

Recommended Practice for Design of Control Systems for Drilling Well Control Equipment

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TABLE OF CONTENTS

Paragraph	Title	Page No.
	Policy	4
	Foreword	5
16E.1	General Description of Control Systems	6
16E.1.1	Surface Mounted BOP Stacks	6
16E.1.2	Subsea BOP Stacks	6
16E.1.3	Electro-Hydraulic/Multiplex Control Systems	6
16E.1.4	Diverter Control Systems	6
16E.1.5	Back-Up Acoustic Control Systems	6
16E.1.6	Auxiliary Equipment Control Systems	6
16E.2	Control Systems for Surface Mounted BOP Stacks	7
16E.2.1	Response Time	7
16E.2.2	Storage Equipment	7
16E.2.3	Pump Requirements	7
16E.2.4	Accumulator Bottles and Manifolds	8
16E.2.5	Hydraulic Control Manifolds	9
16E.2.6	Remote Control Panels	9
16E.2.7	Requirements for BOP Control System Valves, Fittings, Lines and Manifold	10
16E.2.8	Electric Power Supplies	10
16E.3	Hydraulic Control Systems for Subsea BOP Stacks ...	11
16E.3.1	Response Time	11
16E.3.2	Mixing and Storage Equipment	11
16E.3.3	Pump Systems	12
16E.3.4	Accumulator Bottles and Manifolds	12
16E.3.5	Control Manifold	13
16E.3.6	Remote Control and Monitoring Panels	15
16E.3.7	Subsea Umbilical Control Hoses and Conduit	16
16E.3.8	Electric Power Supply and Distribution	17
16E.3.9	Hose Reels	18
16E.3.10	Subsea Control Pods	18
16E.4	Electro-Hydraulic and Multiplex Control Systems for Subsea BOP Stacks	20
16E.4.1	Response Time	20
16E.4.2	Mixing and Storage Equipment	20
16E.4.3	Pump Requirements	20
16E.4.4	Accumulator Bottles and Manifolds	20
16E.4.5	Electrical Control Unit	20
16E.4.6	Control Panels	20
16E.4.7	Control Hoses	20
16E.4.8	Control Fluids	20
16E.4.9	Electrical Power Supplies	20
16E.4.10	Subsea Umbilical Cables and Connectors	20
16E.4.11	Cable Reels	21
16E.4.12	Subsea Umbilical Hoses and Rigid Conduit	21
16E.4.13	Hose Reels	21
16E.4.14	Control Pods and Subsea Electrical Equipment	21

16E.5	Diverter Control Systems	23
16E.5.1	Response Time	23
16E.5.2	Storage Equipment (Self-Contained Units)	23
16E.5.3	Pump Requirements (Self-Contained Units)	23
16E.5.4	Accumulator Volumetric Capacity	23
16E.5.5	Diverter Control Manifold	23
16E.5.6	Control Panels	24
16E.5.7	Control Hoses	24
16E.5.8	Control Fluids	24
16E.5.9	Electrical Power Supplies	24
16E.6	Emergency Backup Control Systems	25
16E.6.1	Acoustic Control Systems	25
16E.6.2	ROV (Remotely Operated Vehicle) Operated Control Systems	26
16E.6.3	Emergency LMRP Recovery System	26
16E.6.4	Backup Nitrogen Power Supply	26
16E.7	Auxiliary Equipment Control System Features and Interfaces	27
16E.7.1	30" Latch and/or Subsea Diverter Controls	27
16E.7.2	Riser Fill/Dump Valve Controls	27
16E.7.3	Control for Upper Riser Accessories	27
16E.8	Periodic Inspection and Maintenance	27
16E.G.	Glossary	28
16E.H.	Schematic Symbols	31

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FOREWORD

Purpose:

This recommended practice was formulated to serve as a guide for the design and installation of control systems for well control equipment.

a. These recommended practices were prepared by the Subcommittee on Control Systems for Drilling Well Control Equipment. They represent a composite of practices employed by various operating, drilling, and equipment manufacturing companies. In some instances, reconciled composites of these practices are included in this publication. This publication is under jurisdiction of the American Petroleum Institute Production Department's Committee on Standardization of Drilling Well Control Systems.

b. The goal of these voluntary recommended practices is to assist the oil and gas industry in promoting personnel safety, public safety, integrity of the drilling rig and associated equipment, and preservation of the environment for land and marine drilling operations. These recommended practices are published to facilitate the broad availability of proven, sound engineering and operating practices. Recommendations presented herein are based on extensive and wide ranging industry experience. Practices set forth herein are considered acceptable for accomplishing the job as described, however, equivalent alternative installations and practices may be utilized to accomplish the same objectives. The formulation and publication of API recommended practices is not intended to, in any way, inhibit anyone from using other practices.

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practices are not intended to obviate the need for qualified engineering and operations analyses and sound judgments as to when and where these recommended practices should be utilized to fit a specific drilling application.

e. This publication includes use of the verbs "shall" and "should" whichever is deemed most applicable for the specific situation. For the purposes of this publication, the following definitions are applicable:

Shall. Indicates that the "recommended practice(s)" is a minimum requirement that has universal applicability to that specific activity.

Should. Denotes a "recommended practice(s)" (1) where an alternative practice(s) that is equally as safe and/or effective is available; (2) that may be impractical under certain circumstances; or (3) that may be unnecessary under certain circumstances or applications.

Changes in the uses of these verbs *are not* to be effected without risk of changing the intent of recommendations set forth herein.

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SECTION 16E.1

GENERAL DESCRIPTION OF CONTROL SYSTEMS

16E.1 This recommended practice establishes design standards for systems, subsystems and components used to control BOP's (blowout preventers) and associated choke and kill valves that control well pressure during drilling operations. Although diverters are not considered well control devices, their controls are often incorporated as part of the BOP control system. Control systems for drilling well control equipment typically use stored energy in the form of pressurized hydraulic fluid (power fluid) to operate (open and close) the BOP stack components. Each operation of a BOP or other well control component is referred to as a control function. The control system equipment and circuitry varies generally in accordance with the application and environment. Thus, six control system categories are addressed.

These include:

16E.1.1 Control systems for surface mounted BOP stacks: These systems are typically simple closed hydraulic control systems consisting of a reservoir for storing hydraulic fluid, pump equipment for pressurizing the hydraulic fluid, accumulator banks for storing power fluid, manifolding, piping and control valves for transmission of control fluid to the BOP stack functions.

16E.1.2 Hydraulic control systems for subsea BOP stacks: In addition to the equipment required for surface mounted BOP stacks, subsea control systems use umbilical hose bundles for transmission of hydraulic pilot signals subsea. Also used are dual subsea control pods mounted on the LMRP (lower marine riser package), housing pilot operated control valves for directing power fluid to the BOP stack functions. Spent water-based hydraulic fluid is usually vented subsea. Hose reels are used for storage and deployment of the umbilical hose bundles. The use of dual subsea pods and umbilicals afford backup security.

16E.1.3 Electro-hydraulic/multiplex control systems for subsea BOP stacks: For deepwater operations, transmission subsea of electric (rather than hydraulic) signals permits short response times. Electro-hydraulic systems employ multi conductor cables, having an individual wire dedicated to each function to operate subsea solenoid valves which send hydraulic pilot signals to the valves that operate the BOP stack functions. Multiplex control systems employ serialized electronically coded messages transmitted over shared conductors. Electronic data processing and transmission are used to provide the security of codifying and confirming functional command signals so that a stray signal, cross talk or a short circuit should not execute a function.

16E.1.4 Diverter control systems: Direct hydraulic controls are commonly used for operation of the surface mounted diverter unit and any associated valves.

16E.1.5 Emergency Backup BOP Control Systems: When the subsea control system is inaccessible or nonfunctional, an independent control system may be used to operate critical well control and/or disconnect functions. These systems have their own supply of power fluid. They include acoustic control systems, ROV (Remotely Operated Vehicle) operated control systems and LMRP recovery systems. For surface control systems, a reserve supply of pressurized nitrogen gas can serve as a backup means to operate functions in the event that the pump system power supply is lost.

16E.1.6 Auxiliary equipment control systems and interfaces: For floating drilling operations, various auxiliary functions such as the telescopic joint packer, 30" latch, etc., require operation by the control system.

SECTION 16E.2

CONTROL SYSTEM FOR SURFACE MOUNTED BOP STACKS

GENERAL

16E.2 BOP control systems for surface installations (land rigs, offshore jackups and platforms) normally supply hydraulic power fluid in a closed loop circuit as the actuating medium. The elements of the BOP control system normally include:

- Storage (reservoir) equipment for supplying ample control fluid to the pumping system.
- Pumping systems for pressurizing the control fluid.
- Accumulator bottles for storing pressurized control fluid.
- Hydraulic control manifold for regulating the control fluid pressure and directing the power fluid flow to operate the system functions (BOP's and choke and kill valves).
- Remote control panels for operating the hydraulic control manifold from remote locations.
- Hydraulic control fluid.

RESPONSE TIME

16E.2.1 Response time between activation and complete operation of a function is based on BOP or valve closure and seal off. For surface installations, the BOP control system should be capable of closing each ram BOP within 30 seconds. Closing time should not exceed 30 seconds for annular preventers smaller than 18 $\frac{3}{4}$ inches nominal bore and 45 seconds for annular preventers of 18 $\frac{3}{4}$ inches and larger. Response time for choke and kill valves (either open or close) should not exceed the minimum observed ram close response time. Measurement of closing response time begins at pushing the button or turning the control valve handle to operate the function and ends when the BOP or valve is closed effecting a seal. A BOP may be considered closed when the regulated operating pressure has recovered to its nominal setting. If confirmation of seal off is required, pressure testing below the BOP or across the valve is necessary.

HYDRAULIC FLUID AND STORAGE EQUIPMENT

16E.2.2 A suitable control fluid should be selected for the system operating medium based on the control system operating requirements, environmental requirements and user preference.

16E.2.2.1 Water-based hydraulic fluids are usually a mixture of portable water and a water soluble lubricant additive. When ambient temperatures at or below freezing are expected, sufficient volume of ethylene glycol or other additive acceptable to the control system manufacturer should be mixed with the water-based hydraulic fluid to prevent freezing.

The hydraulic fluid reservoir should have a capacity equal to at least twice the usable hydraulic fluid capacity of the accumulator system. (See Section

16E.2.4.3 for sizing capacity of accumulators). Air breather outlets should be installed of sufficient size to avoid pressurization of the tank during hydraulic fluid transfers or nitrogen transfers if a nitrogen backup system is installed (see Section 16E.6.4).

PUMP REQUIREMENTS

16E.2.3 A pump system consists of one or more pumps driven by a dedicated power source. Two (primary and secondary) or more pump systems should be employed having independent power sources. Each pump system should have sufficient quantity and sizes of pumps to satisfactorily perform the following: With the accumulators isolated from service, the pump system should be capable of closing each annular BOP (excluding the diverter) on the minimum size drill pipe being used, open the hydraulically operated choke valve(s) and provide the operating pressure level recommended by the annular BOP manufacturer to effect a seal on the annular space within 2 minutes.

The combined output of all pumps should be capable of charging the entire accumulator system from pre-charge pressure to the maximum rated control system working pressure within 15 minutes.

The same pump system(s) may be used to produce power fluid for control of both the BOP stack and the diverter system. Pump requirements relative to the diverter system are given in Section 16E.5.3 and 16E.5.3.1.

16E.2.3.1 Each pump system should provide a discharge pressure at least equivalent to the system working pressure. Air driven pump systems should require no more than 75 psig air supply pressure.

16E.2.3.2 Each pump system should be protected from over-pressurization by a minimum of 2 devices designed to limit the pump discharge pressure.

One device should limit the pump discharge pressure so that it will not exceed the design working pressure of the BOP control system (see Section 16E.2.3.3).

The second device, normally a relief valve, should be sized to relieve at a flow rate of at least equal to the design flow rate of the pump systems and should be set to relieve at not more than ten percent over the design working pressure.

Devices used to prevent pump system over-pressurization should be installed directly in the control system supply line to the accumulators and should not have isolation valves or any other means that could defeat their intended purpose.

16E.2.3.3 Electrical and/or air (pneumatic) supply for powering pumps should be available at all times such that the pumps will automatically start when the system pressure has decreased to approximately ninety percent of the system working pressure and automatically stop within plus zero or minus 100 psi of the system design working pressure.

ACCUMULATOR BOTTLES AND MANIFOLDS

16E.2.4 Accumulators are pressure vessels designed to store power fluid. Accumulators should be compatible with control fluids, should meet ASME Section VIII Division 1 design requirements and should be documented with ASME UA-1 certificates.

ACCUMULATOR TYPES AND INTERCONNECT OF ACCUMULATOR BANKS:

16E.2.4.1 Accumulator designs include bladder, piston and float types. Selection of type may be based on user preference and manufacturer's recommendations considering the intended operating environment.

The accumulator system should be designed so that the loss of an individual accumulator and/or bank should not result in more than approximately twenty-five percent loss of the total accumulator system capacity.

Supply pressure isolation valves and bleed down valves should be provided on each accumulator bank to facilitate checking the precharge pressure or draining the accumulators back to the control fluid reservoir.

PRECHARGING ACCUMULATORS:

16E.2.4.2 The precharge pressure in the system accumulators serves to propel the hydraulic fluid stored in the accumulators for operation of the system functions. The amount of precharge pressure is a variable depending on specific operating requirements of the equipment to be operated and the operating environment.

The accumulator precharge pressure can be checked after bleeding off the control fluid. In the field, the precharge pressure should be checked and adjusted to within 100 psi of the recommended pressure at installation of the control system and at the start of drilling each well (intervals not to exceed sixty days).

Because of the presence of combustible components in hydraulic fluids, accumulators should be precharged only with nitrogen. Compressed air or oxygen should never be used to precharge accumulators since combining them with the oil could result in combustion.

16E.2.4.2.1 The recommended precharge pressures for the BOP components and conditions specified should be stated on a tag permanently

attached to the accumulator banks. Precharge pressure should not exceed working pressure of the accumulator.

ACCUMULATOR VOLUMETRIC REQUIREMENTS:

16E.2.4.3 The BOP control system should have a minimum stored hydraulic fluid volume (VR), with pumps inoperative, to satisfy the greater of the two following requirements:

1. Close from a full open position at zero wellbore pressure, all of the BOP's in the BOP stack, plus fifty percent reserve.
2. The pressure of the remaining stored accumulator volume after closing all of the BOP's should exceed the minimum calculated (using the BOP closing ratio) operating pressure required to close any ram BOP (excluding the shear rams) at the maximum rated wellbore pressure of the stack.

VOLUMETRIC CAPACITY CALCULATIONS

16E.2.4.4 The equation for volumetric capacity calculation assumes isothermal conditions and $P_1 V_1 = P_2 V_2$ (Boyle's Law) where:

P_1	=	Initial Pressure, (absolute)
V_1	=	Initial Gas Volume
P_2	=	Final Pressure, (absolute)
V_2	=	Final Gas Volume

16E.2.4.5 Determine the accumulator system volumetric capacity as defined in Section 16E.2.4.3.

16E.2.4.3 Item 1 (nitrogen plus hydraulic fluid) by the following formula:

$$V_3 = \frac{VR}{P_n/P_{min} - P_n/P_{max}}$$

Where:

VR	=	Usable Fluid Required
$P_n/P_{min} - P_n/P_{max}$	=	The Fraction of Usable Hydraulic Fluid Between P_{max} and P_{min}
P_{max}	=	Maximum pressure of the accumulator when fully charged, (absolute)
P_{min}	=	> Minimum operating pressure recommended by the manufacturer(s) of the component(s) being operated. Where these functions have different recommended minimum operating pressures, the highest value should apply.
P_n	=	Nitrogen Precharge Pressure (absolute)
VR	=	Usable hydraulic fluid volume required including safety factor.
V_3	=	Total accumulator system volumetric capacity (nitrogen and hydraulic fluid)

16E.2.4.6 Determine the number of accumulator bottles required by dividing the total accumulator volumetric capacity (V_3) by the accumulator gas volume capacity. Round off to the next larger whole number.

NOTE: The accumulator gas volume capacity should be determined by consulting the accumulator manufacturer's gas volume specifications.

16E.2.4.7 The usable hydraulic fluid volume of the accumulator system should be used to determine pump system sizing and reservoir capacity. Usable hydraulic fluid volume is calculated by multiplying the actual number of accumulators determined in 16E.2.4.6 by the accumulator gas volume capacity, then multiplying by the percent of usable hydraulic fluid between P_1 and P_2 determined in 16E.2.4.5.

NOTE: These calculations are for system design only and are not to be used as performance criteria aboard the rig. The calculations shown here are simplified examples for estimating minimum capacity requirements. More rigorous design calculations which account for parameters such as adiabatic gas expansion and specific volume of gas may be used.

HYDRAULIC CONTROL MANIFOLD

16E.2.5 The hydraulic control manifold is the assemblage of hydraulic control valves, regulators and gages from which the system functions are directly operated. It allows manual regulation of the power fluid pressure to within the rating specified by the BOP manufacturer. The hydraulic control manifold provides direct pressure reading of the various supply and regulated pressures.

A suitable valve with porting sized at least equal to the control manifold supply piping size should be provided for supply of control hydraulic fluid from an alternate source. This valve should be plugged when not in use.

HYDRAULIC CONTROL MANIFOLD ANNULAR BOP CIRCUIT

16E.2.5.1 A dedicated control circuit on the hydraulic control manifold should operate the annular BOP(s). The components in this circuit should include a pressure regulator to reduce upstream manifold pressure to the power fluid pressure level that meets the BOP manufacturer's recommendations. The regulator should respond to pressure changes on the downstream side with sensitivity sufficient to maintain the set pressure within plus or minus one hundred and fifty psi.

16E.2.5.1.1 The annular BOP pressure regulator should be remotely controllable. Direct manual valve and regulator operability should permit closing the annular BOP and/or maintaining the set regulated pressure in the event of loss of the remote control capability.

HYDRAULIC MANIFOLD CIRCUIT FOR COMMON PRESSURE FUNCTIONS

16E.2.5.1.2 The hydraulic control manifold includes a common power fluid circuit with pres-

sure regulation and control valves for operation of the ram type BOP's and choke and kill valves. This circuit may be provided with a manifold regulator bypass valve or other means to override the manifold regulator to permit switching from regulated pressure to direct accumulator pressure for operating functions.

HYDRAULIC CONTROL MANIFOLD VALVES

16E.2.5.2 Placing the control valve handle on the right side (while facing the valve) should close the BOP or choke or kill valve, the left position should open the BOP or choke or kill valve. The center position of the control valve is called the "block" position. In the block position, power fluid supply is shut off at the control valve. The other ports on the four-way valve may be either vented or blocked depending on the valve selected for the application. The hydraulic circuit schematics should clearly indicate the block position control valve port assignments for the particular control system.

Valves and gages should be clearly functionally labelled.

Protective covers or other means which do not interfere with remote operation should be installed on the blind/shear ram and other critical function control valves. Lifting of these covers is required to enable local function operation.

REMOTE CONTROL PANELS

GENERAL

16E.2.6 A minimum of one remote control panel should be furnished. This is to ensure that there are at least two locations from which all of the system functions can be operated. The remote panel should be accessible to the driller to operate functions during drilling operations. The driller's remote control panel display should be physically arranged as a graphic representation of the BOP stack. Its capability should include the following:

1. Control all the hydraulic functions which operate the BOP's and choke and kill valves.
2. Display the position of the control valves and indicate when the electric pump is running (offshore units only). (See Paragraph 16E.3.6.4.2).
3. Provide control of the annular BOP regulator pressure setting.
4. Provide control of the manifold regulator bypass valve or provide direct control of the manifold regulator pressure setting.
5. The driller's panel should be equipped with displays for readout of:

Accumulator pressure
Manifold regulated pressure
Annular BOP regulated pressure
Rig air pressure

6. Offshore rig driller's panels should have an audible and visible alarm to indicate the following:

- Low accumulator pressure
- Low rig air pressure
- Low hydraulic fluid reservoir level
- Panel on standby power (if applicable)

7. All panel control functions should require two handed operation. Regulator control may be excluded from this requirement.

The BOP stack functions should also be operable from the main hydraulic control manifold. This unit should be installed in a location remote from the drill floor and easily accessible to rig personnel in an emergency.

OPTIONAL REMOTE CONTROL METHODS

16E.2.6.1 Remote control from the remote panels of the hydraulic control manifold valves may be actuated by pneumatic (air), hydraulic, electro-pneumatic, or electro-hydraulic remote control systems. The remote control system should be designed such that manual operation of the control valves at the hydraulic control unit will override the position previously set by the remote controls.

PNEUMATIC REMOTE CONTROL

16E.2.6.1.1 Pneumatic remote controls employ compressed air as the medium to operate actuators for control of the hydraulic control valves. Response time between the actuation of the pneumatic valve at the remote panel and the actuation of the control valve is generally a linear function of the length of the interconnecting hose. Therefore, pneumatic controls are not recommended where hose lengths exceed 150 feet. Pneumatic remote controls are not recommended for use in freezing temperatures because condensate in a control line may solidify and plug the line.

HYDRAULIC REMOTE CONTROL

16E.2.6.1.2 Hydraulic remote control is a method to interface with the hydraulic control manifold. This method can be used in the absence of electrical power and can function in sub-freezing temperatures. Pilot pressure for remote control should be supplied from a hydraulic power source separate or suitably isolated from the main hydraulic power source so that failure of the remote control will not affect manual operation of the BOP control system.

ELECTRO-PNEUMATIC REMOTE CONTROL

16E.2.6.1.3 Electro-pneumatic controls employ electric circuits to operate pneumatic solenoid valves that control the pneumatic actuators which operate the hydraulic control valves. Electro-pneumatic controls have the advantage of fast response and ease of running electrical cables compared to hose bundles of pneumatic remote controls.

Electro-pneumatic controls should not be used in sub-freezing temperatures.

ELECTRO-HYDRAULIC REMOTE CONTROL

16E.2.6.1.4 Electro-hydraulic controls employ electric circuits to operate the hydraulic control valves. Electro-hydraulic controls have the advantages of fast response, ease of running electrical cables and are functional in sub-freezing temperatures. The hydraulic power supply for the remote controls should be isolated from the main hydraulic system so that a failure in the remote control circuit will not affect the manual operation of the control valves.

16E.2.6.2 Electric remote control panels and equipment should be designed to meet the requirements of API RP 14F Sections 2, 4, 5, 6, 8, 10.1 and 10.2. All electrical equipment is to be designed so as to be suitable for use in the atmosphere in which it is installed as defined by API RP 500B.

REQUIREMENTS FOR BOP CONTROL SYSTEM VALVES, FITTINGS, LINES AND MANIFOLD

REQUIRED PRESSURE RATING

16E.2.7 All valves, fittings and other components such as pressure switches, transducers, transmitters, etc., should have a working pressure at least equal to the working pressure of the control system. BOP control system working pressure rating is usually 3000 psi. Other working pressure ratings may be preferred based on function operating requirements.

CONFORMITY OF PIPING SYSTEMS

16E.2.7.1 All piping components and all threaded pipe connections should conform to the design and tolerance specifications for American National Standard Taper Pipe Threads as specified in ANSI B2.1. Pipe and pipe fittings should conform to specifications of ANSI B31.3. If weld fittings are used, the welder should be certified for the applicable procedure required. All rigid or flexible lines between the control system and BOP stack should be fire-resistant including end connections, and should have a working pressure equal to the design working pressure of the BOP control system.

All control system interconnect piping, tubing, hose, linkages, etc., should be protected from damage from drilling operations, drilling equipment movement and day-to-day personnel operations.

ELECTRICAL POWER SUPPLIES

16E.2.8 The electrical power supply to electro-pneumatic and electro-hydraulic panels should automatically switch to an alternate source of electric supply when primary power is interrupted. The alternate source of electric power supply should be capable of maintaining operation of the remote functions for a minimum of two hours if primary source should fail.

SECTION 16E.3

HYDRAULIC CONTROL SYSTEMS FOR SUBSEA BOP STACKS

GENERAL REQUIREMENTS

16E.3 Floating drilling rigs such as drillships and semisubmersibles experience vessel motion which necessitates placement of the BOP stack on the sea floor. The control systems used on floating rigs are usually open ended hydraulic systems (spent hydraulic fluid vents to sea) and therefore employ water-based hydraulic control fluids. In addition to the conventional components used on surface BOP control systems, subsea hydraulic control systems require hydraulic umbilical hose bundles deployed from storage reels to carry function pilot signals and power fluid from the surface to the subsea BOP stack. Pilot operated valves, controlled from the surface, are usually mounted in control pods on the LMRP and direct hydraulic power fluid to the annular and ram type BOP's, choke and kill valves and hydraulic connectors.

Because the subsea BOP stack is not easily accessible for maintenance and repair, redundant (backup) subsea pods and umbilicals are provided. The redundant components include the following:

1. Two complete sets of pilot operated control valves with each set mounted in one of two control pods located on the LMRP.
2. Two control hose bundle umbilicals, each stored on and deployed from an umbilical reel, to connect the two subsea pods to the surface control equipment.
3. Two jumper hose umbilicals to connect the reel mounted umbilicals to the surface controls.

RESPONSE TIME

16E.3.1 The control system for a subsea BOP stack should be capable of closing each ram BOP in 45 seconds or less. Closing response time should not exceed 60 seconds for annular BOP's. Operating response time for choke and kill valves (either open or close) should not exceed the minimum observed ram close response time. Time to unlatch the LMRP should not exceed 45 seconds. Measurement of response time begins at pushing the button or turning the control valve handle to operate the function and ends when the BOP or choke or kill valve is closed effecting a seal, or when the hydraulic connector(s) is fully unlatched.

A BOP may be considered closed when the regulated pressure has recovered to its nominal setting. If confirmation of seal off is required, pressure testing below the BOP or across the valve is necessary.

MIXING AND STORAGE EQUIPMENT

16E.3.2 A solution of potable water and a suitable soluble lubricant should be used as the subsea control

system operating hydraulic fluid. Appropriate proportions of ethylene glycol antifreeze should be added to control fluids containing water if ambient temperature at or below 32°F is anticipated. Additives which may be used to impede bacterial growth should not adversely affect performance. The hydraulic fluid reservoir should consist of two or more storage tanks. The large main tank should contain the control system fluid to be used in the operation of the BOP and valves. Another tank should contain the concentrated water soluble hydraulic fluid to be mixed with water to constitute the control system fluid. A third optional tank may contain ethylene glycol to be used when it is required to operate at temperatures close to, or below, 32°F. A fourth optional tank may contain a dedicated supply of pilot fluid mixture.

16E.3.2.1 The usable control system fluid reservoir capacity should be at least equal to the total accumulator storage capacity as determined in 16E.3.4.1. There should be sufficient space in the reservoir above the upper hydraulic fluid fill valve shut off level to permit draining the largest bank of accumulators back into the tank without overflow.

The lubricant/additive reservoir should be sized using the maximum anticipated ratio for mixing the control system's hydraulic fluid. The reservoir should contain sufficient lubricant/additive to mix at least ten times the total accumulator storage capacity of control system fluid as determined in 16E.3.4.1.

The antifreeze reservoir if required, should be sized using the maximum anticipated ethylene glycol/water ratio for the minimum anticipated ambient temperature to which the control fluid will be exposed. The reservoir should contain sufficient antifreeze to mix the accumulator storage capacity of control system fluid as determined in 16E.3.4.1.

16E.3.2.2 An audible and visible alarm should be provided to indicate low fluid level in each of the individual reservoirs. The alarm control should be set to activate after 75% of the reservoir usable volume has been drained. The alarm should sound and illuminate at the master, driller's and auxiliary remote panels.

16E.3.2.3 Adequate cleanout ports/hatches should be provided for each reservoir to facilitate cleaning. To prevent overpressurization, each reservoir should have suitable vents that have flow capacity in excess of the incoming flow capacity (including flow from accumulators for the mixed fluid reservoir). These vents should not lend themselves to being mechanically plugged, or capped.