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DEEPWATER BOP CONTROL SYSTEMS - A LOOK AT RELIABILITY ISSUES

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Abstract

Historically, drilling contractors have accepted without many questions the reliability of the Blowout Preventer (BOP) components and overall control system. A statistical reliability approach to qualifying, purchasing, and maintaining deepwater BOP control systems should provide a high level of confidence of being able to have long periods of time between planned maintenance of these systems with very few, if any, failures.

A study of deepwater BOP control systems has been performed to look at reliability issues and a means to qualify systems and components for a determined period between maintenance. Of special attention are the regulators and how they are typically arranged and used in the system. This paper will describe a statistical process to determine the reliability and failure rate necessary to accomplish the maintenance goal. In addition, the qualification process will be described and a discussion of the pressure control regulator issues discovered in the study will be provided.

Introduction

Transocean, like many other offshore drilling contractors, recently went through an extensive rig newbuild and upgrade program, which required purchasing a significant amount of customer-furnished equipment for the various shipyards. As with most “boom” cycles, the industry activity before the building cycle had developed ideas for new rig technology, but lacked R&D resources to make them available to be manufactured as already proven systems. Therefore, this building cycle, similar to all the rest, resulted in R&D efforts in parallel with the manufacturing of new equipment to be installed on new rigs. And, as before, this resulted in design and related problems while in service that drove significant downtime, in many instances.

At times, it appears the industry attitude is that we cannot afford R&D in advance of a defined need. However, the industry seems to be able to afford to fix the problems associated with downtime due to an incomplete design.

Many of these problems are directly related to not having a detailed set of design and functional specifications to give to the equipment manufacturer. Plus, the purchaser usually does not understand the duty cycle requirements, or demands, of the particular equipment for an interval that is acceptable to perform maintenance on the equipment without sustaining downtime.

For offshore floating drilling operations, especially in deepwater, one of the most expensive downtime events is associated with having to pull the marine riser and subsea BOP because of a problem. Any problem or failure that requires the riser and BOP to be round tripped will result in a cost of approximately $1.00 MM per event. And whether the contractor or the operator absorbs this cost, it is expensive.

One of the more common causes for pulling the marine riser and subsea BOP is associated with the BOP control system. The deepwater BOP control system associated with dynamically positioned (DP) rigs is typically a Multiplexed Electro-Hydraulic (MUX) Control System. This is schematically shown in Figure 1. The demand on the subsea control system is initiated at the surface. The demand signal is multiplexed down the control umbilical to the subsea control system. There, the signal is decoded, confirmed, and performed. For a demand that requires a BOP Ram to close, for example, the multiplex signal would be received at the subsea control pod and decoded. The decoded signal would cause a solenoid to be opened electrically which would send a hydraulic pilot signal to the proper hydraulic valve. This pilot signal would cause the hydraulic valve to shift and send stored and pressurized hydraulic fluid to the BOP Ram to be closed.

Therefore, the subsea BOP control system consists of two basic elements: electrical and hydraulic components. History has shown that more subsea problems have been associated with the hydraulic components than the electrical, causing the BOP and riser to be retrieved for repair.

Each subsea BOP system has two complete control pods. Each pod is capable of performing all necessary functions on the BOP. While these systems may be considered redundant, any major problem associated with one pod will cause the system to be retrieved to the surface for repair. If a major problem is found, the control of the subsea BOP is transferred to the other

pod and preparations will be made to retrieve the lower marine riser package (LMRP) and riser to surface. Some minor problems may not require the system to be retrieved if considered not necessary for critical operations.

Transocean has recently had an opportunity to review the basic design and requirements for Deepwater MUX BOP Control Systems. During this review, it was obvious: the best time to perform major maintenance on a complicated BOP control system was during the shipyard time of a mobile offshore drilling unit (MODU) during its five-year interval inspection period. This process would lead to minimal or no downtime associated with BOP controls and allow for planning proper resources during the maintenance period.

Therefore, a project was initiated to determine what would be required to manufacture a control system that would require major maintenance only on a five-year interval.

Reliability Discussion

A brief investigation into the specifications given to BOP control vendors revealed that rarely was any equipment performance requirements given. Very often, the system requirements were developed between the contractor engineers, operations personnel, and vendors as the project progressed after the purchase order was given. Reliability was assumed to be as good as the previous systems built. Or, in the case of a new design, it was assumed better than before.

During the bid and purchase negotiations between the contractor and vendor, emphasis is typically given to the following:

- Number, type, and size of specific functions to be provided. The BOP stacks of the newbuilds were built with more functions and volume requirements than in the past. Therefore, the control systems had more components than before;
- With a desire to make trouble-shooting problems easier, the systems have more pressure and position read-backs;
- For ultra-deepwater applications, the working pressure and volume of the stored hydraulic fluid increased dramatically;
- With the increased size of the two control systems on the subsea riser package, careful attention was given to the architecture of the system to fit in the space available.

Currently, factory acceptance testing (FAT) requirements at delivery of the system are generally were no more than function tests to ensure all functions work according to the piping and function drawings.

When the systems are accepted and integrated in the BOP stack, they are sent to the rig for continuing operations.

A new system on a rig generally has a learning curve associated with maintenance requirements. Maintenance schedules are typically established as problems are discovered. Because of the pressure on getting the equipment back to work, root cause analysis of the failures is generally not performed. In many operations, high maintenance is accepted as a necessary evil to prevent downtime.

High maintenance can be a tool to reduce failures in operation. However, this is a very expensive approach, and it is also an opportunity to introduce human error into the system. Also, this method does not establish reliability based on a failure rate.

In general, operating reliability is maintained on rigs mostly through regular maintenance intervals rather than specifying a reliability of a system or component to minimize maintenance.

Project Scope of Work

Floating drilling rig downtime due to poor BOP reliability is a common and very costly issue confronting all offshore drilling contractors. Transocean, as a major player in offshore exploration worldwide, operates numerous floating rigs of various capabilities and configurations. Depending on the drilling contract in place and the nature of the downtime cause, BOP failure can result in substantial revenue loss for the drilling contractor.

In order to reduce the risk of revenue loss to the contractor or operator, Transocean is committed to actively pursuing improvements in BOP reliability at all levels during the equipment lifetime, including the design stage. As part of this process, individual BOP component reliability goals are necessary to ensure that the desired overall BOP reliability target is achieved.

Since the hydraulic components of the control system historically have had more problems that have required the riser and BOP stack to be pulled, the first efforts were directed at the hydraulic system, including all hydraulic stack-mounted components. The systems under review consist of the solenoid pilot valve through to the end function.

The following reliability goals were established for the solenoids and hydraulic components:

- Overall service life of system is 20 years;
- Pressure regulators maintenance 5 years, body 20 years;
- Solenoids 20 years, body 20 years;
- Solenoid shear seal valves maintenance 5 years, body 20 years;
- SPM valves maintenance 5 years, body 20 years;
- Shuttle valves maintenance 5 years, body 20 years;
- Other valves maintenance 5 years, body 20 years;
- Hoses with couplings 5 years;
- Piping and connections 20 years.

Also, a method was established to design a specification to operate a Subsea BOP system for five years without needing to pull the system to the surface for unplanned maintenance; this project determined the method to design a specification to meet this goal. This discussion focuses on the reliability test specification that is necessary to ensure the use of highly reliable components that will result in the hydraulic control system meeting this objective.

The need for highly reliable sub-sea BOP system components results from the following assumptions that are based on actual experience.

- The BOP has a large number of hydraulic control system components;
- During a 5-year period, an individual valve will get cycled many times;
- Within the current design, a failure of any one of the control components may require pulling the BOP to the surface.

This paper estimates the magnitude of the testing requirements necessary to demonstrate the desired level of reliability. This is accomplished by scoping the mission success criteria based on a representative system configuration and a detailed analysis of the required testing. Next, an estimate of the component failure rate goals is established based on the desired operational reliability of the system and the test demands that various component-type groups within the system are expected to be exposed to over the desired duration (5 years). Then, an estimate is made of the number of cycles of a reliability testing program required to provide confidence that the components will perform reliably to achieve the BOP hydraulic control system reliability goal.

This scope of work is accomplished by addressing the following major categories:

- Control System Design Considerations – This process will look at all components to be considered in the study and group the components into "Family" types for further analysis;
- Estimate of Component-Type Reliability Requirements – The requirements of each component for the maintenance interval will be determined and a reliability goal is established to meet the criteria;
- Elements of the Reliability Testing Plan – Each family of components has its own failure rate goal to meet the overall failure rate goal of the system;
- Amount of Testing to Provide Statistical Confidence – The amount of testing to satisfy the failure goals and desired statistical confidence is specified;
- Component Testing Program – Test program to meet the stated goals.

Control System Design Considerations

Component Family Type Grouping Within System

A representative rig was chosen to perform the study. This was a 5th-Generation DP semisubmersible capable of drilling in water depths to 10,000 feet. A worksheet was developed to provide a complete listing of the components in the hydraulic control system. Family types group the components. The term, "Family Type," refers to the general function that the valves accomplish (e.g., pilot valve, check valve, shuttle valves, etc.) It is assumed that within a given component type the component designs are similar enough to assume that the reliability performance of the components may be modeled by one failure rate, regardless of size. The family types are listed below along with an indication of the number of components of that family within the representative system.

Check Valves - There are 22 check valves.
Pilot Assisted Check Valves – There are 6 pilot assisted check valves.
Piloted Hydraulic Valves – Dual Function –There are 38 dual-function pilot valves,
Piloted Hydraulic Valves – Single Function –There are 42 single-function pilot valves.
Regulators - There are two types of regulators, four manually set regulators and eight hydraulically controlled regulators. The operational success criteria for the regulator valve are still under evaluation. The "demands" associated with the regulator relate to the pressure control function performed during periodic testing of specific functions, which is required over the period during which the control valves are being cycled. The severity of the challenges depends on factors in the system that is still being investigated.
Shuttle Valves – There are 74 shuttle valves used in the system.
Solenoid Valves – There is no variation in solenoid valves. All 142 valves are 1/8", 3 way, 2-position valves.

Estimate of Component-Type Reliability Requirements

The goal of this project is to develop a control system that has the potential to operate 5 years between major maintenance without a failure. However, to have a starting point for developing failure rates, it was established that an acceptable failure rate would be one failure in 10 years that would cause a BOP stack to be retrieved to the surface.

Operational Test Summary

An Operational Test Summary worksheet was established showing the BOP operational testing program for the BOP that constitutes the 5-year success criteria for the hydraulic control system. The results for a 10-year period was also established to develop targeted failure-rate goals. The mission is based on the participation of valves in various subsystems of the BOP in a functional testing program of the BOP, both on the surface and subsea. The test program consists of 7 separate BOP Control tests that are conducted over a typical 8-week well drilling operation. An 8-week average per well drilled was assumed. Therefore, for a 5-year duration, approximately 33 wells would be drilled. For a 10-year interval, 65 wells would be drilled.

The component function cycles were established by the fol-

lowing test sequences:

> Test 1. – Function tests a BOP Control function when the stack is retrieved to surface, without pressure testing. This is to remove salt water in the pod.
> Test 1A – Emergency Disconnect Test and Remote Operated Vehicle Tests.
> Test 2. – Surface pressure test prior to running BOP.
> Test 3. – Run and land BOP, lock wellhead connector and line up BOP valves for drilling operations.
> Test 4. – Bi-weekly subsea pressure and function test for the duration of the well.
> Test 5. – Line up valves in preparation of pulling BOP. Unlock wellhead connector and adjust accumulator pressure on trip to surface.

This worksheet calculated the total number of component functional cycles based on the years of service that will form the basis for the reliability requirement. Figure 2 is a summary of the component functional cycles occurring due to the operational test sequences by Family Type. This summary shows the resultant total number of demands for valve position changes over the specified operational testing period. It can be seen in this summary, over 87,000 valve-cycle demands would have to be performed successfully subsea. And, almost 140,000 total cycles would occur during the 5-year period.

Specification of Reliability Goals

A Reliability Goal Evaluation provided a means to estimate individual component failure rate goals based on system reliability goals. Figure 3 represents a worksheet used to provide an interactive tool for evaluating different reliability goals. As shown, it is an estimate of the component-type group failure rates required to produce an average of 1 failure, among all six component types, within the hydraulic control systems per rig per 10-years of operation.

The estimate is designed to produce component failure rates that produce a system reliability that has been "balanced." As every component must function successfully when required during tests, the BOP hydraulic control is a series system; its reliability is modeled by the product of the reliabilities of all the components. This is done in two stages. First, an equal reliability requirement is allocated to each component-type group. Then the reliability requirement is allocated to each component within that group through the specification of a failure rate that will produce the component-type reliability when applied against the total number of test demands for that group. The resultant component failure rates are given in the column labeled "Component Failure Rate Goal."

Those component types that must respond to the most demands should be the most reliable, which agrees with common sense. For example, Solenoid Operated Valves are exercised about twice as much as any other component type. Consequently, they should have the lowest failure rate. Conversely, those valves that are not challenged as often as others can have somewhat higher failure rates without becoming a dominant contributor to failure.

A number of sensitivity studies with the worksheet developed the table at the bottom of the worksheet. It illustrates the current reliability of the system and the required improvement in failure rates needed to achieve system reliability goals of up to 95% over a 5-year period. This table shows that very low failure rates are needed to achieve a high reliability.

As shown, the upper two tables reflect the goal of averaging one failure per rig per 10 years of operation (65, 8-week test cycles or wells drilled). The system reliability goal is varied until component group failure rates are obtained that as a composite produce an expected value of 1 failure over the more than 171,000 subsea valve demands made during that period. The values in the "Comp. Failure Rate Goal" column then becomes the failure rates to be demonstrated by the reliability testing program.

Elements of the Reliability Testing Plan

Each group of similar valve types needs to undergo reliability testing to provide confidence of its failure rate. If any one of the valve types has a significantly higher failure rate than its failure rate goal, it will generate a "weakest link" system whose reliability would be dominated by that component. The failure rate goal for each of the Family Groups is shown in Figure 4.

A binomial process for demand-related failures and the Poisson process for time-related failure modes may represent the failure rate. Both of these processes assume that observed failures result from random failures of a population of componoents characterized by a failure rate independent of the previous life cycle of the valves under test. This implies that:

- A FAT has verified that manufacturing defects and any infant mortality failure mechanisms are not present;
- The total cycling of the valve is not of an amount to cause wear that is significant enough to precipitate wear-out failure mechanisms.

For demand-related failures, when the failure rate is low and the number of demands is large, the binomial process may be approximated by a Poisson process, so that the formulation of the statistical analysis of both time and demand related is mathematically the same, with only the units differing. (The Poisson process relates a continuous time-related failure mechanism with units of failures/unit of time. A large number demands may be considered to occur over time, so the similarity of form should not be difficult to accept.)

Valves placed under test must be randomly selected in order to be representative of the population. If the vendor conducts the test, the components to be tested should be selected by someone independent from the vendor.

The design of the test will depend on the historically observed failure mechanisms that contribute to failure.

- If cycling the valves put stress on them, then the reliability tests should involve repeated operational evolutions where they are demanded to open and

close in accordance with the operational requirements;

- If exposure to the subsea environment precipitates the failures, the test must include exposure to these conditions, or more severe conditions that can accelerate the mechanisms, for a period of time that can simulate the total exposure.

As both mechanisms are most likely involved, the reliability test needs to address both environmental exposure and operational evolutions.

Testing alone does not improve reliability or guarantee that no failures will occur within a given time frame. It verifies that systems and components are reliable or serves to identify weak spots if they are not. To be effective, a reliability test needs to account for the following:

- The tests need to be similar to actual operational conditions;
- The duration and/or operational evolutions in the test needs to be large enough to provide confidence that the needed reliability can be achieved;
- The root causes of any observed failures and anomalies need to be identified and corrected.

Testing done by specific purposes, such as burn-in, FAT and endurance testing to identify wear-out life, can provide indirect evidence that will increase confidence that a group of similar valves will perform its mission successfully.

Amount of Testing to Provide Statistical Confidence

Classical statistics relies strictly on outcome of valid tests or actual experience to provide statistical confidence in the reliability of a system or component. The higher the reliability requirement, the more tests needed to provide that confidence.

The confidence limit is a means of judging the impact of the uncertainty of the component failure rates. When one establishes failure rate estimates on the results of reliability tests or samples from actual experience, it must be recognized that any given sample result can be produced by populations with different failure rates. The confidence limit is a means of expressing the probability that the sample result might have been the result of a "lucky" statistical outcome of a population that actually has an unacceptably high failure rate. That is, if the test were repeated again, the result would most likely be worse.

For the BOP system, it is assumed that the failure rate of all components within each of the 6 component-type groups, defined previously, can be modeled by a single-component group failure rate. The impact of component failure rate uncertainty on the uncertainty of system failure rate is illustrated by Figure 6. The curve on the left-hand side of the chart represents 1 of 6 components having equal failure rates (equivalent to the 6 component-type groups in the BOP hydraulic control system). The curve is typical of the uncertainty in failure rates. It illustrates that one does not have to demonstrate component reliability to a very high confidence limit when it is part of a larger series system. With many random variables, the impact of the higher end of the distribution of 1 component tends to get balanced by the lower portions of the distributions of other components. For this 6-component series system, an 80% confidence that each component group failure rate <0.006/mission produces 90% confidence that the system FR is no more than 0.036/mission. This means that one can achieve reasonable confidence of a given system reliability with less test cycles for the individual component groups.

Using the system reliability goal of 1 failure per 10 years of subsea operation. Figure 5 was generated from a Poisson worksheet. The table illustrates the number of test cycles with no failures required to meet the failure rate goals with 80% confidence for each of the component family groups.

Component-Testing Program

The component-testing program should focus on exercising as many different hydraulic control system component types as possible within an integrated test bed capable of mimicking functions associated with the hydraulic control subsystems. Such a test bed should require that subsystem and component interfaces be adequately tested under the range of operational and environmental conditions expected during actual subsea operations. It is anticipated that there are many functional similarities among the 8 subsystems, such that a representative test bed could be designed and built which would also be at a scale that would permit enclosing it in a suitable environmental chamber

Each type of control system will probably have its own requirements for a specific reliability test, such as number of components and number of cycles that should be in the program. However, the following types of tests should be included:

- A test to verify that manufacturing defects that leads to early infant mortality are not present. (The valve manufacturer should be doing this before it delivers the valve);
- Tests that demonstrate the anticipated operational life of the components in the anticipated subsea environments. This test would need to identify controlling parameters and correlate accelerated testing conditions to those parameters so that confidence in the operational life can be obtained in a reasonable period of time;
- Reliability tests on a suitable test bed that simulates subsea conditions of a set of components comprising all the major component groups and interfaces. This test bed should be able to exercise the components over all the significant operational evolutions that would be required in the actual BOP system;
- Product-acceptance tests for batches of components being delivered by vendors;
- Post-maintenance tests for field use that can assist in verifying that the component has been returned to an acceptable condition.

The program should focus on known problems based on tracking previous problems, but it also needs to maintain some kind of confirmatory testing for all component groups.

Pressure Regulators

Most components in a control system, such as solenoid valves, piloted hydraulic valves, shuttle valve, etc., have a discrete number of cycles in a 5-year life and can be determined by knowing the frequency of BOP tests or operations. However, a regulator typically has many cycles during a large volume demand function such as an annular close. Figure 7 shows a sample of the original modeling of a pipe ram close for a previous project. Obviously, there appears to be a lot of activity of the regulator position during the function.

And, clearly, it would be impossible to determine the number of cycles, or movements, of the regulator in a 5-year period. Therefore, an additional project has been initiated to determine if the regulator spool can be controlled or calibrated to be able to determine its cycle behavior under various volume demands. This project is on going.

Conclusions

The process described in this paper is contrary to how the offshore industry typically specifies its equipment. Historically, functionality has been the primary focus of bid specifications. However, the content of this paper shows it is feasible, and should be practical, to specify the equipment used on our Mobile Offshore Drilling Units (MODU's) by performance specifications which meet our planned requirements.

It must be noted that component failures are random events and may still occur. However, demonstrated component reliability at this level provides a high confidence that significant downtime can be minimized over the drilling cycle.

Obviously, the requirements contained in this paper will require additional R&D by the vendors as well as a greater effort by the purchasers to understand and specify the requirements for any particular system. The end result of purchasing a more reliable system will be some form of additional cost. Plus, the vendors that can deliver a control system that can go 5 years without maintenance will only see spare purchases once every 5 years for each rig. The desire of vendors to provide this type of equipment and service should allow a possible new economic model to be developed which allows the vendor, contractor, and operator to share in the savings resulting from no controls-related downtime.

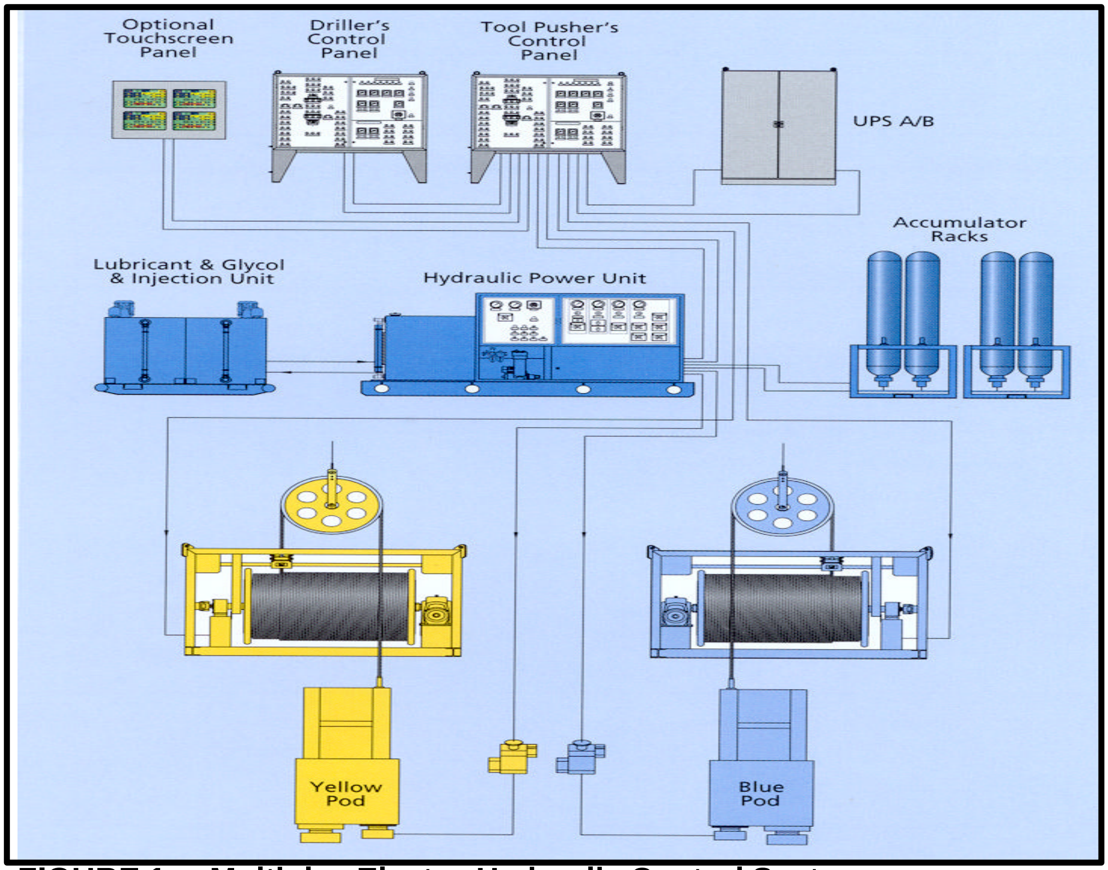

FIGURE 1. Multiplex Electro-Hydraulic Control System

ESTIMATED NUMBER OF CYCLES IN 5 YEARS

QUANTITY	FAMILY TYPE	SUBSEA CYCLES	ALL CYCLES
24	Accumulators	N/A	N/A
22	Check Valves	1,050	1,900
6	Pilot Check Valves	1,300	2,000
38	Pilot Valves, Dual Action	14,850	24,600
42	Pilot Valves, Single Action	20,600	29,750
12	Regulators	N/A	N/A
74	Shuttle Valves	11,550	20,450
142	Solenoid Valves	38,000	60,600
Total 360	TOTAL	87,350	139,400

FIGURE 2. Estimated Cycles

RELIABILITY GOAL TO ACHIEVE ONE FAILURE IN TEN YEARS OF OPERATION

Overall System Reliability Goal	36.0%	Enter Reliability Goal Here.
Number of Component Groups	6	
Comp Group Overall Reliability	84.3%	
Comp Group Mission Failure Rate	1.6E-01	

Component Failure Rates Required to Achieve System Reliability Goal for 65 Test Cycles

Comp Group	Definition	Number of Compx.	Unit of Exposure	Reliability for Subsea Tests	Exposure All Subsea Tests	Comp. Failure Rate Goal	Exposure All Tests	Reliability for All Tests
ACC	Accumulator	24	TBD					
CHK	Check Valve	22	Demands	84.3%	2,080	8.2E-05	3,770	73.4%
PAC	Pilot Assisted Check Valve	6	Demands	84.3%	2,600	6.5E-05	3,900	77.5%
PVD	Pilot Valve Dual Action	38	Demands	84.3%	29,250	5.8E-06	48,425	76.4%
PVS	Pilot Valve Single Action	42	Demands	84.3%	40,560	4.2E-06	58,630	78.2%
REG	Regulator	12	TBD					
SHV	Shuttle Valve	74	Demands	84.3%	22,750	7.5E-06	40,235	74.0%
SOV	Solenoid Operated Valve	142	Demands	84.3%	74,490	2.3E-06	119,340	76.1%
Totals	All Modeled Components	360		36.0%	171,730		274,300	18.9%

Comp Group	Definition	Number of Compx.	Comp. Failure Rate Goal	Unit of Exposure	Exposure All Tests	Exposure All Subsea Tests	Expected No. Failures, All Tests	Expected No. Failures, Subsea Tests
ACC	Accumulator	24		TBD				
CHK	Check Valve	22	8.2E-05	Demands	3,770	2,080	0.31	0.17
PAC	Pilot Assisted Check Valve	6	6.5E-05	Demands	3,900	2,600	0.25	0.17
PVD	Pilot Valve Dual Action	38	5.8E-06	Demands	48,425	29,250	0.28	0.17
PVS	Pilot Valve Single Action	42	4.2E-06	Demands	58,630	40,560	0.25	0.17
REG	Regulator	12		TBD				
SHV	Shuttle Valve	74	7.5E-06	Demands	40,235	22,750	0.30	0.17
SOV	Solenoid Operated Valve	142	2.3E-06	Demands	119,340	74,490	0.27	0.17
Totals	All Modeled Components	360			274,300	171,730	1.67	1.02
							Average failures/rig over all test cycles.	

FIGURE 3. Reliability Goal Spreadsheet

BOP CONTROL SYSTEM COMPONENT FAILURE RATES

AVERAGE OF ONE RISER PULL PER 10 RIG YEARS (ACHIEVED IF SUBSEA FAILURE RATE IS 0.0156/ WELL or 1/65 WELLS)

FAMILY TYPE	FAILURE RATE GOAL	or FAILURE RATE GOAL
Accumulator	N/A	N/A
Check Valve	8.2E-5	1 IN 12,200 DEMANDS
Pilot Check Valve	6.5E-5	1 IN 15,400 DEMANDS
Pilot Valve Dual Action	7.5E-6	1 IN 133,300 DEMANDS
Pilot Valve Single Action	5.8E-6	1 IN 172,400 DEMANDS
Regulator	N/A	N/A
Shuttle Valve	4.2E-6	1 IN 238,100 DEMANDS
Solenoid Valve	2.3E-7	1 IN 434,800 DEMANDS

FIGURE 4. Component Failure Rates

COMPONENT TESTING TO ACHIEVE FAILURE RATE GOAL

FAMILY TYPE	ALL DEMANDS IN 5 YEARS	NUMBER OF QUALIFICATION TEST CYCLES PER FAMILY TYPE
Accumulator	N/A	N/A
Check Valve	1,900	20,000
Pilot Check Valve	2,000	25,000
Pilot Valve Dual Action	24,600	220,000
Pilot Valve Single Action	29,750	280,000
Regulator	N/A	N/A
Shuttle Valve	20,450	380,000
Solenoid Valve	60,600	700,000
	139,400	1,625,000

FIGURE 5. Component Testing

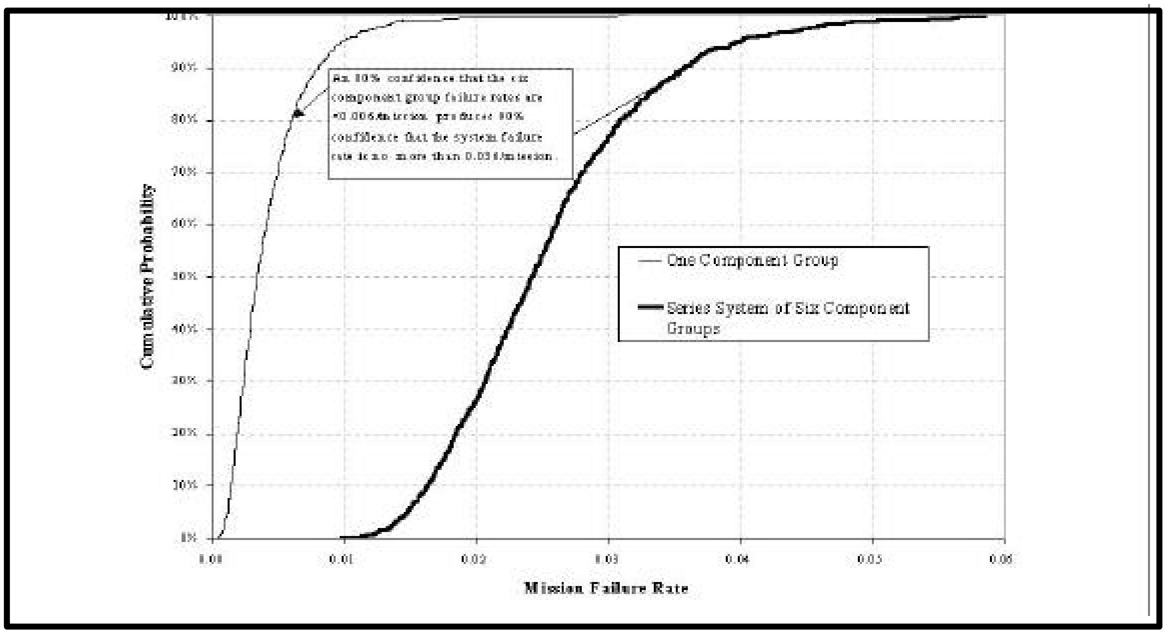

FIGURE 6. Confidence Level for Component Group and System

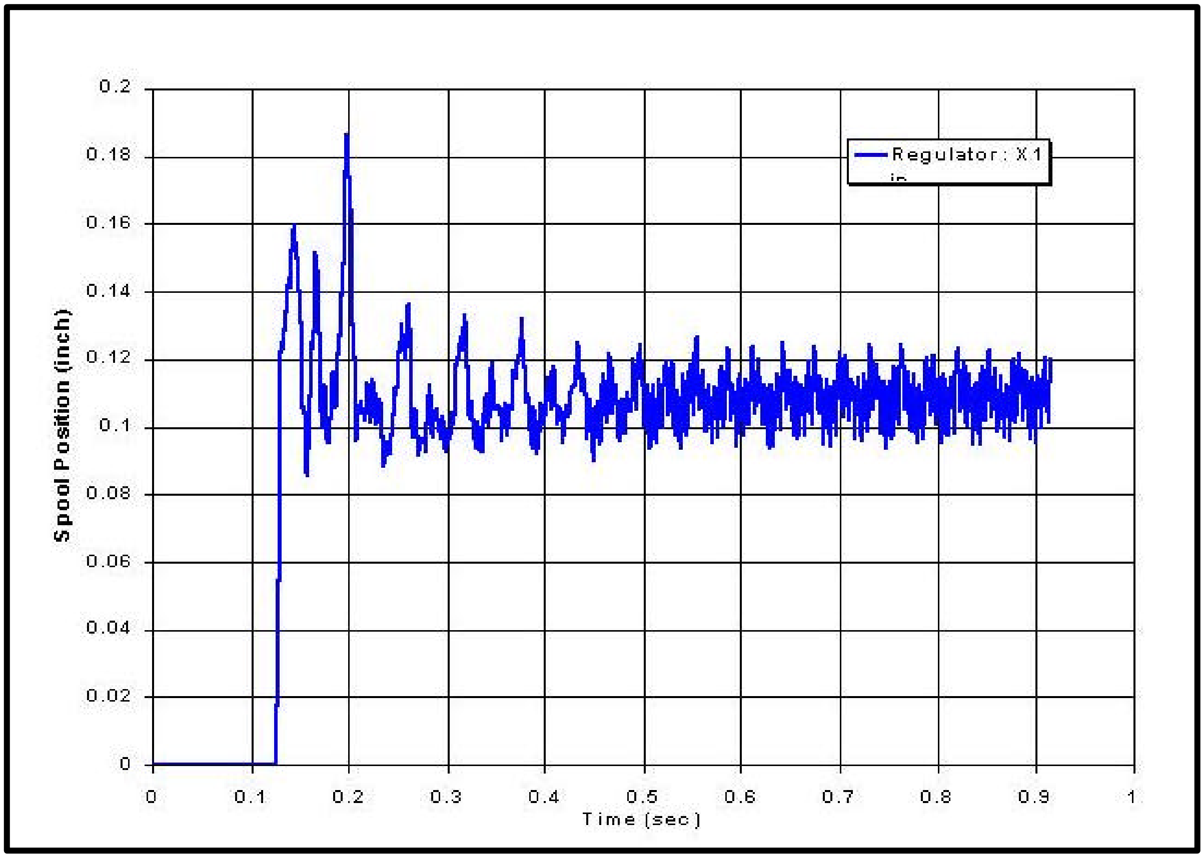

FIGURE 7 Regulator Piston Position