SHIPS

A ship's draught mark can be accurately read only if:

1. the ship is steady;
2. the water is calm;
3. the mark can be seen clearly.

Ship motion

In service, the ship is rarely completely at rest. A slow rocking motion (Fig 1), has a typical time period of 30 s and

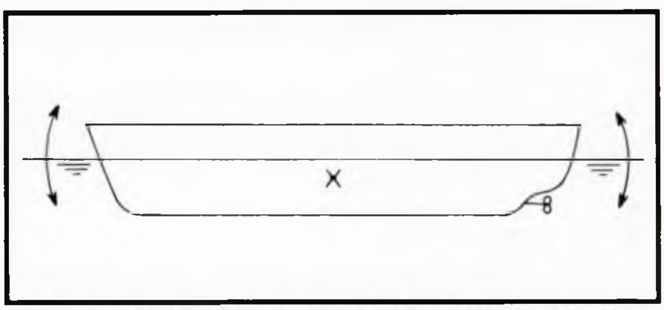

Fig 1: Slow rocking motion acting around point X

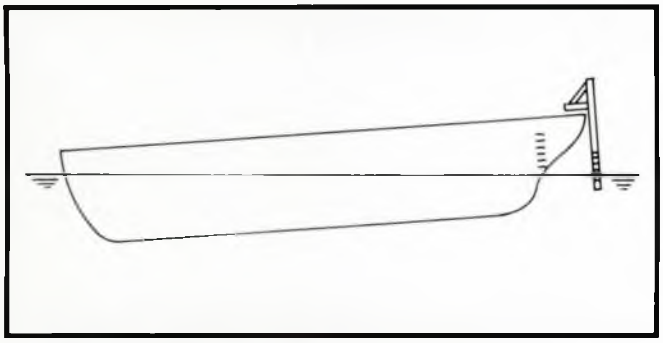

Fig 2: Use of dipstick – no compensation for trim

observations show amplitudes forward and aft of some 200–300 mm; even on calm days. Placing a heavy load at the extreme end of the deck can start this sinusoidal motion, which can take several minutes to stop. If such a load happened to be the last unit onto the ferry then due account of the movement has to be made when viewing the draughts.

Rocking motion across the ship can have a time period of as little as 2 s (as can be seen when loading the ship). A change in the wind direction or force or the state of the tide can rapidly alter the heel angle of a loaded ship. When a draught mark has been viewed from one side only (aft for example), the heel angle is needed to calculate the draught at the longitudinal centre line. If the angle is not recorded at the same time as the marks are read then an uncertainty in the reading is introduced.

Wave motion

Small wave motion on the water surface can usually be 'averaged' by eye. Inside docks and harbours the wave motion is a mixture of wave shapes because of reflections from the dock walls. This distorted wave is less easy to average and will introduce further uncertainty into the reading.

When the engines are running a wash is created around the aft marks. The crests and troughs have been observed to exceed ± 500 mm and will lead to inaccurate readings.

Viewing the draught marks

The best view of draught marks is from a small boat adjacent to the marks. Some berths allow good viewing albeit at some distance. In general, however, viewing depends on the tide state, ship hull shape (especially aft end), state of loading and berth layout (Plate 2).

Use of dipstick (Plate 3)

On berths shorter than the ferry a dipstick is used to estimate the draught (Fig 2). This cumbersome pole has a stop to align with the main deck. The stick projects downwards to below the water. When withdrawn, the draught is read from the water line on the graduated stick.

This can only provide a guide to draught in dead calm and even trim conditions. Tolerances of some 300 mm have been observed on sequential dipstick readings when sea conditions were described as 'average'.

Dock water density

Dock water density varies from dock to dock, with the state of the tide and other factors such as fresh water flow from local rivers. Whilst in most docks, the density is known not to vary or to follow a regular pattern, in others it is necessary to measure the water density before every departure. This should be done whilst the draught marks are being read.

Plate 2: Aft marks are hidden below the main deck

Plate 3: Using dipstick to read draught
Forward draught marks can be seen at an acute angle.

Conclusions drawn about draught marks

A reasonable time should be spent when reading draught from the marks in order to observe and compensate for ship and wave motion. Bearing in mind some of the time periods involved in the resultant movement, 2 or 3 min for forward and aft points is not unreasonable. Also care has to be taken to obtain a simultaneous heel angle reading, if the aft marks can only be read from one side. On fast turn around services this delay is a burden that can be relieved with automatic draught gauges.

AUTOMATIC DRAUGHT GAUGE

The automatic draught gauge provides readings of the forward, aft, port and starboard midships draughts, and the draughts remaining to the midships load lines. The readings are displayed on one panel and may be repeated on other panels elsewhere on the ship. The gauge operates continuously, taking readings of draught every 3 s.

The compensation for wave and ship motion takes one time period of the slow longitudinal rocking, typically 30 s. A delay of 1 min is recommended after loading or unloading the ship before reading the gauge. Alternatively the gauge can be considered as showing draughts as they were 1 min previously.

The gauge has an accuracy and resolution of 1 cm. Draught changes that previously could not be observed are shown clearly. Lifting the loading ramps, slackening the hawsers or a change in wind direction are a few causes of draught changes without a change in load.

To maintain reading accuracy a few simple procedures can be followed. Sea valves and any vent line valves should be kept fully open. The datum test valve should be used to confirm water flow through the sea valve. Average midships draught calculated from forward and aft should be compared with that calculated from port and starboard. A faulty sensor will show on an unexpected hog or sag. Periodically, readings should be compared with the ship's marks, preferably during a pause in service when the ship is steady, the water calm and the marks can be viewed from a boat.

Equipment

The system comprises four sensing units, a central control unit and a number of display units (usually three).

Each unit has a particular function or range of functions. The operating principles and allied problems associated with each function are presented with a brief description of each unit.

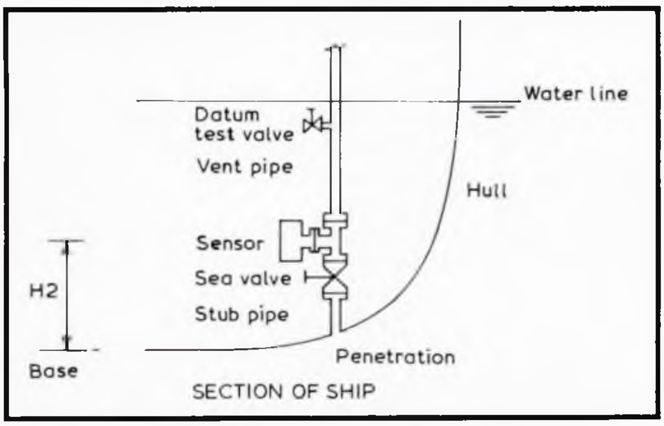

Fig 3: Typical pipework arrangement

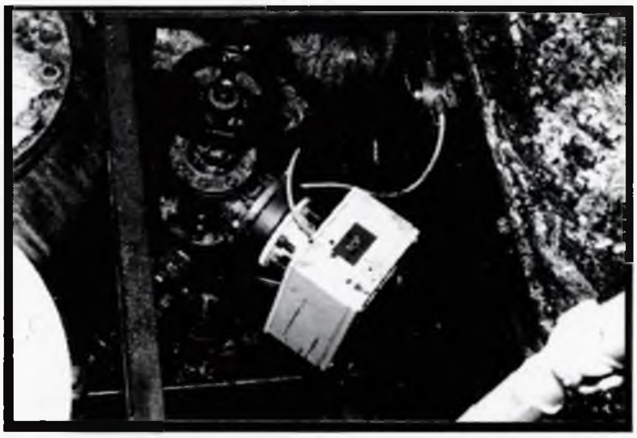

Plate 4: Midships sensor in position, but vent pipe required for correct operation

Plate 5: Aft sensor fixed directly to vent pipe – datum test valve positioned above the sensor

The principles of the sensor operation

The sensing units operate on water pressure. This is obtained from a hull penetration below the water line through a sea valve. Fig 3 shows a typical arrangement of pipework (see also Plates 4 and 5). Fig 4 shows the theoretical pressure layout.

In Fig 4, the pressure applied to the sensor consists of the ship's draught (H1 x water density) – (H2 x water density). As long as the stub pipe is filled with the same water as that found outside, then the ship's draught can be accurately measured from the observed pressure plus the sensor distance above the base, H2. Given a short stub pipe, the ship's motion will ensure that the water is well mixed up. If any air gets trapped in the stub

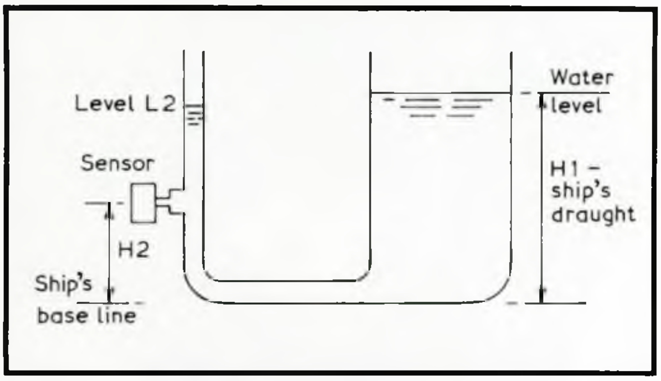

Fig 4: Theoretical pressure layout

pipe it can create an air lock. This effectively reduces H2 or increases the overall draught reading.

Water density in the vent pipe does not affect the pressure at the sensor: if this density increased, then level L2 would be reduced. Similarly an applied pressure to the vent surface cannot change the pressure at the sensor.

The pressure sensing system is a 'gauge' system in that the local atmospheric pressure around the sensor must be the same as the atmospheric pressure on the water. If the pressure around the sensor at the time of measurement is lower than atmospheric pressure then a high draught reading will result.

Water flow along the hull across the penetration will alter the observed pressure if the flow is fast enough. Currents or tidal flows have not been observed to change the pressure, but flow from the propellers does. An aft sensor location very close to the propellers can also be subject to direct pressure fluctuations.

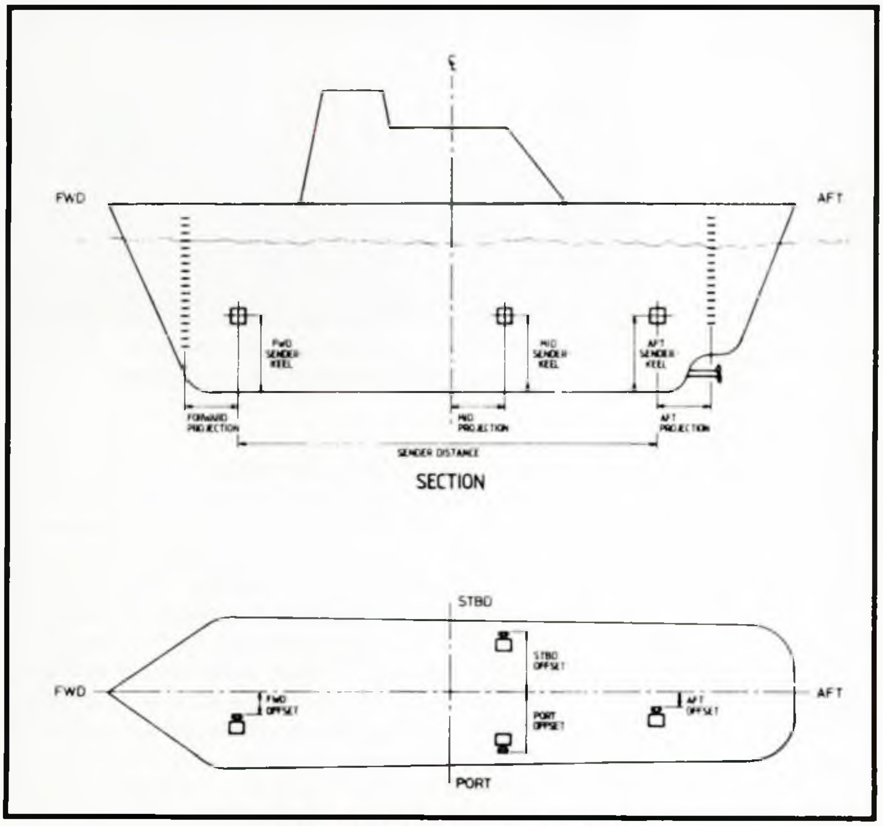

Fig 5: Location of draught senders

From these principles, the guidelines for sensor position are established.

1. Vent pipes should operate efficiently without obstruction, with a continuous vertical rise below the water line.
2. Stub pipe or connection to external water should be as short as possible.
3. Sensors should be placed in vented void spaces or in machine rooms that are not pressured when draught readings are required.
4. Aft penetration should be located away from a direct line with the propellers.

Sensor technical operation

Within the sensor there is a pressure transducer, which converts the applied water pressure to a small electronic signal and an electronic unit. The latter converts the transducer output to a digital signal and transmits this to the central control unit.

The transducers used have substantial electrical isolation from the applied water and enclosing metal work. On early installations considerable trouble was experienced using transducers with a 'thin film' electrical isolation. This would be punctured from time to time by small voltage transients between the electronic circuitry and local metalwork, causing erratic calibration changes.

Location of sensors on board

The forward and aft sensors are ideally placed on the longitudinal centre line, in line with their respective marks and the midship sensors on the lateral centre line. Access and space is required to install and service the sensors. They cannot be placed inside tanks nor can pipework be fitted through double bottomed ships.

Within the automatic gauge there is a correction system that will compensate for the forward and aft sensors being away from the marks and off the longitudinal centre line. Corrections are also included for midships sensors if they are located away from the midships lateral centre line, or on different lateral lines. These compensations will operate correctly as long as the forward or aft sensors are not more than 25% of the ship's length from their respective marks. Fig 5 shows, in diagrammatic form, sensor locations and the dimensions required to calculate all the required corrections.

Central control unit

This unit is the heart of the system. It handles the input from the sensors, carries out the calculations, applies the necessary corrections and transmits the data to the remote displays. Any adjustments to the calibration is carried out at this central point, which also provides the power for the complete system.

The computers carry out the following functions.

1. Sensor input
2. Conversion to draughts
3. Correction of draught to longitudinal centre line
4. Density correction
5. Correction of draught to draught marks
6. Presentation of data to the remote display panels with additional information

7. Draught reading calibration
8. System fault detection

Each function will now be described in greater detail.

Sensor input

A digital signal representing the applied pressure is received from each sensing point. Sensors are preset to give an accurate output for a water density of 1025 kg·m^{-3} (for other densities correction is made at a later stage).

The incoming signal varies with the wave and ship motion and noise picked up on the cabling. The electrical noise is removed by a filter circuit that rejects noisy information. Most of the faster wave effects are removed by a simple average of ten successive readings.

At this point, the head of water reading ranges up and down with the ship's motion. For a ship rocking with a time period of 30 s this ranging is about ± 200 mm. To eliminate this factor, a further averaging is made, with an automatic tuning loop that synchronises with the ship's motion. The resultant reading is then steady and will reproduce draught changes with load albeit after a delay of about 30 s.

Conversion to draught

To the incoming head of water is added the vertical distance from the base to the sensor centre line. The resultant figure is called the sensing point draught.

Correction of draught to the centre line

From the port and starboard sensors and the distance between them, the ship's heel angle is calculated. If either the forward or aft sensor is away from the longitudinal centre line, a correction is calculated using the heel angle and the distance from the centre line. Fig 6 shows this in diagrammatic form.

The sensor is offset distance 'D' from the centre line. For the heel angle shown the head of water at the sensor H1 is greater than that on the centre line H. A correction, D·sin (heel angle), is subtracted from H1 to give H. The sign for the correction is derived from the direction of D (to port or to starboard) and the angle of heel. If D is 1.000 m and the heel angle 1° the correction will be –17.5 mm.

Density correction

The gauge indicates sea water draught, with a reference density of 1025 kg·m^{-3}. No further corrections are needed in docks where the density is 1025 kg·m^{-3}.

Either automatic or manual corrections can be made if the dock water density is not 1025 kg·m^{-3}. The automatic density system samples dock water drawn in via a tapping from any convenient sea water pumped main and produces a density figure for correction calculations.

Without an automatic density system a preset manual figure is used. This is usually set at 1025 kg·m^{-3}, but may be set at any figure between 1000 and 1030, if the ship is always loaded in water of that density.

To determine the correction calculation consider a ship loaded to a draught of 5.00 m in sea water. A sensor fixed 1.50 m above base is subject to a pressure equivalent of 3.50 m of sea water. A 3.50 m signal is returned to the computer where the 1.50 m sensor-to-base distance is added. The result is 5.00 m draught.

With the same load but now in fresh water, density 1000 kg·m^{-3}, the ship's draught increases to (5.00 x 1025)/1000 = 5.125, and the applied head of water at the sensor is 5.125 – 1.50 = 3.625 m.

At the reduced density the sensor returns a signal of 3.537 m. The 1.50 m sensor-to-base distance is added to give a gauge draught of 5.037. This is shown to the nearest centimetre as 5.04 on the display. The sea water draught of the ship is still 5.00 m, so a correction of – 4 cm is required. By revising the sensor-to-base distance using the formula:

sensor – base x (d/1025)

where d is density of local water, and adding this to the incoming signal, a corrected draught is obtained. In this example, revised sensor-to-base distance is 1.463 m and thus gauge draught is 5.00 m.

Correction of draught to draught marks

The previous processes calculated four corrected sensing point draughts. These can now be extrapolated to the marks by calculating the slope between the forward and aft sensing points and projecting the figures along this slope. This is shown in simplified form in Fig 7. The difference between the forward and aft draughts is divided by the sender distance. When multiplied by a projection, the addition (or subtraction) to the sensing point draught figure is found. It has been assumed that the midships' sensors are located at the same frame number. In practice this is not always possible and the calculation can accommodate different distances to the midships' marks for port and starboard senders.

As the ship is loaded a hog or sag will develop, the keel showing a continuous curve. If the sensors are placed some

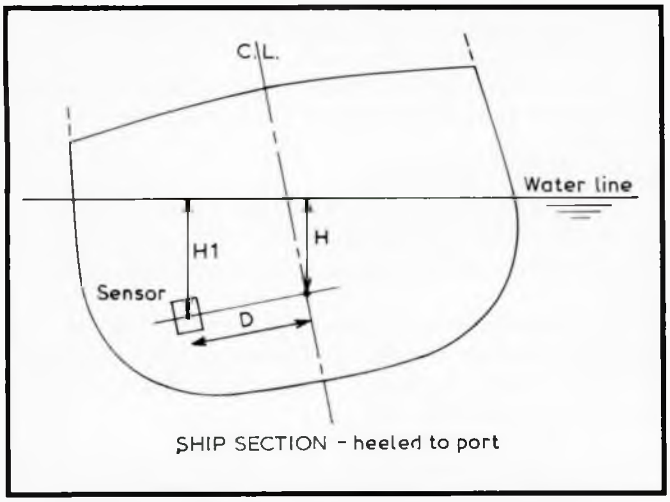

Fig 6: Correction of sensor reading to centre line

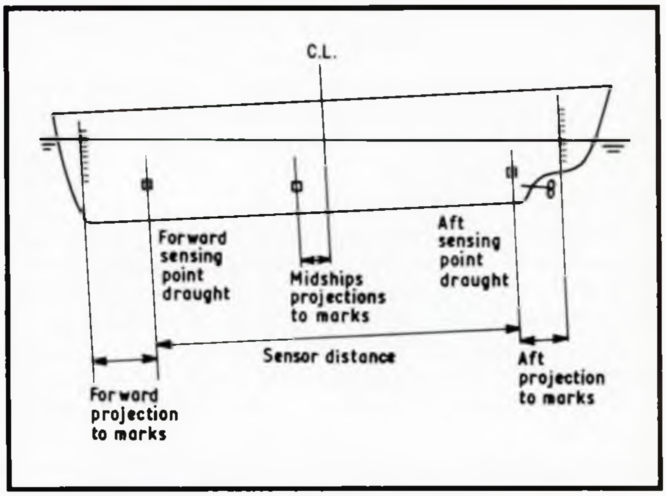

Fig 7: Correction of sensing point draughts

distance in board of the marks then the projection sum above could be in error. This error is reduced by limiting that distance, but where this is not possible the error is reduced by calibrating when the ship is partially loaded.

It is only now, with the fitting of 4-point automatic draught gauges, that any continuous observations of hog and sag during loading can be made. If, as result, a more complex projection correction is required then this can easily be added to the existing program.

Presentation of data

One complete set of measurements, reading each sensing point and carrying out the calculations, takes 3 s. This can be seen at the remote display panels as the new information wipes over the old. In order to provide a smooth and steady reading, the readouts are only changed by 1 cm with each wipe or update. Additional information that can be displayed includes draught remaining to the subdivision load line, heel angle, tonnes to limit, and so on, and are calculated from the displayed draughts so that all the figures can be verified easily.

Draught reading calibration

A system, when first installed, is set up with the dimensional data of the sensing points supplied by the ship's operator. After installation a comparison is made between the draughts read from the ships' marks and the gauge – best carried out after dry docking or when the ship is not in service.

After taking due account of water density, any corrections are set into the gauge digitally. A record is kept of these calibration numbers so that if they are altered for any reason the system can be reset to match its original calibration. A key switch has to be used to make the calibration adjustment and a secret code can be provided to limit access to this adjustment if required.

Sensors are preset to a standard calibration using a precision pressure tester at the factory. Each has an individual offset figure that will have been set into the system at installation. If a sensor fails, the replacement offset figure is set into the system to retain the original calibration.

System fault detection

If a sensor or cable fails, no reading can be obtained. This is detected and shown as 'Line fault' at the display. Without all the sensors working, none of the corrections can be reliably calculated and only the working sensing point draughts are shown. If only one of the computers develops a fault, the draught gauge will stop operation and attempt to restart after a short period. If unable to do so, the remote displays will simply fail to update.

A mains power failure will not stop the unit from operating until its internal batteries have discharged. This takes about 2 h, after which the system will switch off. As soon as power is reconnected the system switches itself on again.

Electrical installations

It was realised from the beginning of the development that for the ease of installation the simplest cabling system was required between the units, with a single mains supply point and operation under electrically noisy conditions. Cable or junction deterioration should not change the gauge accuracy (although complete cable failure should signal a fault).

The cable required between each sensor and the central control unit is 2 core twisted and screened. This same 2 core cable is used between the central control unit and the remote displays. Connections are not polarized and can be reversed. Power for the sensors and displays is carried by the same cable (at low voltage) and only a single mains connection is required at the central box.

All the information is sent digitally – this means either all or none of the information sent is received. (Compare with an analogue system, where poor cable insulation can create calibration errors.)

Display panels (Plate 1)

Draught readings and additional information are shown on an alphanumeric liquid crystal display. Whilst these displays have a relatively limited viewing angle they consume very little power. Therefore a local mains supply is not required – simplifying the electrical installation. Power is obtained from the 2 core connection to the central control unit.

For use on the bridge, displays with internal lighting are available so that they can be read in low level light conditions.

The display shows forward and aft draughts and heel angle, updating every 3 s. A third section of the display is changed every 3 s and shows, sequentially, port and starboard draughts, port and starboard draught remaining to load line (condition C1), port and starboard draught remaining to load line (condition C2), tonnes to limit, and density. Single compartment ships do not show C2 and density is omitted on ships without automatic density compensation.

Control of the information presented on the display is by the computer software. It is easy, therefore, to incorporate changes required by the ship owners. For example, trim and mean midships draught can be displayed if required.

Connection to stability computers

Being in digital form the information shown on the displays can be directly linked to a stability computer. An RS232 interface can be fitted inside the bridge display for connection to a local computer. If desired the link to the display cable can be made elsewhere.

Operation in use

Within a few days of installation any latent problems are usually revealed. The major cause of initial problems is incorrect venting, whilst the closing of sea valves or vent line valves by the crew is a close second. Automatic density systems require a period of operation and observation whilst their performance settles.

A feature of continuous service offered by ro-ro ferries is the number of crews that serve on one ship. Demonstrating the system to all the relevant members of each crew is not usually possible and it takes some time before they are familiar with the use of the gauge. Invariably comparison is made to the draught marks, but unfortunately not often under the ideal conditions noted earlier. A comparison made when conditions are ideal and all the factors, density and heel angle for example, are taken into account will demonstrate the gauge's accuracy.

Operational problems

A review of the performance of the gauges installed between November 1987 and December 1988, showed that the majority of the faults were caused by problems at the sensing points.

On the first installations, failures or calibration problems were caused by the original choice of pressure transducer. A change of manufacturer eliminated that problem. Other problems encountered have been:

1. closing of the sea valves
2. closing the valves on the vent pipe
3. blockages in the pipework
4. inefficient venting

5. submerging the sender under water
6. electric welding close to the sensor
7. Damage caused by grit blasting and painting in dry dock,when the sea valves are left open.

With a sea valve shut the sensing point draught drops to the sender to the base distance. After the various calculations the effect of one incorrect input has a marked effect on all the displayed draughts.

Venting problems (where air gets into the penetration more quickly than it can escape up the vent) show as increased readings (usually aft).

If a sensor unit is submerged for any length of time water creeps into the sensing element through its cable and and connector. This causes a very slow calibration drift – the reading requires resetting every few days and a replacement sensor unit is required to cure this.

Electric arc welding on the sensor pipework generates high transient voltages enough to damage the transducer. Removal of the sender during welding will prevent any damage.

The sensor will be damaged if it is subjected to pressures in excess of 4 bar or successive mechanical shock. External pressure painting and cleaning operations can apply sufficient pressure to damage a sensor if the sea valve is left open.

There are occasions when a sensing point fails because of a mechanical failure, and sometimes a sensor cannot be fitted at the time of the original installation because of a mechanical problem that can only be attended to in dry dock. If the repair or rework is likely to take some time, the draught at the missing point can be calculated from the other three. Clearly this cannot provide perfect results over the full range of hog or sag variations but can provide accurate results if calibrated at or near full load conditions. Whilst not complying fully with the regulations, this temporary facility does enable use of the automatic gauge to continue.

CONCLUSIONS

Throughout the early days of the development of this automatic gauge system it seemed, when standing beside a ferry such as the *Pride of Dover*, a daunting task to measure the draught of such a large piece of engineering to an accuracy of 1 cm. There was no technical reason why this could not be done using the appropriate components and designs. If the rules of installation and operation are followed, the gauge system described and discussed in this paper will reproduce a ship's draught to 1 cm accuracy.

Having fitted an automatic gauge system it will give a draught readout at any time during loading or unloading. Compare this with the manual method, where the draught would only be taken when fully loaded. Also, the draught can be observed at any display point to see the current state of the ship. Draught can be read at any state of wind or tide, in daylight or at night, with the doors open or closed.

A 4-point system has been described; systems using two measuring points, as suggested by the amendment to the SOLAS 74, with an inclinometer for heel angle measurement and sensor correction are available. These would not give a true midships draught, some other method being required to accurately account for change in hog and sag.

Finally, it is obvious that this system can be used on any class of ship to optimise the loading conditions, particularly when loading is completed at a fast rate, as with bulk carriers or tankers. In these ships there would be considerable financial advantages in having accurate measurements of draught, draught remaining to the Plimsoll line, heel angle and tonnes to limit, these values being corrected for density throughout the loading process.

ACKNOWLEDGEMENTS

Appreciation is expressed to P&O European Ferries at Dover and Felixstowe and to Sealink British Ferries for fitting gauge systems during the development period. Also to Tim Chaplin of Fibron (UK) Ltd for the realisation that a project aimed at the diving industry could be adapted for the measurement of draught, to the staff and Directors of Dive Time Systems Ltd for their continued support of the project and to the Department of Transport for their valuable advice during the development of the gauge.

Discussion

J W Harrison (Three Quays Marine Services Limited) The author has given an interesting presentation of what to many is a fairly emotive topic and is to be thanked for this.

It is also interesting that the author's company has succeeded in an apparently new field to them, ie draft measurement, whereas little has been heard from 'marine equipment' companies who already had similar equipment in their catalogue, with reference to their successful approval by the administration.

The Department of Transport Merchant Shipping Notice No M1366 requires in Appendix I, 1.7, provision of means to confirm the accuracy of the measuring units by comparison with established datum marks fitted within the ship. The author has made no reference in the written script to this although a datum test valve is shown in Fig 3, strangely below the water line. Should a drain valve be provided below the sensor to enable water of a known density to be used for checking?

Additionally, would any representative from the Department of Transport amplify their interpretation of this requirement, in particular the accuracy required?

Is the author able to quantify the errors caused by water flow through the sea chest as shown in the slides during the presentation? (A reference is made in the paper to the effect of propeller-disturbed water.)

How significant is the effect of over-atmospheric pressure at the sensor location? (Typical engine room pressure could be 25 mm WG.) What solutions are available to overcome this?

The particular equipment referred to has been applied to ro-ro ferries with relatively shallow draught and a very limited range of operating draughts. The author mentioned in his presentation a pressure limit of 4 bar for the sensor – what potential has this equipment for use in larger ships, VLCCs, bulk carriers, etc, with a loaded draught of maybe 25–30 m?

The author described how, with a ship at sea, the measuring system is no longer considered accurate. Can this be quantified? Additionally, can anything further be done, if needed, to provide an accurate and consistent enough set of draught data to be used as an input to the presently talked about 'ship black box recorder'?

A Coyston (Dive Time Systems) Mr Harrison asked about the provision of means to confirm the accuracy of the measuring units and queried the datum valve being situated below the water line. This test valve is sited below the water line in order that water of the same density as that surrounding the ship can flow into the pipework. The sea valve closed and the test valve opened to leave a fixed head of water. This test is first carried out when the system is commissioned and can be carried out as and when required. The figures displayed should be the same as those obtained at commissioning, thereby proving sensor repeatability. The only reliable way to check the draught gauge readings is by direct comparison with the ship's marks.

In reply to Mr Harrison's question about errors caused by water flow in the sea chests, there have been tests carried out on ships with sensors fitted in sea chests, by fixing a clear tube vertically from a test point on the sensor to the engine room deck head and observing the results. While the ship was unladen and there was no shipboard activity, a level was marked. This level was then observed when the harbour pumps, followed by the main pumps being switched on in turn. No effect was registered. The head of water does move up and down with the ship's motion, but the program corrects for this.

The senders have only been fitted in compartmentalised sea chests, allowing the isolation of the draught gauge penetration from that of the pump inlets. A potential problem is rubbish being drawn into the vicinity of the draught gauge penetration. This can be cleared easily but can cause inconvenience. It is recommended that wherever possible sensors have their own penetrations.

In reply to Mr Harrison's query concerning the effect of over-atmospheric pressure, this can be a problem as the sensors will be affected. Vented void spaces are checked before installation to ensure that the vent is clear. Tests have been carried out in engine rooms using manometers. It was found that the pressure build-up dissipated as soon as the watertight doors were opened on reaching port. If there is a problem in the siting of the sensors, this can be cured by running a small flexible tube into the electronics box from an area of atmospheric pressure. The transducers have an integral vent tube which runs from the transducer to the electronics box.

Mr Harrison queried the use of this equipment on ships other than ro-ros which have far deeper draughts. The choice of transducer is tailored to the range of draughts encountered, as the best results are obtained if most of the range of a particular transducer is used. Ro-ro ferries with shallow draughts are fitted with a 1 bar transducer, bulk carriers requiring a range of 25–30 m would be fitted with a 3 or 4 bar transducer to cover the range. This entails no hardware changes, only a small software change to scale the readout. It is probably worth mentioning here, that as the display figures are software configured, the wording can be translated into other languages if required.

Further to Mr Harrison's query on the accuracy of the draught of a ship underway, this is very difficult to quantify with water flowing under the hull continually, there is an ever-changing pressure at the penetration. There are points of neutral motion on every ship, but these can only be found with extensive tank testing.

Dive Time Systems are looking for ways of measuring draught underway but it is a difficult problem. Once the draught can be measured, there is no barrier to feeding data into a ship's black box.

D Rhoden (Three Quays Marine Services Limited) I welcome this paper and thank the author for his valuable and helpful work.

In view of the number of problems mentioned in the paper, which would occur in service, would Mr Coyston let us know the sizes of errors associated with particular faults and comment on the risk of believing readings which may be in error? Would he favour valve position indicators, automatic and periodic (water) purging of stub pipes, with suitable indicators on the readout panels, or any other precautions to reduce the risk of problems occurring in service? Would the author comment on the possibility of automatic plotting (graphically) of the readings given by the automatic system and the potential value of such plots in detecting errors in the readings?

A Coyston (Dive Time Systems) In answer to Mr Rhoden's queries on the size of errors associated with particular faults, firstly there are error detection mechanisms within the system. If the sea valve is turned off, the reading will become much shallower and if it reaches a pre-set level the program will indicate a line fault. To prevent this happening most sea valves have on/off indicators and are labelled draught indicators. If an air lock occurs the readings read deeper, thus will automatically prevent the ship being overloaded. The transducer was chosen because the diaphragm will break under excess pressure rather than bend and add an unknown error to the draught reading. This means the program will pick up a line fault rather than incorrect data. In the event of water entering the transducer breather pipe a line fault will be registered. The tabulation of readings taken, say, when the ship is empty would quickly show up a trend of small errors, whereas the system itself handles the gross errors. Dive Time Systems have found that the ferry operators know roughly what to expect their draught to be, and then monitor it more closely the readings do not tally.

K S Harvey (Salvage Association) I was particularly interested in the author's comments that if an air lock occurred in the pipework it could not be cleared.

Would the author please advise why no provision was made for clearing the pipes by compressed air or steam, as is common practice in sea chests? The blockage of sea inlets by mud, ice, weeds, etc, has always been a problem, and this is aggravated by present day pollution, particularly plastic materials. It seems that no matter what diameter of vent pipe is provided this problem can occur, not necessarily only in harbour waters, and unless some means of cleansing is available the equipment must remain out of action until the vessel is next in drydock.

A Coyston (Dive Time Systems) In reply to Mr Harvey's interest in the occurrence of air locks, these can be cleared. The drain plug fitted to the sender is removed, then opening the sea valve will purge the system of air.

Mr Harvey further questioned the lack of provision for clearing blockages in the inlets. We have not yet had a blockage in any installation. Perhaps the minimal flow in the pipework contributes to this. No provision has been made to clear solid blockages as part of the fixed installation because of the possibility of damaging the transducer. If a blockage does occur, the sender can be removed and an airline or compressed air cylinder used to remove the blockage. Replacing the sender when the blockage has been removed.

P Paloyannidis (Department of Transport - Marine Directorate) I am the Department of Transport surveyor involved in the appraisal of this equipment during its development stages and testing. I did would like to comment on Mr Coyston's paper and hope it is not considered prejudiced.

I agree with Mr Harrison on the point he made as regards compensating for the drop in pressure when the transducer is fitted in way of main or auxiliary ERs.

In addition to what Mr Coyston said, it is understood that when the transducers are fitted in a main or auxiliary ER, where there appears to be a pressure constantly less than atmospheric, the transducer's (plastic, thin) breather pipe is led to the open.