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CONTROL SYSTEMS FOR HYDRAULICALLY OPERATED CARGO AND BALLAST VALVES ON LIQUID CARGO SHIPS

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The cargo and ballast pumping control system on liquid cargo carriers must be designed to speed "turn round", with reliability, simplicity of operation and minimum of overall cost as basic concepts. The system must form an integrated whole, and not just consist of a series of components. The paper details the methods by which local, semi-centralized or fully centralized control is achieved. Remote control employs either pneumatic, hydraulic or electrical piloting of valves located close to, or on, the individual actuators. Intrinsically safe circuits are used for electrical piloting. Details are given of the hydraulic circuit devices to control the speed of operation of actuators and to retain them in position. Constant and differential pressure systems are described. Valve position indication can be provided locally to the actuators and remotely at the control points. Intrinsically safe electrical signal transmission is used and the display can be given by light emitting diodes. Hydraulic power is provided by electrically driven power units. The paper concludes with notes on commissioning and maintenance of cargo valve control systems.

INTRODUCTION

Cargo ships carry cargo from port to port. Time spent loading and discharging must be kept to a minimum in order to speed "turn round" time and therefore increase unit efficiency. The cargo pumping control system must be designed accordingly with reliability, simplicity of operation and minimum overall cost foremost in the engineer's mind.

In a previous paper [(1)] the authors described the various types of actuator and valve combinations which are used on liquid cargo ships. In this paper the methods of control of these actuators, and the source of hydraulic power, are discussed.

The control sections must be designed as an overall system and not as a group of poorly matched components. Only by operating in this way can a high standard of reliability be hoped for.

ACTUATOR CONTROL SYSTEMS

The most simple form of control of a hydraulic actuator is by the use of a manually operated hydraulic valve mounted on, or immediately adjacent to, the actuator. Pressure and return lines are taken to the control valve and from this, control lines are fed to the actuator. This system has the advantage of complete simplicity in design and installation but not in use. In the operation of some types of ship it may be a relatively simple matter for a number of men to control actuators on deck by local means, but pump room actuators present a very different problem. There it is virtually essential to group the actuator controls in one easily accessible position.

This form of semi-centralized control, which is normal in pump rooms, is also often applied to groups of actuators located on deck. In such cases racks carrying the hydraulic control valves can be mounted either at the pump room top or in deck boxes (generally of watertight construction) mounted in logical positions along the deck. See Fig. 1.

For reasons of economy and manpower and more accurate overall control, many operators prefer to have a completely centralized control system enabling a single officer to operate any of the valves in the cargo and ballast lines.

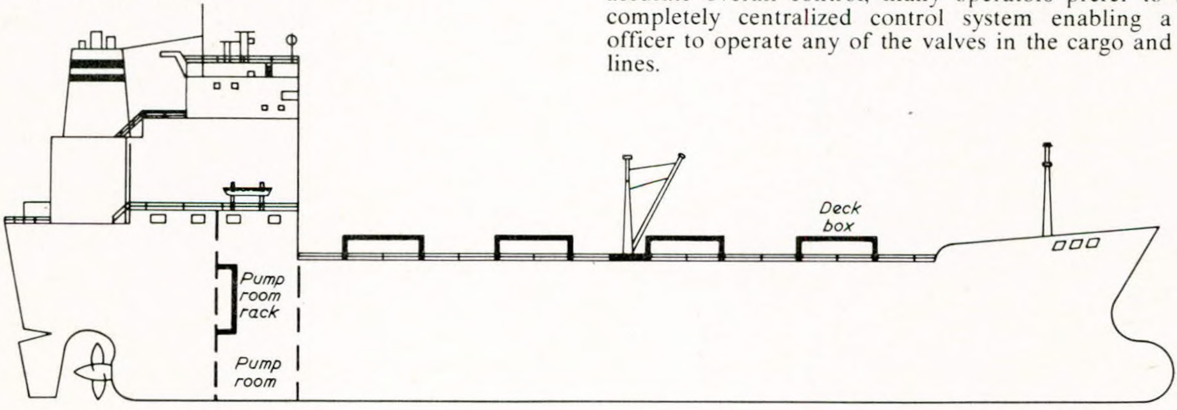

FIG. 1—*Outline of tanker*

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There are in regular use three basic methods of actuator control (Fig. 2), namely:

1) local manual control;
2) semi-centralized control from pump room racks or deck boxes;
3) fully centralized control.

In addition there are a variety of combinations of these systems. For instance, many product carriers have the pump room valves controlled from racks at the pump room head with all the deck and tank valves locally controlled on deck. Another common combination is the control of the pump room actuators from a console in the control room, with grouped control of deck and tank valves from a small number of deck boxes. The choice depends on the ship layout, its pumping programme and, perhaps mainly, on the operator's preference.

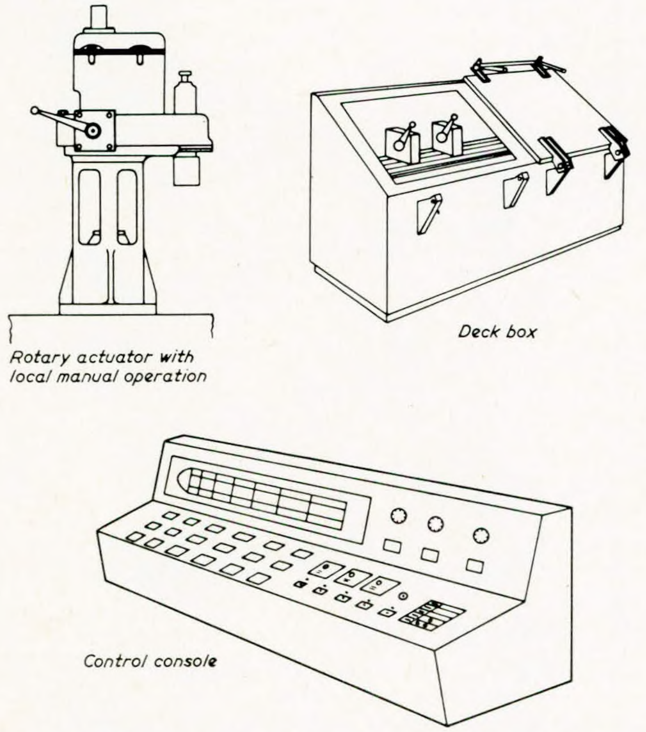


FIG. 2—*Methods of actuator control (rotary actuator, deck box, console)*

Local Manual Control

A directional control valve is mounted on, or adjacent to, the actuator. The valve may be any of a wide variety of types, e.g. ball, spool, or poppet. The choice of valve will depend on the type of actuator and the hydraulic circuit employed. A piston type actuator (whether linear or semi-rotary) may require a flow as small as 0·25 litres/min of oil which would require a 3 to 5 mm bore control valve. If a differential area type actuator is used then the valve will be three-way and if it is a double acting system a four-way valve will be needed. A hydraulic motor driven actuator requires a flow which may be as much as 70 litres/min and hence a 20 to 25 mm bore control valve.

When the control of the actuators is local, the pipework requirements are simple. A pressure line and a return line can be taken around the entire system with the feeds to each actuator control valve tee'd off. The feed lines to the control valve and thence to the actuator will be smaller than the mains. These must be able to carry, without undue pressure drop, the flow required by the maximum number of actuators which will be required at any one time. In some cases it will be convenient to form the pressure and return mains into closed rings and this gives added security in the case of sea damage. See Fig. 3.

For this reason it is normal to provide isolating valves at points around the ring. The ring can be closed at any one of a number of points after which it can be fed in two directions with a damaged section isolated, thus minimizing the number of actuators deprived of power.

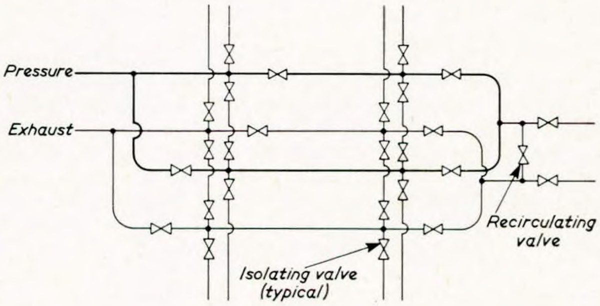


FIG. 3—*Ring main system*

Remote Control

When the control valve is removed from the immediate locality of the actuator, a number of remote control systems become possible and these apply whether a semi-centralized system (e.g. deck boxes) or a fully centralized system is used. The remote control can be by one of two main methods with a number of sub-divisions of one of these.

a) Direct hydraulic control

In this system the control circuit remains exactly as with local manual control but the distance between the control valve and the actuator is increased. Three factors must be considered:

(i) As already mentioned the main hydraulic distribution around the deck or pump room can be by means of relatively large pressure and return pipes with a low pressure drop. For reasons of economy, pipe sizes are normally reduced from the teeing off points to the actuators. See Fig. 4. With remote control the distance from control valve to actuator is increased and so a greater pressure drop will be experienced. This effect can be offset by the use of a higher system pressure or of larger bore pipes. Alternatively, the actuator sizes can be increased to give the required power at a lower effective pressure.

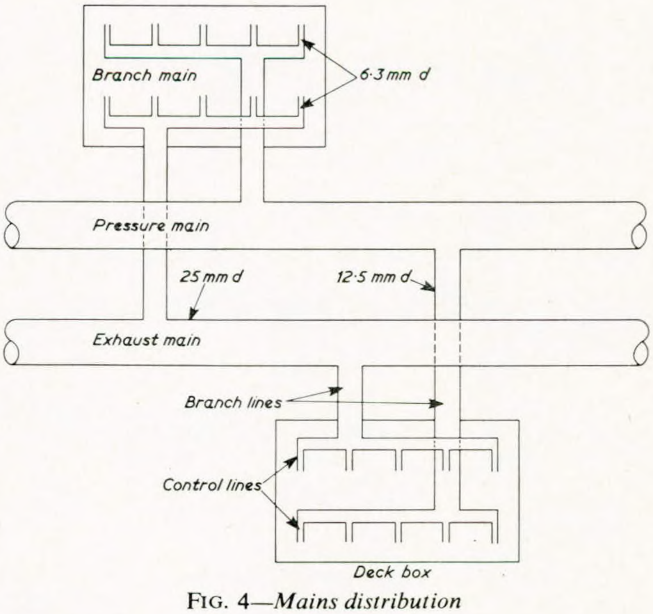


FIG. 4—*Mains distribution*

(ii) Some types of piston actuator are effectively locked in position by the use of a valve which is leak tight in the closed mode. The actuator piston is held in position by the slug of oil between it and the leak tight control valve. If the intervening pipework is short, then this slug of oil is quite solid and the locking of the actuator is positive. If, however, the distance is increased then a degree of sponginess tends to be introduced into the locking. In addition, changes of temperature can cause pressure intensification in the pipework, or lack of locking when the temperature falls. These effects are not normally serious but must be borne in mind in system design.

(iii) The total amount of hydraulic piping required in a direct control remote system is obviously much greater than is used with local control. If the diameters have to be increased to obviate pressure drop, then costs will begin to rise substantially. In any case the vulnerability to sea damage will increase with the number of pipes used and so this aspect is important for deck mounted systems. When actuators are submerged in tanks there will obviously be a need for remote control. This means that control pipes must be run to the actuator from the control valve at deck level. This is unavoidable but at least these pipes are well protected from external damage, and temperature variations are not as great inside a tank as on deck.

b) Piloted hydraulic control

In this type of system the hydraulic control valve is located as closely as possible to the actuator but it, in turn, is controlled from a remote point. This achieves the best of both worlds. It may be possible to mount the directional control valve actually on the actuator or alternatively it may be located in a deck box or on a pump room rack, a relatively small distance away from it. The problems of pressure drop and thermal expansion, etc, are overcome.

Remote control of this main hydraulic valve can be exercised, see Fig. 5, by:

1) pneumatic;
2) hydraulic;
3) electrical means.

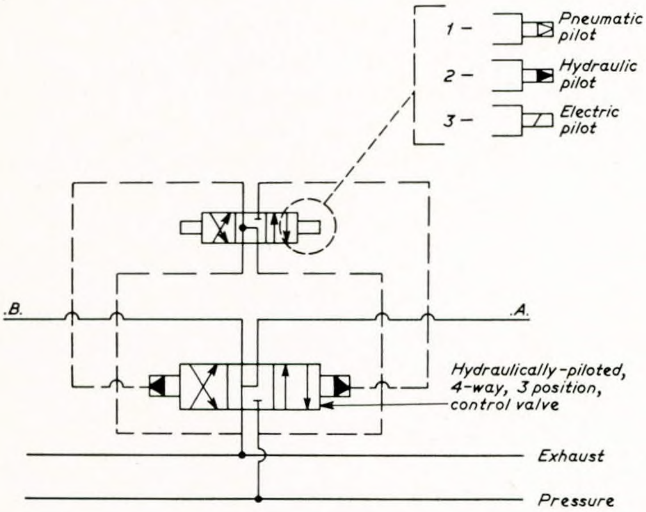


FIG. 5—*Pneumatic, electric, hydraulic, pilot on hydraulic control valve*

Pneumatic control is seldom used because it is difficult to keep the control air dry, and severe deck conditions are likely to cause blocking of control lines by ice. In addition such systems, where control distances are substantial, are prone to time delays. The systems mainly employed for control are therefore hydraulic and electric.

When the main hydraulic valve is hydraulically piloted, the flow of oil required to operate it is minute. Consequently pressure drop virtually disappears. Pipes down to 3 to 5 mm bore can be used and cost savings result. In such a system the control valves in the central console (or the semi-centralized deck box or rack) would be 3 to 5 mm bore and can easily be built into the mimic diagram displaying the pipe layout.

These advantages of a hydraulically piloted system compared with a direct hydraulic system are substantial but they are generally outweighed by the advantages of an electrically piloted system. The main hydraulic valve is controlled by electrical solenoids (return or centring may be by springs) and the pipework from the control console to the valve is replaced by highly flexible electric cables which can be run in the most sheltered situations and out of the way of other equipment. Installation costs are low and reliability is high.

In all cases of remote control of the directional control valve provision is made for local manual operation. This satisfies two requirements. Firstly, it may be convenient to operate the actuator locally when commissioning the system and during maintenance. Secondly, if some fault occurs on the control side of the valve, (sea damage, electrical failure, etc) local control permits continued use of the system.

The manual operation may be either direct on the spool of the main directional control valve, or on the pilot valve (if one is used). In the former case the manual effort required may be substantial, but added security results as manual operation is possible even if there is trouble on the pilot valve.

The use of electricity on board a crude oil carrier or a refined products carrier immediately raises the question of safety. There are, of course, certain areas on a ship which are non-hazardous. It is possible to confine the use of electricity to these areas. A system sometimes used consists of an electrical control console from which control cables are run to solenoid operated hydraulic directional control valves located in a non-hazardous hydraulic room. See Fig. 6.

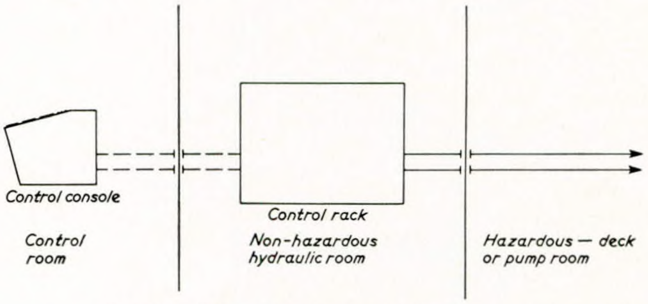


FIG. 6—*Non intrinsically safe layout*

From this point either direct control lines are run to the actuators or alternatively hydraulic pilot signals are taken to the main directional control valves located on, or close to, the actuators. The only advantage of such a system compared with hydraulic piloting from hydraulic valves in the control console is that no hydraulic pipes need enter the main control room. This is regarded by some operators as a major advantage and, of course, an electric control console with its associated lights is not only small and neat but also enables the operator quickly and clearly to assimilate the system condition. However the extra cost of equipment and space involved in the use of a "hydraulic room" reduces its popularity.

The normal method of ensuring safety in the use of electrical equipment on these ships is to use the now well proved and highly popular intrinsically safe electrical circuits. See Fig. 7. The absolute safety of such systems relies upon the fact that there is a known minimum level of energy which can cause ignition of the most dangerous gas/air mixture for any given flammable liquid or gas. It is possible to design and manufacture an electrical system in which, under the most severe fault conditions, this danger level of energy cannot be reached. Obviously a suitable factor of safety is applied before deciding on the permitted level of energy build up. This energy limitation is achieved by the use of self-limiting transformers and barrier components which only permit the passage of the required amount of energy. The input side of the equipment, i.e. before these barriers, can only be located in a non-hazardous area, but all of the circuit beyond this barrier can be in a hazardous area. Rigid testing and certification of such systems is called for and the circuit as a whole is defined in the approval certificate.

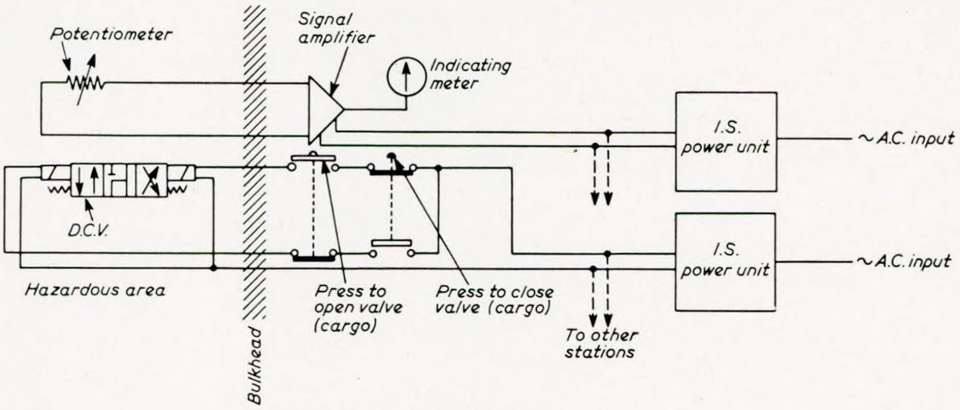


FIG. 7—*Intrinsically safe layout*

The degree of development of intrinsically safe electro-hydraulic system is such that this is now the most favoured method of centralized control of cargo and ballast systems on crude carriers and product carriers of any great size.

CONTROL CIRCUITRY

In the introduction to this paper the authors commented on the need for design of a system as a whole, rather than trying to string together a series of components. In no section is this more true than in the design of the hydraulic circuitry. Comments have already been made on the main directional control valve. This must be appropriate for the type and size of actuator, the associated control circuit and, above all, the environmental conditions. This control valve may be operated frequently during the loading or discharging period and then, on a crude carrier a period of weeks may elapse before the valve is called upon to operate again. The moment the operating signal is given, reliable operation must take place. It is usual to specify an acceptable temperature range from −20°C to +60°C. If the valve is operated in an intrinsically safe electrical circuit the amount of energy available to move the spool is very low. Under these conditions it is normal to use an internal or auxiliary piloting system so that the electrical energy only has to move a lightly loaded pilot spool and this in turn permits the hydraulic system pressure to operate the main spool, see Fig. 5.

Actuators must not only operate promptly and reliably, they must also operate at the correct speed. Too rapid operation of a valve may cause very serious hydraulic hammer in the main cargo lines. Too slow a speed of operation is unacceptable as it can lead to lack of control and consequent oil spillage. Typical operating times can vary from 15 seconds for a 100 mm bore valve up to 90 seconds for a 1200 mm bore size. Many actuator circuits must therefore include some form of flow controller. See Fig. 8.

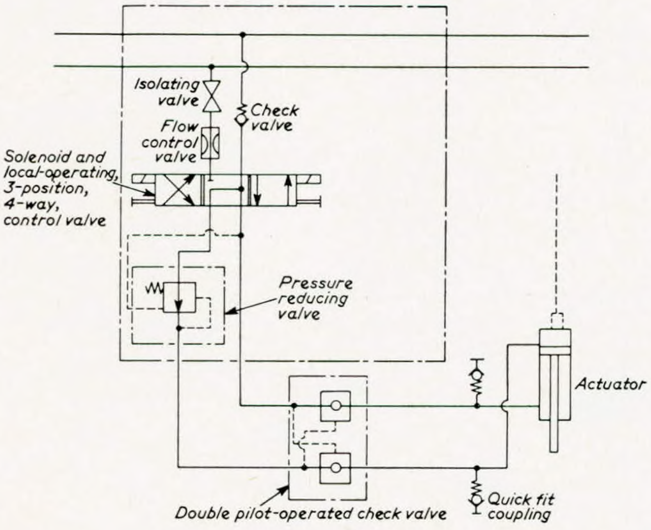


FIG. 8—*Circuit diagram showing pilot operated check valve*

Under some conditions this may be a fixed device whereas in other circumstances an adjustable unit is called for. The fixed device may be such that it can be adjusted by the manufacturer's commissioning engineer when the system is initially set up, after which it remains set for the rest of its life. If adjustable devices are included in a marine system it is essential that they will remain adjustable and not become locked by corrosion. Bearing in mind that periods of months, if not years, may elapse between adjustments, there is a serious danger of corrosion taking place if the device is exposed to the elements. For this reason there is much to be said for the use of flow controllers having fixed settings. In some cases it may be important that these units are pressure compensated, so that the rate of flow of the fluid and correspondingly the rate of operation of the actuator remains sensibly constant irrespective of the pressure available at the actuator.

Mention has already been made of the need to ensure that some valves cannot move when the control valve is in the stop position. In the case of some actuators, e.g. those operating through high ratio gear boxes, locking of the actuator is inherent in its design. In the case of some piston types, locking is ensured by locking in the oil between the control valve and the actuator. If the distance between the control valve and the actuator is great enough to permit some sponginess then a hydraulic lock system is used. This normally consists of a pair of pilot operated check valves interconnected across the two lines so that flow from the actuator is impossible in either direction until one or other of the two control lines is pressurized. The system is made clear in the diagram, Fig. 8.

Some piston and cylinder type actuators are operated on a differential area system. This implies that system pressure is permanently maintained on the underside of the piston and movement is achieved by connecting the top of the cylinder *via* a control valve either to the pressure line or to exhaust, Fig. 9.

The operating force is therefore the system pressure times the annulus area in the one direction and times the piston rod area in the other. There is one inherent potential disadvantage of this system. When the actuator is left in the closed position, i.e. with the piston rod extended, there is system pressure on both sides of the piston. If this system pressure is removed, e.g. when the power unit is closed down, and pressure gradually decays, the greater volume of oil on the upper side of the piston will cause a tendency for the valve blade to be nudged in. After this nudging in, the application of the normal opening force may be inadequate to get the valve wedge out of its seat. To avoid this a special circuit is employed. This consists of a non-return valve bridging the two actuator lines. The permanent pressure on the underside of the piston holds the non-return valve on its seat.

Should system pressure be removed, then the greater volume of oil on the upper side at the piston can decay across the non-return valve, thus preventing nudging in.

The use of the differential area system just described has the advantage that the actuator can easily be designed to

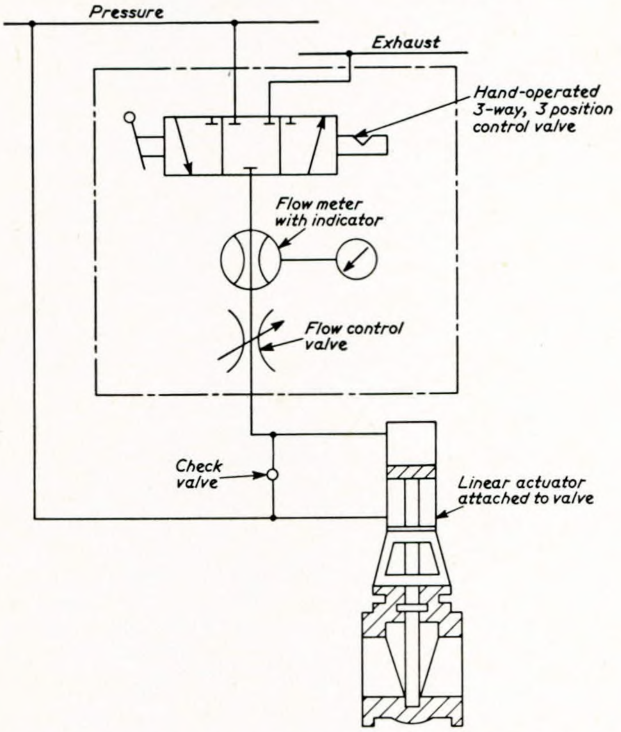


FIG. 9—*Circuit diagram showing control, constant pressure, differential areas*

ensure that the valve opening thrust (pressure × annulus area) is appropriately greater than the valve closing thrust (pressure × piston rod area). By correct choice of piston rod diameter in relation to cylinder bore, the desired ratio of something between 1·25 and 1·5:1 for these thrusts can be obtained. However, this differential area system is inefficient in as much as the cylinder bore has to be increased so that the opening thrust is adequate. The alternative is the use of the double acting system in which system pressure is applied by the control valve, either to the upper or to the lower side of the piston with the opposite side connected to exhaust. The thrusts now become:

opening = pressure × annulus area

closing = pressure × full cylinder area

As the piston rod area no longer dictates the closing thrust, the piston rod diameter can be made as small as strength and mechanical considerations allow. This means that the cylinder bore is reduced and the actuator becomes smaller and cheaper. In order to maintain the ratio of opening to closing thrusts between desirable limits it is now necessary to use a smaller pressure for closing than for opening. This can be achieved by one of the following methods:

a) The use of a power unit having two different pressure outputs. These can be obtained from two separate pumps or from two streams on a single pump. Two pressure mains can then be taken round the whole system with the top sides of the cylinders fed from the lower pressure and the lower sides from the higher pressure.
b) By using a single pressure main around the system and incorporating pressure reducers to provide a reduced pressure for the upper sides of either groups of actuators, or individual actuators.

The latter system is the one normally employed as it gives the maximum degree of flexibility and control in matching individual actuators to the valves.

In all theoretical considerations of hydraulic system it is assumed that the oil is able to flow freely through all devices. There are two considerations which may adversely affect such free flow. The viscosity of hydraulic fluids varies with temperature. The viscosity characteristics of oils differ widely and in every case a fluid is chosen which has as flat as possible viscosity curve over the anticipated operating temperature range. See Fig. 10.

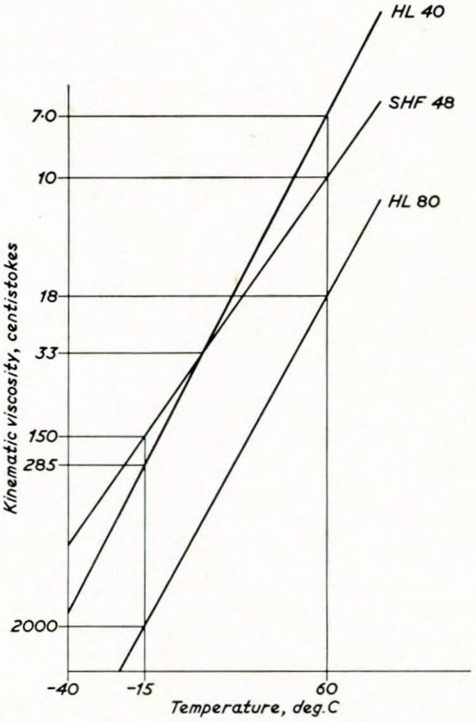


FIG. 10—*Viscosity temperature graph*

High temperatures may be due to high ambient temperatures, e.g. sunshine on the ship'sdeck, and little can be done to control this. A second source of heat input is the actual thermal energy generated in the hydraulic system. The effects of these two factors can be at least partly offset by the inclusion in the hydraulic circuit of an appropriate oil cooler. This is normally fed with sea water which can carry the thermal energy overboard. The cooler is generally positioned in the return line to the hydraulic power unit tank.

The other factor which can adversely affect the flow is dirt in the system. The hydraulic system should be sealed and once it is clean it should stay clean. However, during installation a great deal of dirt can and probably will get into the system and this must be removed by adequate flushing, section by section before commissioning is commenced. Such flushing not only requires patience but also skill in appropriately sectionalizing the pipework. During flushing, factory assembled units, e.g. control racks must be looped out of the system as they will have been flushed and despatched clean by the manufacturers. All hydraulic pipework should be tapped with a mallet during flushing, in order to dislodge any scale that may be inside the pipe. This procedure is important and if ignored can result in a contaminated system caused by ship vibration dislodging the pipe scale after the commissioning period.

Circulation of the flushing medium should be by special flushing pumps and not by the system hydraulic power unit as high fluid velocity at low pressure is required and this is exactly the opposite to the characteristic of the normal power unit pump. Once the system is as clean as possible, it must be permanently protected by the inclusion of appropriate filter elements.

Filtration

When discussing filtration two facts are certain:

1) no system ever failed because the fluid was too clean;
2) no hydraulic fluid has yet been examined that does not contain a measurable quantity of solid contaminant.

Filtration is required in hydraulic systems to avoid wear and maloperation of components with fine clearances and to avoid degradation of fluidic properties. The filters remove fluid contaminants such as metal particles and oxidation products, and prevent the slimes produced by bacteria altering the chemical and physical constitution of the fluid.

Wherever possible the filters in a hydraulic system should be situated down stream of possible contaminant sources. Generally high pressure filters are situated in the high pressure line immediately down stream of the hydraulic pump. Low pressure filters are usually situated in the return to tank, and are mounted adjacent to the tank (reservoir). In systems installed on ships, where the hydraulic main is usually of some considerable length, it is adviseable to increase the number of high pressure filters in the system so that one high pressure filter is used in each high pressure branch line from the main. This is to ensure that minute particles that are washed from the inner walls of the hydraulic main do not silt up precision components situated in the branch lines off this main. See Fig. 11.

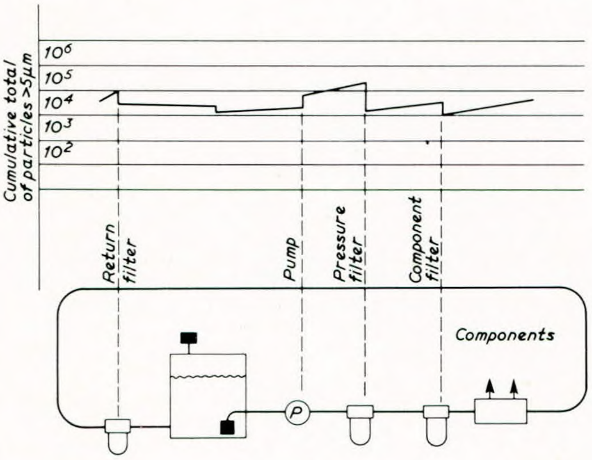


FIG. 11—*Contaminent distribution*

Filter cleaning should be carried out when contamination has reached a pre-determined level. This is shown on most filters by a visual indicator. It is essential that filter elements are either changed or cleaned before the contamination level reaches its maximum.

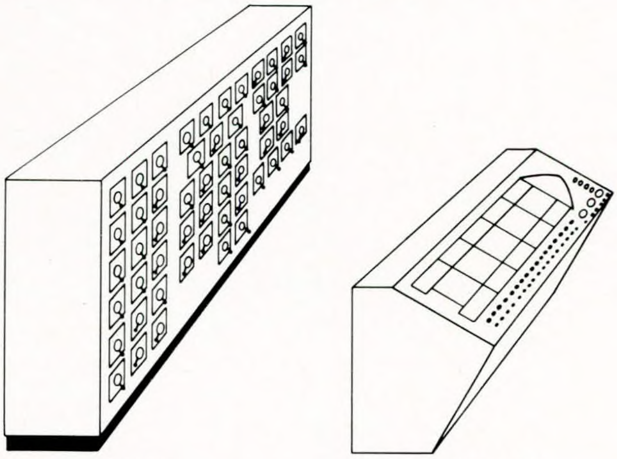
It is important to realize that in systems that are subject to high pressure pulses, the soft filter elements can deform under such pulses and large particles can then pass through these deformed pores and cause sudden dirt discharge into the system.

Control Consoles and Panels

There is such a wide variety of alternative design features available that it is tempting simply to say "you pays your money and takes your choice". Two illustrations depict the extremes. One is a simple rectangular sheet metal unit with a vertical face in which can be seen the handles of the direct hydraulic control valves. See Fig. 12.

This is a typical centralized control system for a pump room. A simple mimic diagram on the face of the console shows the position of each valve in the appropriately coloured cargo or ballast pipeline. The other extreme is a 10 m long electro-hydraulic control console containing not only the whole of the pushbuttons for 194 valve stations but also such items as system alarm units, power unit controls, telephones, scanners, etc.

Most operators choose to have the valve operating units (pushbuttons, lever switches, valve handles, etc, and the associated valve position indicators, located in the appropriate position in a mimic diagram depicting the layout of the cargo and ballast pipelines. The bulkheads separating the tanks and the outline of the pump room with the pumps, ejectors, etc are usually also shown on this diagram within the outline of the ship. In some cases not only is the actual position of the valve element shown but also the last operating instruction ("closed" or "open") given to the actuator is demonstrated by memory lights. The various controls and indication devices on such a console will give the operating officer control of the cargo handling equipment and also a complete indication of its current state.



(a) Upright console *(b) Desk type console*

FIG. 12—*Typical control consoles*

Some operators prefer to have a mimic diagram of the cargo system displayed on a vertical panel behind the sloping top of the control deck without any controls or indicators inserted in it. These components are then arranged in a logical pattern on the desk top.

Indication of the depth of cargo or ballast in the various tanks may also be given on the main control console but quite often a separate control console or panel is used for this purpose. This may be mounted adjacent to, or behind, the main control console.

It is, of course, perfectly feasible to interconnect the tank gauging system and the valve operating system so that the appropriate valves automatically open and close as the tanks fill and empty. Such interconnexion will normally be made through a form of computer but up to the present this system has not achieved a great deal of popularity. There is little doubt that the future will see an increase in interconnected systems.

The physical construction of such control consoles, desks and panels calls for little comment as it is typical of many similar items regularly used on shipboard. The control room is normally air conditioned and so environmental conditions are not severe. It is normal to include a storm grab rail along the front edge of the low built consoles, and access must be adequate for all maintenance purposes. Internal lighting is generally built into the unit larger than about 4 m, to help with maintenance.

VALVE POSITION INDICATION

Local and Remote Indication

On most valve/actuator assemblies, provision is made for local indication of the valve position. This is generally a simple mechanical system by which a pointer gives this information. If control is from a position remote from the actuators there will probably be a need to indicate valve position at the control point. In many cases the indicators are built into the mimic diagram on the central control console thus giving an easily assimilated picture of valve positions. See Fig. 13.

Remote Systems

Hydraulic Indication

A system particularly suited to linear actuators is that of using a flowmeter through which the oil required to operate the actuator passes. If, for example, an actuator cylinder requires the supply of 5 litres of oil to move it through its full stroke, then valve position can be shown by the indicator head of a flowmeter which is calibrated from "open" to "closed " and traverses this span when 5 litres is fed through it. See Fig. 14.

Flowmeter indication can also be used in association with a rotary actuator. In this case it is necessary to calibrate the flow of oil required to operate the motor through sufficient revolutions to give full valve operation. The flowmeter is then calibrated to show full valve movement when this quantity of oil passes.

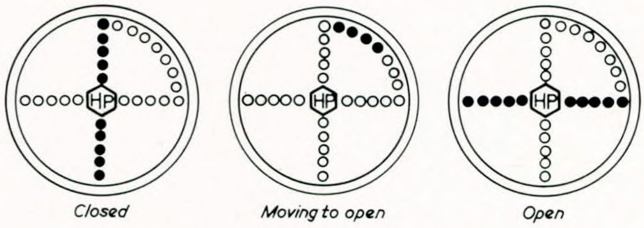


FIG. 13—*Valledin indicator faces*

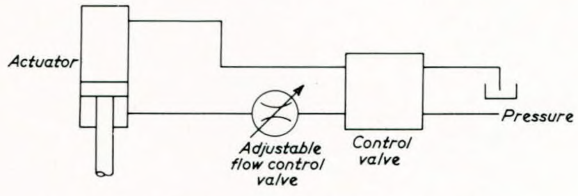
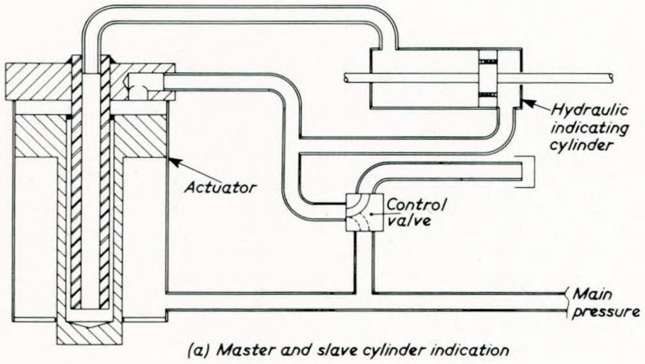
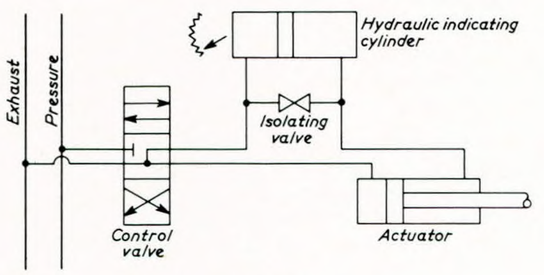


FIG. 14—*Flowmeter in cylinder circuit*



(a) Master and slave cylinder indication



(b) Indicator cylinder

FIG. 15

A second form of hydraulic indication is the displacement system (see Fig. 15). There are two main forms:

Firstly a system in which the movement of a master cylinder attached to, or built integrally within, the actuator is exactly reproduced by a slave cylinder located where indication is required; e.g. in the control console. See Fig. 15a. The system requires provision for bleeding off air trapped in the hydraulic oil and provision for regular phasing if the slave is to line up with the master. The shorter the distance between the master and slave cylinders, the more accurate and speedy is the indication. The distances from control room to for'd actuators on modern VLCC are generally considered to be too great for satisfactory displacement indication. The system is also affected by substantial oil temperature changes.

A second form of displacement indication is that in which an indicator cylinder is built into the pressure line feeding the actuator at a convenient point, e.g. at tank top level in the case of a submerged tank actuator. The indicator cylinder piston effectively is interposed in the main flow of oil and so the cylinder must have a volume slightly less than that of the actuator cylinder. This ensures that the indicator piston always re-phases at the end of each stroke. The indication device is then operated from the movement of the indicator piston. The system is shown in Fig. 15b.

Pneumatic Indication

The travel of the actuator or valve can be used to operate pneumatic limit switches at each end of its stroke/travel and these can pass, or block, a pneumatic supply to an indicator device in the control console, etc. This system normally gives "end position indication" only and does not show the full travel. Alternatively, valve travel can be used to operate a small pressure regulator in an auxiliary supply and the output of this regulator is fed to a pressure gauge.

Appropriate calibration of this gauge causes it to indicate the position of the valve blade. If the distance between the actuator and the remote indicator is great, the response time may be somewhat protracted.

Electrical Indication

As with the pneumatic system, electrical indication can be used to give either "end position" only, by limit switches operating lights, or "full position" display. This latter system has, until recently, used a milliameter as an indicator, this being fed by a circuit which includes a potentiometer or a series resistor driven by the actuator movement. Such indicator systems will normally be operated by an intrinsically safe system (Fig. 7).

A recent innovation displays the state of the cargo or ballast valves in a form which is more readily assimilated by the operator. The milliameter needle is replaced by light emitting diodes set in a small instrument facia located at the valve position in the mimic diagram. See Fig. 13.

When the valve is closed a row of red diodes lights up at right angles to the pipe line on the mimic demonstrating that flow is blocked. As the valve moves from the fully open position a series of yellow diodes lights up around the circumference of a 90° section of the indicator face.

When the valve is fully open the yellow diodes are extinguished and a row of green diodes, set in line with the pipe on the mimic, lights up to indicate that full flow can take place.

POWER UNIT

The purpose of the hydraulic power unit, see Fig. 16, is to convert electrical power, which cannot be used in hazardous areas because of safety considerations, into hydraulic power. Basically the power unit consists of an electric motor driving a suitable hydraulic pump. A storage tank for the hydraulic fluid is provided and this has to be of ample capacity to provide the variations in volume of fluid required as pistons move in the actuators.

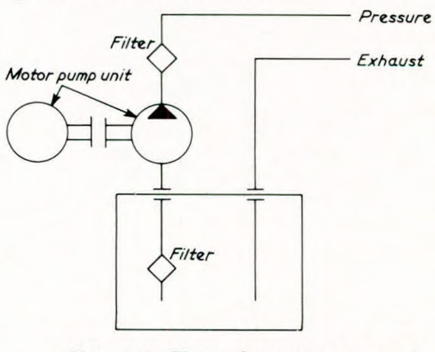


FIG. 16—*Typical power unit circuit*

A number of ancillary features are required and the final unit is a good deal more sophisticated than might be imagined from this simple basic description. First of all the vital nature of the availability of hydraulic power demands that there is a 100 per cent stand-by feature. This is provided by having two electric motors each driving a hydraulic pump. Normally either one of these pumps can supply the total requirements of the system. Under certain circumstances the two pumps may be called upon to operate together but it is important that one pump alone can operate the system albeit rather more slowly than may be normal. Both these pumps are interconnected within the same hydraulic circuit.

The electrical starting and control equipment for the two motors is designed so that they can be controlled remotely as well as locally. It is normal for them to be operated from the central control console where either motor may be selected as the duty motor, the other unit then forming the stand-by reserve. It is important that periodically the motor chosen for duty is changed over, so that each motor and pump is regularly brought into operation.

The oil storage tank is provided with internal baffles so that ship movement does not cause excessive oil movement and it is also designed for a list condition. Care is taken in the positioning of the suction and return lines to ensure that there is no danger of air being drawn into the system. The tank is normally provided with a clean out door, a filler breather and a sight glass level gauge. The suction is provided with a strainer and there is a tank drain cock. Electric motors are normally of the totally enclosed type and the hydraulic pumps are generally flange mounted onto the motors.

The pumps may be either of two basic designs. Fixed delivery units (normally of the gear type) may be used, in which case the pumps must be capable of supplying continuously the maximum amount of fluid which may be required at any time. When the operation of the actuator demands a lower flow of fluid, the excess flow must be "dumped" back to the tank. This necessarily means a substantial waste of electrical energy. The alternative is to use a variable delivery pump of the axial piston type. The delivery is varied, either by changing the angle of the body, or the angle of the swash plate. This control is automatic and usually of the constant pressure type. Under such circumstances the pump only delivers the required amount of fluid and consequently the electric motors only draw from the mains the amount of energy actually required to operate the actuators in use.

A variable delivery pump of this type is substantially more expensive than a fixed delivery unit. If the pump is only used relatively infrequently then the extra cost may not be justified. The authors recently inserted a recording watt meter in the supply lines to fixed and variable delivery pumps on two identical product carriers. These two ships were loading and discharging under exactly similar conditions and it was therefore possible to examine the consumption of electrical energy in the two cases. See Fig. 17.

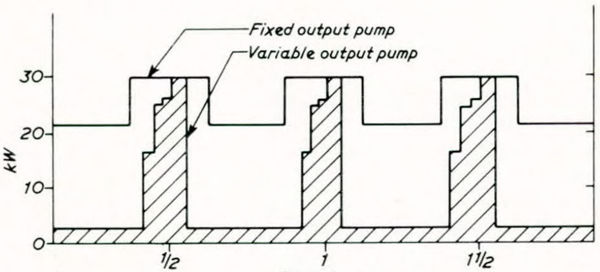


FIG. 17—*Graph showing fixed and variable output pump consumption*

These particular product carriers were on European coastal work and were being partly discharged and loaded two or three times each week. Examination of the watt meter traces revealed that the extra cost of the variable delivery pump would be recouped in electricity saving in, at the very most, 1·5 years.

If a fixed delivery pump is used then some device is employed to ensure that the pressure of the system does not build up above the required level. Oil is permitted to re-circulate from the pressure line to the tank by means of two alternative devices. A simple hydraulic pressure relief valve can be used and is set at the required system pressure. Alternatively, an electrical pressure switch is used which, at the required system pressure, operates a solenoid operated dump valve which allows the excess hydraulic fluid to flow to tank.

The return line to the tank is fitted with an appropriate filter. A good standard of filtration is of the order of 10 microns and a unit of this type is fitted with a clogging indicator and a by-pass.

A hydraulic system is equipped with appropriate pneumo-hydraulic accumulator capacity. The accumulators are of the nitrogen filled bag type. In some cases storage of hydraulic energy is required to operate a minimum number of valves for safety reasons if electric and hydraulic power fails completely. In other cases emergency operation is provided by manual operation of the valves or by use of a handpump on piston type actuators. In such cases a smaller capacity accumulator is employed simply to act as a pressure smoothing device. A power unit is fitted with a system pressure gauge which is protected by a suitable isolator.

Safety features include a high pressure alarm and a low oil level alarm. These take the form of electrical switches which operate audible and visual alarms.

Where hydraulic power units are fitted, space is generally at a premium and so designs are available which occupy an absolute minimum of floor space. This is achieved by building the electric motors and pumps underneath an overhanging oil storage tank with all the control equipment mounted on the tank front. Antivibration mountings are generally employed.

The safety switches are connected to the electric motor starters so that the motors stop automatically when system pressure becomes unacceptably high or the oil level drops below the danger level. When the ship is being loaded or discharged, the duty pump is kept running continually and simply dumps its excess flow whenever pressure builds up above the acceptable system level. As soon as the pressure falls again below a somewhat lower figure, the dump valve will close and pressure builds up again. A typical differential range for the operation of such a pump would be cut out at 80 bars and cut in at 65 bars.

If the specification calls for automatic cut in of the second pump then a second pressure switch would be set at for example 55 bars and whenever the pressure falls as low as this, the second pump would come in automatically and cut out again at, say, 70 bars.

Wedge gate valves which are widely employed on liquid cargo carriers have an inherent tendency to open when left in the closed position unless some restraining force is applied to the gate in the form of a hydraulic lock or system pressure. For this reason on ships containing such valves it is usual to leave the hydraulic system pressurized during a voyage.

Pressure is then left applied to the top of the piston to restrain the gate valve elements. There is of course no need to leave the hydraulic power unit running continuously to apply this pressure. The system is built up to pressure with the hydraulic power unit controls in the "auto" position. Under these circumstances the controlling pressure switch will switch the electric motor off when the system pressure reaches its upper limit of the differential and switch it in again when the pressure falls below the differential limit. With a normally leak tight system the pump might run for only a few minutes and then cut out again for several hours, the accumulators maintaining pressure. Some operators prefer to use a very small auxiliary pump and motor for this "on voyage" service and so such a unit is commonly built onto the main power unit. There is no need to have duplicate small pumps as failure of this pump would not be serious as the system could still be pressurized by one of the main pumps.

GENERAL

The majority of hydraulic on board tanker systems use a pressure and exhaust main of 25 to 35 mm diameter with branch lines in the order of 12·5 to 18 mm diameter and control lines 6 to 12·5 mm diameter.

The size of pipe depends upon the maximum allowable pressure drop for each individual system, based on the following formula for laminar flow

$$d^4 = \frac{P1\, V\, Q\, L}{14030\,\Delta p}$$

where d = diameter of pipe bore in inches
$P1$ = specific gravity
V = kinematic viscosity O centistokes
Q = flow rate in^3/sec
L = length of pipe in feet
Δp = pressure drop in lb/in^2

System working pressures vary between 70 and 140 bars for the majority of control systems, the limiting factors being customer preference or individual component limitations.

Oil velocities can vary according to individual system requirements but are usually in the region of 4 to 5 m/sec in pressure lines, 3 to 4 m in exhaust lines, 1 to 2 metres for suction lines.

Filtration is usually between 5 and 15 micron and the contamination level for a system incorporating precision type control equipment is: above 5 micron, 130 k to 250 k particles per 100 ml of fluid, and above 15 micron 2 k to 4 k particles per 100 ml of fluid.

For systems incorporating less sophisticated control equipment these figures can be relaxed to 1 m to 2 m particles per 100 ml above 5 micron and 8 k to 16 k particles per 100 ml above 15 micron. Hydraulic power units can vary in size depending upon the type of system, i.e. for a system incorporating rotary hydraulic motor driven actuators, a hydraulic pump output of 110 to 160 litres/min is usual whereas for a system incorporating linear piston or semi-rotary piston actuators a pump output of 30 to 45 litres/min is usual.

MARINE CONDITIONS

In a lecture to this Institute there is no need for the authors to stress the importance of the choice of materials in the equipment which will be exposed to sea and weather. Precautions normally taken in the construction of hydraulic cargo control equipment may be briefly summarized.

In the construction of deck mounted equipment it is usual to avoid the use of light alloys completely. Wherever possible cast iron is used in preference to mild steel or carbon steels. Exposed bolts are normally of stainless steel and nuts and washers are either of the same material or are non-ferrous. In the choice of stainless steels, attention must be paid to tensile strength. The most corrosion resistant of stainless steels is EN58J but unfortunately its tensile strength is substantially lower than the slightly less corrosion resistant EN57. EN56 is sometimes described as "stainless steel" but for deck mounted purposes it is unacceptable unless protected by paint.

All materials which are not inherently corrosion resistant must be treated with appropriate paint protection. It is normal to apply an approved marine primer before the top coat paints are used. Virtually all acceptable marine primers require complete descaling of the base metal and this implies a shot blast preparation with immediate application of the primer before surface oxidization can take place.

Actuators, deck boxes and other deck mounted equipment have to be effectively sealed against the ingress of water and wave pressures can be very substantial. Particular attention has to be paid therefore to the choice of gasket materials, and basic design is such that the components are "self clearing" after submersion under waves. Corners where water might lie must be avoided and substantial mechanical strength must be built into all components.

Cable and pipe entries must be sealed and inspection windows must be constructed of strengthened or wired glass. These statements are no more than a recognition that appropriate precautions must be taken. To cover this subject adequately requires space beyond the limits of this paper but numerous books and papers have been written on it.

HYDRAULIC SYSTEM INSTALLATION

Mention has already been made of the desirability of sectionalized ring mains for the hydraulic supply to actuators on the deck. Individual feeds are required to the actuators in tanks and in the pump room. Factors affecting the choice of tube material are cost, strength and corrosion resistance.

Steel is cheap and strong but it corrodes. It can be adequately protected and is used on deck on some vessels. Paint protection must be maintained to prevent weakening of the tube wall by pitting although thickwall tube can be used.

Cupro-nickel is excellent as to corrosion resistance but it is expensive and has a lower strength than steel. Wall thickness can easily be made adequate for the system pressure and so this material is widely used on deck, in tanks, and in pump rooms etc. Tungum (a complex alpha brass) falls in between steel and cupro-nickel as to strength and it too has good corrosion resistance. The fittings used for joining the pipework and connecting to components must be compatible with the pipe and suitable for the environment. Brazed type fittings are frequently used with cupro-nickel although there are satisfactory compression type fittings available. When a ring main is run on deck it is usual to insert an isolator valve between pressure and return line at the for'd end. See Fig. 3.

In very hot and very cold weather, when no actuators are in use, this valve can be opened and the power unit run so that oil circulates through the system thus preventing extremes of heat or cold in the oil in this deck main.

SYSTEM COMMISSIONING

A hydraulic cargo control system will require skilled commissioning before it is put into operation. Many items must be finally "set-up" after the equipment has been installed. Actuator timings must be checked and adjusted. Where rotary actuators are used, the ratio between opening and closing thrusts must be established by appropriate setting of the pressure relief valve associated with the actuator. Where piston type actuators are used on a double acting system, pressure relief valves must also be appropriately set to provide the correct open/close thrust ratio. The power unit cut-in and cut-out pressures must be established and the various safety sequences checked.

Valve indication systems must be trimmed to ensure accuracy and all operations tested. As far as possible all of this work will have been carried out at the manufacturer's works but, as has been stressed in the opening paragraphs of this paper, the authors are considering a system and not a series of components. It is impossible to regard the system as operational until the required relationship between the functions of the various components has been finally established, and a great deal of skilled work is involved.

This commissioning work is quite apart from the normal work involved during the installation of the equipment. One most important item is ensuring that the system is completely clean and this involves thorough flushing of all the pipework. This is normally regarded as the duty of the installers, but the commissioning engineers will take their own checks to ensure that results are satisfactory. If the hydraulic system is not absolutely clean, the commissioning engineer will find out very quickly as a result of troubles which are bound to arise. The engineer will normally change the main filters on the power unit at the end of the commissioning process as it is virtually certain that some remaining foreign matter will have been carried round the system into these filters and the ship must start its life with a completely clean filter system.

There is sometimes a tendency for shipbuilders to assume that this commissioning work can be carried out in a matter almost of hours just before the ship goes on trials. The time taken for commissioning will be very greatly influenced by the care and skill with which the equipment has been installed. However efficiently this work has been carried out, it is vital that adequate time is allowed for commissioning and it is much better to call for the commissioning engineer early rather than late. It is normal for this engineer to sail on trials but it is much better for him to have a few days of apparently wasted time between the completion of his commissioning and the commencement of trials than for him to try to complete the commissioning of the system under the chaotic conditions which so frequently reign during the trials.

DRYDOCKING AND SERVICING

It is rare indeed for any complex system to operate during the first 12 months of the ship's life without any minor defects showing up or adjustments being required. Even if none should be observed it is still desirable for the manufacturer's service engineer to be present at the guarantee drydocking to survey the system. The original supplies to the ship should include adequate onboard spares to ensure that replacements are available for any defective components. Normally, however, information will have been passed from the ship to the manufacturers to ensure that they have appropriate spares available with them when they visit the ship at drydocking.

Availability of worldwide after-sales service is an essential part of the "stock-in-trade" of any worthwhile marine component manufacturer. This service will not only be available for the repair of breakdowns, but also for the carrying out of regular maintenance inspections to ensure that breakdowns do not occur. Prevention is not only better than cure but it is much, much cheaper. The growth in the use of general purpose crews has brought in its wake an increasing reliance on manufacturers for maintenance work and some now make available a very high quality preventive maintenance scheme. This promises to be of the greatest possible value to ship operators.

This after-sales service must include the availability at short notice of spare parts for systems throughout the life of a ship. This can be a very tall order in a rapidly growing technology. A system which was the latest and best when the ship was built will almost certainly be obsolescent half way through the ship's life if not at a much earlier date. The high cost of money means that carrying of stocks of obsolete pattern spare parts for a period of many years is impossibly expensive. The manufacturers are therefore forced into the position of having to be able to manufacture spare parts in small quantities at a moment's notice. Sometimes this does mean that manufacture must be on a one-off basis where the original supplies were mass produced. This means a relatively high cost for some spares but operators accept this as being a necessary alternative to holding up the operation of the ship.

SYSTEM IMPROVEMENTS

When the manufacturer does improve his technology and produces a second generation of a particular component, consideration must be given to the possible introduction of this improvement on ships at sea. Frequently operators will be glad to take advantage of incorporating such improvements. The cost of so doing will often depend upon the long sighted vision with which the manufacturer has designed his original components and made the modifications. If possible the improved version will be readily interchangeable with the original component and so the improvement can be incorporated relatively easily and cheaply. If alternations to fixings etc are substantial, the cost of incorporating the improvement may be prohibitive.

There is one field in which maximum co-operation between component manufacturer, ship builder and ship operator is vital for the good of all concerned. This is in the feedback of information on troubles and faults, however minor, to the original designer and manufacturer. It is only by knowledge of the reactions of the ship builder during the installation period, and of the operator during the life of the ship, that the manufacturer can "improve the breed". With ships far from base for most of their life this is not a simple matter. For this reason some marine equipment manufacturers employ one or more engineers specially to maintain contact with their equipment at sea in order to feed back information to the works and to give the operator every assistance in using the equipment as efficiently as possible. The authors' company has done this for many years and found it to be a most valuable item of expenditure albeit a substantial one. However it is just part of the recognition of the fact that this type of operation is "system engineering" and not mass production component manufacture. The paper is ended on that thought because there is no more basic or important concept than this which can be so stressed.

REFERENCE

1) Joseph, R. A., and Rogers, J. A. 1974. "Hydraulic Operation and Position Indication of Cargo and Ballast Valves on Liquid Cargo Ships." *Trans.I.Mar.E. Vol 86 Part 8.*

Discussion

Mr. A. N. S. Burnett, F.I.Mar.E., commended the system approach put forward by the authors. So often in the marine field manufacturers, and sometimes users, did not "fully" understand that one item depended on another, and that when one started to amend one part of a control system or a pump system one was automatically involved in modifying more than just one part of the system.

The first sentence in the paper stated that liquid cargo ships (tankers) carried cargo from port to port, and although this was true of perhaps 98 per cent of these ships, some large liquid cargo ships either transferred cargo (oil) at sea or received from single point moorings (SPM), etc. He asked the authors to comment on the control problems faced in these activities when a SPM could be 100 miles away from land or when the transfer took place in rough weather.

The paper dealt with the various types of actuators and controls to suit different types of systems. He thought that crew training had a part to play here. One always had to look at the whole system, which included the person as well as the equipment itself. At present, it was often very difficult to obtain sufficient or adequately trained crew, and it was very important to realize that these controls and their operation had to be very easy to understand, operate and maintain.

He was very interested in the problem of using electricity on board a crude oil carrier. As the paper stated, the idea was prevalent that it was dangerous and impossible to think about the use of electricity outside the machinery compartment aboard a crude oil carrier. The authors had asked why electrical circuits should not be used, if the energy of the circuit was safe. The answer was, of course, that it could be used, but one would have to break down a bit of prejudice and modify some of the classification rules first. This might take a year or two to achieve, and then in addition one would have the four or five year cycle of design and building ships before the revised rules could be incorporated.

He then referred to the temperature in the control circuitry (Fig. 4). There appeared to be a number of varying temperature limitations which were referred to from time to time, and he would like to see some more definite rules and practice followed. He asked why had the authors stated a temperature range of −20°C to +60°C?

He said that where one had a mimic diagram describing a flow system it often paid to put some of the actual component lights in the diagram. This had many other applications.

With regard to the question of corrosion of the pipes on deck, there were varying views as to whether one should go for the highly sophisticated materials or the cheaper materials and hope that they would not get abrased and misused in service. His experience was that the pipes which were installed over the deck did get damaged in service, and therefore one had to use the better materials, but perhaps there were new developments in this area on which the authors could comment on in view of the fact that the shipowner was always looking for reduced costs.

With regard to commissioning the system, it could not be stressed too often that planning on the shipbuilding side should be done very conscientiously. The problem was really one of re-education, because those involved were conservative people, not liking change.

He thought that ease of the servicing at sea was also a very important item when considering design. He asked if the authors' company supplied system handbooks. It was always useful to have such system handbooks and manuals printed in different languages as was necessary, for the crews of differing nationalities.

He said that he had come across, over the last four or five years, a number of deck machinery manufacturers who offered high pressure hydraulic package systems for operating deck winches, cranes, and so on, from power packs sited aft. He asked if the authors saw this as being part of an integrated hydraulics system for the whole ship, where safety and ease of operation could be incorporated into one whole, not necessarily dividing the liquid cargo handling from the deck hydraulic control systems.

MR. G. VICTORY, F.I.Mar.E., said that like Mr. Burnett he was interested in the intrinsically safe method of operating any mechanical device. It was not possible to say that one could have one watt, or any lower power in an intrinsically safe circuit unless one specified the capacitance or inductance effect of that circuit. The intrinsically safe energy level for certain gases was so low that he would like more information on how even the lightly loaded spool referred to in relation to Fig. 7 was operated. The safe operating conditions could also vary with the particular gases concerned, and for these reasons any B.A.S.E.E.F.A. certification could only be in relation to certain gases. He did not think that electrical powers should be used in hazardous areas unless there was a positive limitation on the energy at a level which could not possibly ignite any gas which might reach it. As an example, he pointed out that it was possible for a man in a pair of nylon underpants to ignite gas escaping from a tank hatch on a tanker by putting his finger near the hatch cover.

He thought that the different methods described in relation to the indication, of actuator positions were very interesting. He agreed that no actuator position indication which operated by measuring the flow of oil to the valve, or by measuring the point at which the pressure rose after an initial drop due to the flow through system, could positively indicate the closed position of the valve. He suggested that even the rheostat type was not entirely reliable on this point because the zero position of a rheostat could change in use. He asked whether the indicating arrangements, particularly with a rheostat on an actuator, could be tied up with a micro switch operated by the valve at the bottom of the closure so that when the indicator in Fig. 13 came round to the closed position another light came on alongside it which would indicate that something else had shown that the valve had positively closed. This was very important when one considered the question of pollution, for all too often pollution had been caused even with double shut-off valves when valves had leaked, even though people had thought that the valves were shut. In this respect, although it was somewhat outside the scope of the paper, he wondered whether the authors had looked at any arrangement for monitoring the space between double shut-off valves so that one would know positively if either of the valves was leaking, because generally a fault in one valve could not be detected until the second became defective.

Referring to Fig. 3, which depicted the ring main system, he said that if one wanted to isolate one end of the ring main presumably one had to open the double shut-off valves across the two sides of the ring main, to ensure that at no time were these leaking and thereby passing into a section which should be shut off. Was this the reason that two valves were shown?

Mr. Joseph, when talking about the different positions where the actuators could be positioned had mentioned manual valves on the tank decks. He thought this probably meant manual actuators for hydraulic valves, because it was to be hoped that the days when crews slogged it out, opening large tank and line valves was finally at an end.

MR. D. C. WILLIAMS, (whose contribution was read out by MR. P. JOHNSON) commented on the section dealing with choice of tube materials. The authors had, he felt, taken a view of cost in their evaluation of alternatives that concentrated the analysis on the purchase price of the tubes rather than the installed cost of the system. Both steel and Tungum were, as far as he was aware, commercially available in short, straight lengths only. Where lengthy pipe runs were envisaged this, of course, meant the use of numerous fittings and the attendant labour costs. Moreover, every fitting in the line was a potential leak point due to possible faulty workmanship on installation.

In comparison, copper-nickel was available in long length coils, and, indeed, there were many instances where continuous unjointed runs could be taken from deck box to actuator. He would not expect there to be any ready rule of thumb for comparing the installed cost of various tube materials, but there was good evidence that the summation of extra fittings cost, labour to install and protective painting of the steel would often show a balance in favour of copper-nickel when evaluating the alternatives. He asked if the authors had carried out any research in this particular area, and if so, what their findings were.

MR. H. WOODS, M.I.Mar.E., referred to fixed and variable delivery hydraulic pumps. His experience had only been with fixed delivery pumps for cargo handling hydraulic systems. The systems had pilot operated unloader valves which dropped the pump discharge pressure to zero, the load on the motor dropping to very little — certainly less than the two-thirds full load shown in Fig. 17. In fact, he estimated the unloading power consumption to be about one-fifth of the full load.

With a system running for 50 hours per week and using the graphs of Fig. 17, it could be easily believed that the difference in cost between fixed and variable pumps could be recouped in one and a half years, but if the unloaded power consumption was along the lines of his experience the time to break even was something like ten years. He did not think that having to wait ten years to break even using a more complex pump, with no doubt a higher maintenance cost, could be justified unless the authors' company could guarantee that the spares/maintenance cost of running the variable pump was no more than the fixed delivery pump's maintenance cost, and was willing to back its guarantee up with free spares and labour.

He felt that the authors might benefit by looking for a lower power consuming unloaded condition of fixed delivery pumps.

Would the authors care to state the type of unloader arrangement used in the example?

From a watchkeeping point of view, fixed delivery pumps with unloaders gave some indication of the health of the system by the frequency of cutting in of the pump. One always knew when these pumps were cut-in owing to the noise made. He said that on one occasion when the accumulator had lost its gas, through maloperation of the system, the pumps had cut in and out rapidly, indicating a fault, and on another occasion a bypass valve had started to leak past causing lengthy cut-in times. A variable delivery pump would not give these indications, at least, not so readily, and instruments would be hard put to it to show that either of these faults had occurred. He would, therefore, prefer to use fixed delivery pumps, and asked the authors to comment on this.

Authors' Replies

Mr. R. A. Joseph said that Mr. Burnett was quite right to say that a person was part of the system. This had been one of the fundamental reasons why his company had started sending out people to talk to those on board who had been doing the job.

Crew training was also very important. His company took it as part of their responsibility to help with crew training—giving frequent lectures at the yards, and lecture courses at the authors' company's own factory, but it was sometimes difficult to get people to attend.

Of course, crews changed ships, and it was up to the owners to help people in the industry to keep in touch with them. Certainly the authors' company was always willing to help to educate the first crew, and they would go back and do more if given the chance.

He agreed that drawings and handbooks were enormously important and apologized for the fact that they had not been mentioned in the paper. His company did supply handbooks and found that an intelligent and interested engineer on board would take a manual and study it and learn a lot from it, but fundamentally it should firstly teach him how to operate the system, and secondly, how to maintain it. One had to give such a person easily accessible and understandable instructions on preventative maintenance and repairs which were within his capability. Producing such manuals was an art and was not a job for a project engineer. It was a job for a professional technical author.

His company did get asked for translations of these manuals and handbooks, and they called on their agents in the countries concerned to help with this.

With regard to Mr. Burnett's point about prejudice against electricity on crude oil carriers. If this prejudice were based on ignorance and refusal to accept modern technology, then Mr. Joseph had no use for it, but if it was based on long years of intelligent experience, one must respect it, and one must only expect it to disappear when one produced an understanding of a sound technology that justified removal of that prejudice. If the industry wanted to introduce electricity on board ship they must satisfy those concerned that it was the right thing to do. The sort of energy levels they were talking about was a maximum of one watt, which was a very small energy level.

Mr. Joseph agreed with Mr. Victory in that an approval of an intrinsically safe system must include approval of the circuit as a whole. Then he assured Mr. Victory that if he shuffled about in his nylon underpants he could produce a lot more than one watt and he would be far more dangerous than an intrinsically safe system. Intrinsically safe electricity must rely on two things. The first one was the fundamental limitation in the electrical energy which could be available. He referred to Fig. 7, and stated that the bulkhead, which in this figure was represented as a shaded barrier, separated the hazardous area from the non-hazardous area. To the right of the bulkhead there was the a.c. input into the two separate intrinsically safe electrical power units. These were units in which there was a transformer. If a short circuit occurred on the output side of that transformer the voltage fell away and the multiple of voltage and current, was limited to a figure no greater than a constant; that constant was the maximum safe energy level, so that the transformer was incapable of giving out, under any circumstances, more than this acceptable energy level. The acceptable energy level depended upon the particular gases with which one was dealing, but it was now officially laid down and categorized. Secondly, one built into the circuit a zenor diode barrier which would not pass more than that level of energy — if for any reason it faced it on the input side. So one had "braces and belt" and one just could not get excess energy on the hazardous side. He had been concerned with the mining industry and he could state categorically that he did not know of one documented case of more than a safe level of energy arising on the output side of an intrinsically safe system. In the mining industry, of course, there had always been certain gases which could not safely accept a useful energy level. The only acceptable electrical system was one which was contained within a pressurized conduit system. The system was such that the conduit and all components were pressurized with an inert gas at about 34·5 mb (0·5 lbf/in^2) above atmosphere which excluded the explosive gas from the system. There was a pressure switch connected to the system and the moment the pressure fell, the whole system was automatically made dead. It was the only system which was safe with certain types of gas.

Mr. Victory had asked if the spool valves could be operated with these very low energies. This was not possible with appreciable hydraulic flows. The method used was to operate a small hydraulic pilot valve by the intrinsically safe system, and the output of that pilot operated the main spool. It was a piggy-back arrangement.

With regard to commissioning, he wished shipbuilders would learn that there was a lot of work which the manufacturer's commissioning engineer could do before the ship was finished, and before the installation was complete, if only they would permit proper consultation at an early stage.

Mr. J. A. Rogers, referring to Mr. Burnett's point about single point moorings, said that the time spent loading and discharging must be kept to a minimum.

With regard to the $-20°C$ to $+60°C$ figures for temperature in control circuits, this was the sort of range his company had come across in their experience. With the Alaskan fields coming along they had felt that if they could possibly design a system to cover the complete range, which was very difficult, they might have a winner, so they had tried to match the -20. He admitted that in the majority of cases it was more likely to be -10. To get that extra 10° down at that end was rather difficult. The only way it could be done was by having a change of oil in the system or having pipes lagged, because when one got down to that temperature oils got rather thick and systems became sluggish.

His company, as suppliers, were fully aware of corrosion problems on board. Not only on deck but also in the tanks, components could be attacked by the sulphur in the crudes. His company had developed a piston rod coating which would withstand any corrosion that it was likely to come across in the normal crude or product carrier.

He said that it was possible to integrate the cargo handling system with the deck machinery, but there were one or two problems involved. Ideally, one could say that if one had a pressure main on board one could tap off for all hydraulic equipment, but deck machinery, depending upon the size of vessel and the amount of machinery on board, could require a hydraulic power pack of anything up to 746 kW (1000 hp). The question of economics came in here, for instance, it could not be considered economical to run a 746 kW (1000 hp) power pack, even though it may be built up using 4 x 186 kW (250 hp) units and have only one of these units in use, to operate a 7 kW(10 hp) stores winch or luffing crane.

In multi power pack systems of this size it was recommended that one of the hydraulic pumps be of the variable volume fitted with a constant pressure device so that the power absorbed in operating equipment up to the maximum capability of the single unit was always kept at a minimum.

With regard to Mr. Victory's point about intrinsically safe systems, he suggested that he asked B.A.S.E.E.F.A. for Code SFA 3012. He agreed with Mr. Victory that the most positive point for indication in regard to actuator position must be the valve blade or paddle. Again economics came into it. It meant that the valve position sensing device would need to be of cargo valve manufacturer's supply. He felt that the best position for indication was either directly off the cargo valve shaft or, if that was not possible, directly off the actuator coupling to the cargo valve. There must be a mechanical link between the cargo valve blade that was being operated and the actual position indication device.

Mr. Victory's question about the need to monitor conditions of liquid in between isolating valves: normally all the valves would be open except for the recirculating valve on the right hand side of the diagram, which connected the pressure and exhaust mains. That was always closed, except when one was flushing initially. All the other valves were normally open. This was because if there was sea damage then any single length of piping could be isolated.

Mr. Rogers referred to Mr. Johnson's point about selection of materials, and said that system pressures came into this. Pressures were being pushed up almost yearly, and once one got above around 103·4 bar (1500 lbf/in^2) with cupro-nickel for pressure mains for the larger bore pipes one could run a little close to the mark with regard to the Lloyds' Register of Shipping's regulations for pipe dimensions. So there one stepped over to Tungum, which could withstand much higher pressures.

With regard to Mr. Wood's point about fixed *versus* variable delivery pumps, he said that perhaps he had not used the right unloader valves. The slide was purely diagrammatic, but the actual figures they had used to calculate the one and a half years had been actual readings taken on tape on board.

He thought that Mr. Woods would probably agree that the variable delivery unit would come into its own with much higher flows.

Mr. Joseph then referred to Mr. Burnett's point about transfers at sea. He agreed that one might be transferring under much more difficult conditions than when one was loading or discharging alongside. This seemed to him to point to two things. One was a greater need for remote control, and the other was an even greater need for reliability and flexibility. He thought the industry was succeeding in this area.

With regard to Mr. Victory's point about actuator position indication, he said that in the systems his firm used, the potentiometers were actually used as series resistors. They never came back to zero, and they worked at a minimum of about 500 ohms. This gave one a little bit to play with. There was triple trimming: each end was trimmed, as was the range. This was one of the most important adjustments made during commissioning.

He thought Mr. Victory had raised a very good point when he had asked why one should not use a micro switch, or a pair of micro switches, actually down on the valve or, if one accepted the integrity of the coupling of the valve to the actuator, on the actuator. An absolutely positive open and closed indication could then be obtained, and only use the LED device to give the travel. There was no problem about this, except price. It could be done but it meant extra components and extra cables. It was worth mentioning that a pair of micro switches needed a three core cable, whereas a series resistor only needed a two core cable. It was a question of "paying one's money and taking one's choice."

He said he very much liked Mr. Victory's point about monitoring the space between a pair of shut-off valves. He did not know anybody who had done this but he could not see why it should not be done, and it certainly gave him food for thought.