CATERPILLAR®

Marine Engine Application and Installation Guide

• Control Systems — Pilot House

- o General Information
- o Types of Control Systems
- o Engine Stall and Reversal

General Information

The use of a reliable control system is essential. The controls must be precise, dependable, and easy to operate.

The control system, in its most basic form, is the equipment that allows the pilot to adjust the propulsion engine's throttle (speed) and the marine transmission's clutches from neutral to ahead or astern.

To control throttle setting, a control system must rotate and hold the angular position of the governor control throttle on mechanical engines or send a electronic signal to the ECM on electronically controlled engines.

To effectively control the marine transmission with mechanically actuated hydraulic control valves, a control system must move a short lever on the hydraulic control valve to any of three positions (forward, neutral, reverse) and maintain the selected position without placing undue stress on the linkage or allowing the lever position to creep.

To effectively control the marine transmission with solenoid-actuated hydraulic control valves, an electrical signal energizes one of two solenoids to pressurize either the forward or astern clutch. If neither solenoid is energized, the transmission remains in neutral and neither clutch is pressurized.

Types of Control Systems

Two-Lever Control

Two-lever control systems use two levers for the pilot's control. One lever controls the engine speed, and the other lever controls the marine transmission direction — ahead, neutral, or astern positions.

Two-lever control systems are the most simplified, and most economical, but have the possibility of changing the transmission direction while the engine is at a high throttle setting. Transmission clutch damage is likely if this occurs.

Single-Lever Control

Single-lever control systems provide automatic sequencing of the control functions, preventing the transmission from changing direction until the throttle lever is moved to the neutral position (refer to Figure 1.1).

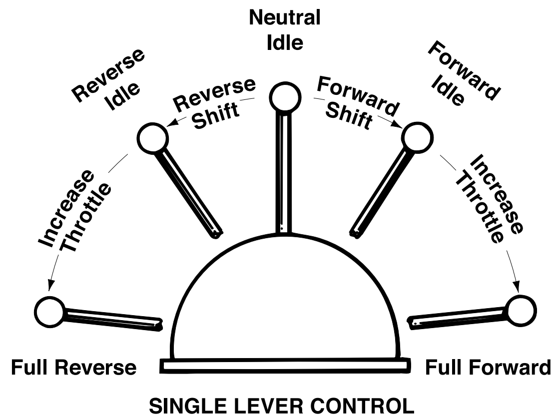


Figure 1.1

Neutral Throttle

Neutral throttle allows independent speed control when the marine transmission is in neutral. This feature is useful when controlling the speed of engine-driven accessories such as generators, pumps or winches.

Multiple Control Stations

All vessels require one control station where the pilot controls engine and transmission. It is convenient to have other control stations when specific activities, such as docking and fishing, demand the pilot's close attention.

The simplest and, in most cases, most efficient multiple (dual) station system consists of two-lever controls installed in a parallel system. Cables are run from the controls at each station directly to the clutch and throttle levers at the engine, and are connected there with the appropriate parallel dual station kits.

A second type of multiple (dual) station system consists of two-lever controls in series. Cables are run from the upper control station to the lower control station. A cable attachment kit is required to connect these cables to the lower station controls. Cables are then run from the lower station controls to the clutch and throttle levers at the engine and connected there with the appropriate engine connection kits. Series installations are less precise than parallel systems and should be used only when a parallel installation would be impractical due to long cable runs and excessive or sharp bends in the cable. The system selected is determined by the cable length and total degrees of cable bend required.

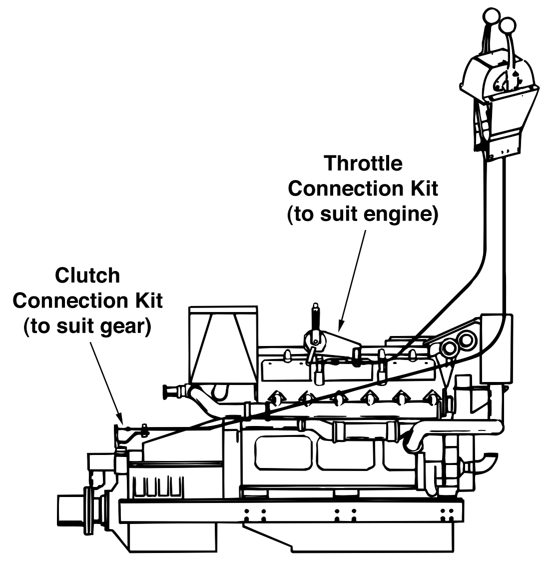


Figure 1.2

Engine/Transmission Mounted Bracket Design

Brackets supporting the control systems cables/actuators at the engine/marine transmission must be rigid. Good alignment of the cable-ends with the engine's throttle lever and transmission's clutch control lever is necessary to avoid binding. Control system manufacturers can provide suitable brackets to the user/installer.

Push-Pull Cable System

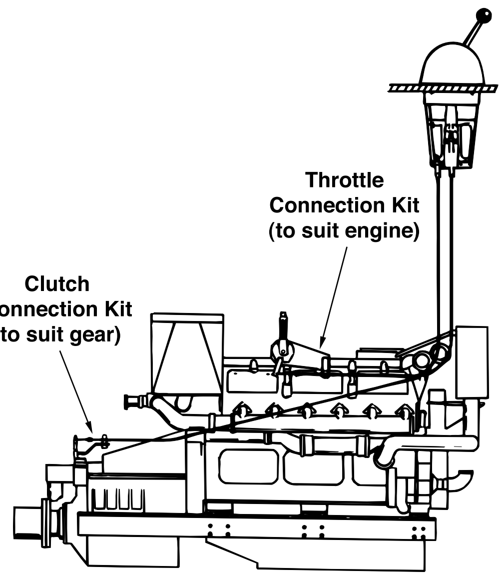
Push-pull cable control systems are reliable and economical. The distance between the control head at the pilot station and the engine is limited by friction in the cables.

For best results, keep cable length under 30 ft.

The number and included angle of bends in the control cables add significantly to their internal friction. Avoid all unnecessary bends. Keep all bends in the cables as gradual as possible (minimum 200 mm [8 in.] bend radius).

Stiffness or binding in the operation of the hand lever can usually be traced to:

- Excessive number of bends in cable runs
- Sharp bend in the cables too close to the control head
- Bends smaller than the recommended minimum radius of 200 mm (8 in.)
- Tight or misaligned engine linkage
- Cable compressed too tightly by cable support
- Engine or transmission clutch lever hitting its limit stops at forward and/or reverse

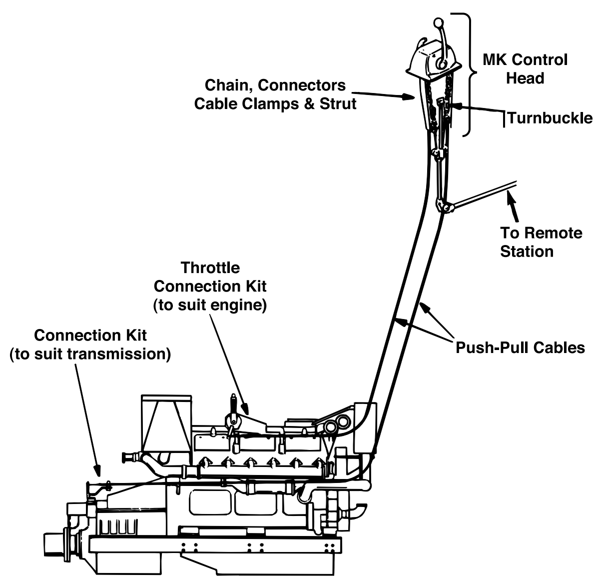


MT CONTROL SYSTEM

Figure 1.3

The installation of push-pull cable control systems is fairly simple.

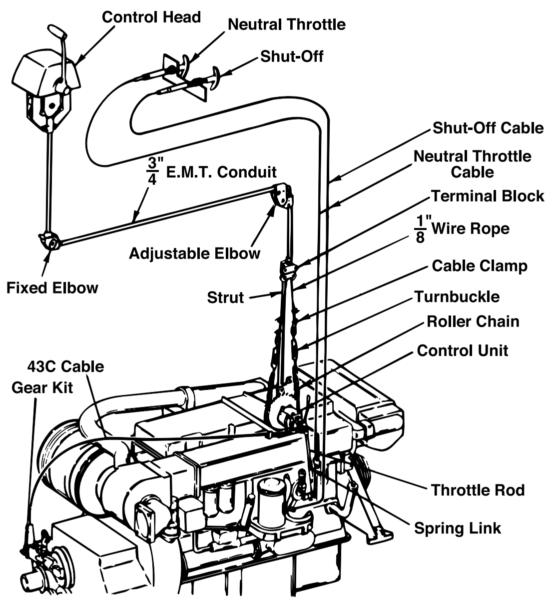
Manufacturers' installation bulletins for both two-lever (Figure 1.2) and single-lever lever (Figures 1.3 and 1.4) systems illustrate the systems.



MK CONTROL SYSTEM

Figure 1.4

Where a cable control system is preferred and long runs and numerous bends may be encountered, a system is used with two cables in tension, running over pulleys mounted on antifriction bearings (refer to Figure 1.5). To reduce the number of cables and to maintain precision in the response of the system, a single-lever type of control system is used. A control gearbox to the governor and reverse gear is installed on the engine.



MD 24 CONTROL SYSTEM

Figure 1.5

Hydraulic Control System

Hydraulic controls offer smooth, precise control of engine/marine transmission without significant limitation on number of control stations or distance between control stations and the engines. The cost of hydraulic controls and the number of installation man-hours are slightly higher than either of the mechanical cable controls.

Electronic Control System

Electronic control systems should be considered when the following control requirements are encountered.

- Electronically controlled engines
- Limiting the engine power during acceleration
- Engine overload protection
- Integration with controllable pitch propeller control systems
- Sharing of load between multiple engines, driving a single load
- Very long distances between the control station and the engine
- Integration with telemetry systems
- Adding additional control stations after vessel completion

Electronic Control System Components Control Station

The control station is generally simpler than a similarly functioned mechanical or hydraulic version. The forces involved in driving rheostats and switches are much less than those to operate push-pull cables or hydraulic cylinders. Electric control stations are very easy to install.

On mechanically controlled engines, the electric control systems will install an electric-to-mechanical converter box in the engine room/compartment. The electric-to-mechanical converter box accepts electrical signals from the various control stations and converts them to mechanical forces (generally via push-pull cables), suitable to operate the engine throttle and marine transmission control valve. On electronically controlled engines, control systems are capable of using electronic engine governors and electric marine gear control valves that eliminate the need for the electric-to-mechanical converter box.

Engine Throttle and Marine Gear Actuator

See electronic installation guide for electronically controlled engine.

3126B, C7, C9, C12 & C18	REHS1187
3196 & 3406E	SENR1187
3412E, C30 & C32	SENR5014

Caterpillar Multi-Station Electronic Engine Controls

Caterpillar Multi-Station Control System (MSCS) provides engine controls and transmission control for single or dual engine applications with a maximum of eight control stations per vessel. The MSCS can be connected to the following electronically controlled Caterpillar marine engines: C7, C9, C12, C18, C30, C32, 3126B, 3196, 3406E, 3412E, and 3500C. The MSCS system is capable of up to seven stations with long distances between the engine and the control stations. The maximum distance from the Power Train Control Processor is dependent on the voltage used and the number of stations. The MSCS is capable of monitoring and performing operator control functions, identifying and reporting critical vessel control parameters, and reporting failure conditions though self-diagnostics. The system contains a fully redundant backup system that will ensure operation of the propulsion system in the event of catastrophic failure of the primary control system. Refer to installation guide LEGM2735 for details.

Other Manufactures of Electronic Controls

Mathers, ED Electric, Sturdy, Twin Disc and Kobelt are control manufacturers that can provide fully electronic control packages with our electronically controlled engines. They have electronic controls that are programmable for shifting and provide an electronic signal compatible with Caterpillar electronic engines.

Control Logic

Generally, the control logic is either contained in the Power Train Control Processor on the Caterpillar controls system, a similar processor for other control manufactures, or an electric-to-mechanical converter box in the engine room/compartment for mechanically controlled engines. Larger systems may combine the logic circuitry with a propulsion system monitoring system in a cabinet in the engine room.

System Connectors

Electric control systems are generally interconnected by multi-conductor electrical cable. This is much less expensive than mechanical cable or hydraulic tubing.

Pneumatic Control System

Pneumatic controls offer several advantages over other mechanical control systems:

- Ability to control engines at long distances. 90 m (300 ft) is a realistic distance to run air-lines for pneumatic control. The only real limitation is the speed of response in the case of very long lines.
- The ability to control from an unlimited number of control stations.
- The ability to add logic to the system, to protect against abuse of the driveline components.

There are some disadvantages to pneumatic control systems:

- A relatively heavy and expensive compressor with air storage tank is required.
- Tanks and lines require regular maintenance (draining of condensation).

Engine Stall and Reversal

When a marine transmission is shifted from forward to reverse or vice versa, sufficient engine torque must be available at idle speed to overcome propeller and driveline inertia, marine transmission inertia, and slip stream torque*. If sufficient torque is not available or if sufficient engine safeguards are not installed, the engine will stall or reverse itself.

* Slip stream torque is the torque generated in a free-wheeling propeller, being turned by the water flowing past the hull. Slip stream torque can be as high as 75% of the engine's rated torque.

In vessels where rotating masses are moderate to small, clutch modulation and engine torque can control the reversing cycle. Heat buildup caused by the clutch slipping is normally well within the clutch capacity. Heat generated through increased modulation necessary to control large inertia forces can damage clutches. To prevent this buildup of heat, auxiliary devices may be necessary.

Also, under crash reversal conditions, it is conceivable that unless some device is used to counteract the inertia of large masses, the engine could stall or actually be motorized to run in reverse rotation.

Avoiding engine stalling and/or reversal with mechanical controls is difficult. One method is by careful clutch engagement and by allowing the boat to slow down before the shift is made. The adept operator can repeatedly engage and disengage the reversing clutch, until the vessel's speed is checked sufficiently, and then complete the maneuver. Where large, heavy vessels or those attached to a tow are concerned, this method may cause overheating of the reverse clutch. When this danger exists, other means must be employed.

Engine stalling and reversal problems can be avoided if close attention is paid to the engine and transmission control system. Pneumatic and electronic controls that provide sequencing and timing of speed and directional signals offer optimum maneuvering as well as protection for the engine and transmission.

When Engine Stall and Reversal Could Be a Problem

The likelihood of this being a problem is significantly increased for vessels equipped with:

- Propulsion engines producing over 500 hp
- Fixed pitch propellers
- Deep ratio reduction gears, usually 4:1 and deeper

What the Operator Can Do

Loss of acceptable engine speed can be prevented by prudent use of the controls by the operator during maneuvering.

Engine Speed Limits During Emergency Maneuvers

It is imperative that engine speed does not drop below 300 rpm for slow speed engines (rated at nominally 1200 rpm) or 400 rpm for high speed engines (rated at nominally 1800 to 2300 rpm) to assure adequate engine lubrication and to prevent the possibility of stalling.

Need for Sequencing Control Systems

Sequencing and timing of the controls when using electronic or air control systems is necessary to:

- Reduce vessel maneuvering time
- Prevent excessively low engine speed
- Prevent excessive loading of driveline components
- Reduce the possibility of engine stalling

The possibility of engine speed reduction to the point of stalling due to sudden vessel maneuvering demands will be dependent upon the speed of the vessel when the maneuver is undertaken. During low vessel speed maneuvers, the engine torque capabilities are usually sufficient to respond adequately. However, if a sudden maneuver, such as a crash stop of the vessel, is demanded at full vessel speed, auxiliary driveline devices may be required to prevent stalling and loss of vessel control.

Sequencing Control System Features

To forestall the possibility of engine stall during high-speed maneuvers in emergency situations, one or more of the following may be required:

- Raised low idle speed setting
- Throttle boost control
- Shaft brake
- Control system timing

Electronically controlled engines and 3500 Family engines equipped with 3161 governors will shut off their fuel if subjected to engine reversal.

Raised Low Idle Fuel System Setting
To increase the engine's low speed torque, the low idle speed setting may be increased if the vessel's low speed maneuvering is not jeopardized. This will help prevent the engine from stalling or reversing during maneuver. Raising of the low idle speed setting should be done by an authorized Caterpillar dealer. Excessive shock loading and transmission clutch wear can occur if the engine low idle speed is too high.

Throttle Boost
Controlled throttle boost momentarily raises the idle speed setting of the engine. The engine speed increase comes just before engagement of the marine gear clutch. This momentary speed increase occurs only during maneuvering, not at steady boat speed conditions.

Throttle boost is kept as low as possible because it tends to increase the load on the clutches during maneuvering. The control system should permit adjustment of both the amount and duration of throttle boost. The throttle boost for most marine transmissions should be set no higher than 750 rpm for 1800 rpm engines and 600 rpm for 1200 rpm engines at no load. Sea trials should determine the level of throttle boost necessary to ensure a safe shaft reversal and maintain engine speed above the minimum limits. Consult the marine transmission manufacturer for boosted-shift clutch capability.

Although reversing problems seldom occur with marine transmission ratios more shallow than those previously mentioned, it is recommended that a throttle boost system be incorporated with more shallow ratioed transmissions as an additional safety feature.

Shaft Brake
In vessel applications where heavy maneuvering is required or if full speed reversals may be encountered, the use of a propeller shaft brake is recommended. A properly controlled shaft brake will stop the rotation of the propeller whenever the transmission clutches are disengaged and the engine is at low idle speed. This action reduces the amount of torque required from the engine in order to complete a shaft directional change. Several advantages are gained with the use of shaft brakes.

1. A propeller shaft brake can safely reduce vessel maneuvering time. A vessel will slow in half the time with a stopped propeller as compared to a windmilling propeller. The propeller slip-stream torque, therefore, falls to a level lower than the slow speed torque of the engine in half the time.
2. The propeller shaft brake accepts half the speed reversal loads when maneuvering. The brake brings the propeller to a stop. This load is transmitted directly to the hull. The clutch and propulsion system are only asked to pick up a stopped propeller shaft rather than a windmilling propeller. Because load on the engaging clutch is greatly reduced, clutch life is extended. Transmission gears, engine, and other major components of the propulsion system are subject to less shock.
3. The propeller shaft brake will prevent engine stall when attempting crash stops or when high vessel speed shaft reversals are attempted during maneuvers.

A propeller shaft brake should be considered on any marine propulsion system using engines over 500 hp where the reduction ratio is 4:1 or deeper and where high speed maneuvering is a requirement.

Disc brakes and drum-type brakes are available. The brake should be sized to handle at least 75% of the full rated shaft torque and should stop the shaft within three seconds during a crash reversal. Brake size requirements will vary with type of propeller, vessel speed, and vessel application.

Proper control and sequencing of a propeller shaft brake is very important. Overlap can occur if the clutch engages before the brake is released. This would show as an extra load on the engine, slowing it and even stalling the engine. Under-lap is releasing the brake well ahead of the clutch making contact. The propeller will quickly begin to windmill in the wrong direction and much of the advantage of the brake is lost.

Event Sequence Timing
Sequencing and timing of engine governor, marine transmission clutch, and shaft brake action are critical and only systems of the following characteristics should be used:

- Pilot house control movement
- Full ahead to astern and full astern to full ahead

Event Sequence

1. Governor to low idle
2. Clutch to neutral
3. Shaft brake applied propeller shaft stops
4. Shaft brake released

5a. Throttle boost applied

5b. Clutch engaged*

6. Throttle boost off, governor to full open

* Timing sequence from brake release to clutch engagement should result in from one quarter to one revolution of the propeller shaft in the wrong direction to ensure there is no overlap between brake release and clutch engagement.

With the above sequencing and timing, the shaft brake will engage any time the pilot-house control lever is in the neutral position. Throttle boost will activate each time the pilot house control lever is shifted from neutral to a clutch-engaged position.

A proportional pause-type control system will allow for a variable time between Steps 3 and 4 in the event sequence when the shaft brake is applied. The pause is in proportion to the last-called-for speed. A crash reversal from full speed will leave the brake applied for a longer period than when slow speed maneuvering. This full speed reversal pause in neutral is made just long enough for the vessel speed to slow to a point that the propeller slip stream torque will not stall the engine when the reverse clutch is engaged.

Properly adjusted electronic or air controls should provide event sequence time in the area of 5 to 7 seconds for slow speed maneuvering and in the area of 7 to 12 seconds or more for full speed crash reversals. The timing is set as fast as the propulsion system can safely be operated. The timing should be set permanently at the time of sea trials.

Without a propeller shaft brake, a longer pause in neutral in place of Steps 3 and 4 in the event sequence will normally be required to allow reduced vessel speed.

The control system must be carefully maintained. Follow the manufacturer’s maintenance recommendations explicitly.

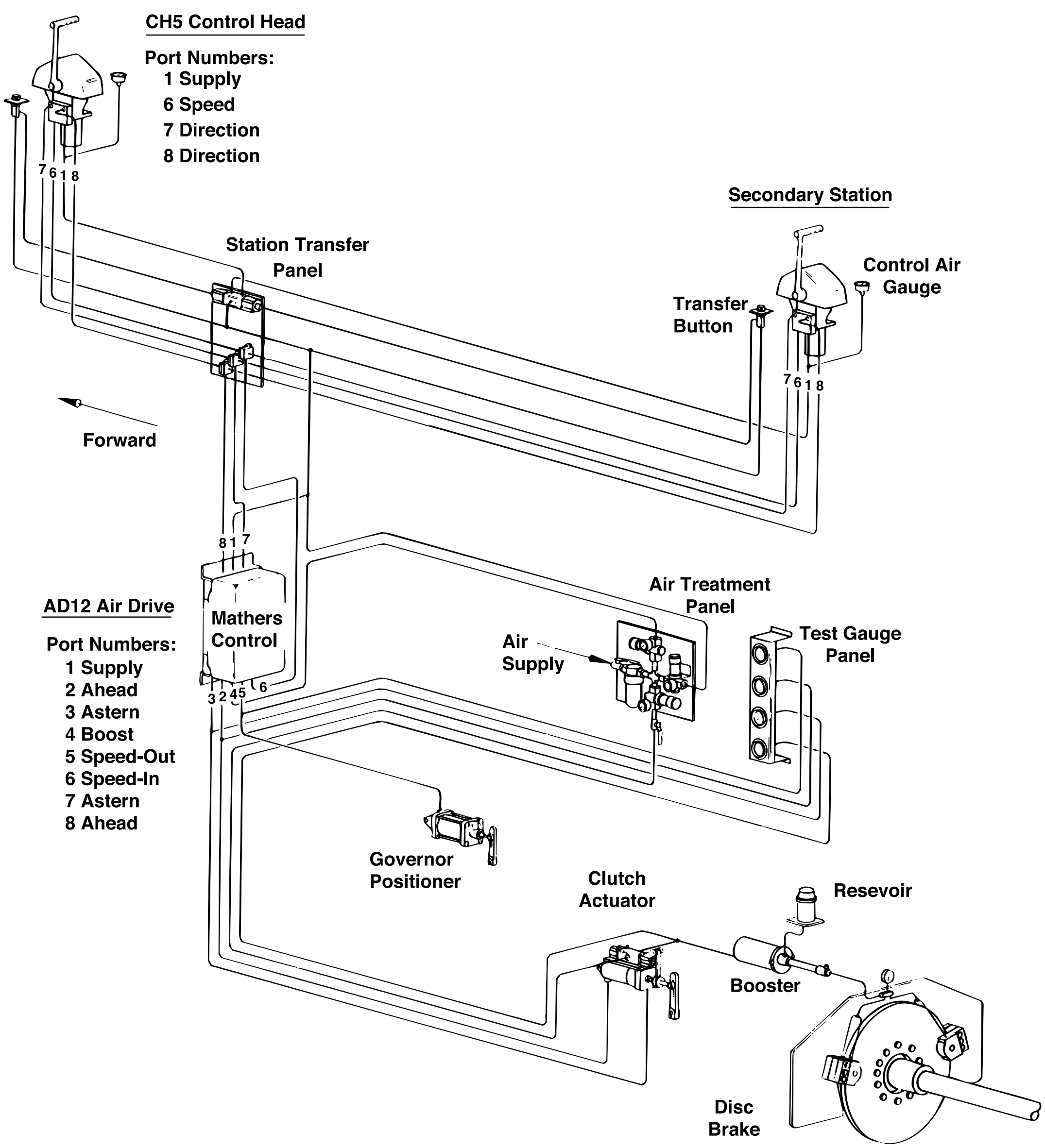
Recommended Systems

Consult with the manufacturers of control systems to determine their availability to provide event sequence systems as described previously.

The shipyard should furnish a low air pressure alarm located at the supply air to the pneumatic control system. The alarm should be audible and visual and should be actuated if the air pressure should fall below a predetermined level, generally 90 psi (620.5 kPa).

Mathers

The Mathers control system offers single-lever pneumatic control of speed, clutch, and brake (if required). The system uses fixed orifice timing with option for as many control stations as required. They also offer electronic controls with the same sequence timing adjustments.



Mathers Controls Inc.
AD12 Propulsion Control System
For
Hydraulic Clutches

Figure 1.6

WABCO
WABCO, a division of American Standard, also provides complete sequencing control systems.

Controllable Pitch Propeller to Avoid Engine Stall and Reversal

The controllable pitch propeller allows smooth, well-controlled vessel reversals while the engine rpm and horsepower are kept at optimum levels. This is most desirable on vessels equipped with deep ratio marine transmissions that must be reversed while moving at full vessel speed. To reverse a vessel equipped with a controllable pitch propeller, reduce propeller pitch to the “neutral pitch” position, then increase pitch in the “astern” or reverse direction slowly enough to allow the engine to maintain its full load rpm and horsepower.

Determined Likelihood of Stalling During Sea Trial

Initial sea trials should determine the likelihood of the control system/engine combination stalling during a crash reversal maneuver. Adjustment and timing of air controls can be determined and properly set during sea trials. Suggested procedure is to start with a low forward vessel speed and make crash shifts into reverse at small increments of increased forward vessel speed until it is determined that the system will allow a crash reversal at the most severe condition the vessel will encounter.