Deepwater Horizon Accident Investigation Report

September 8, 2010

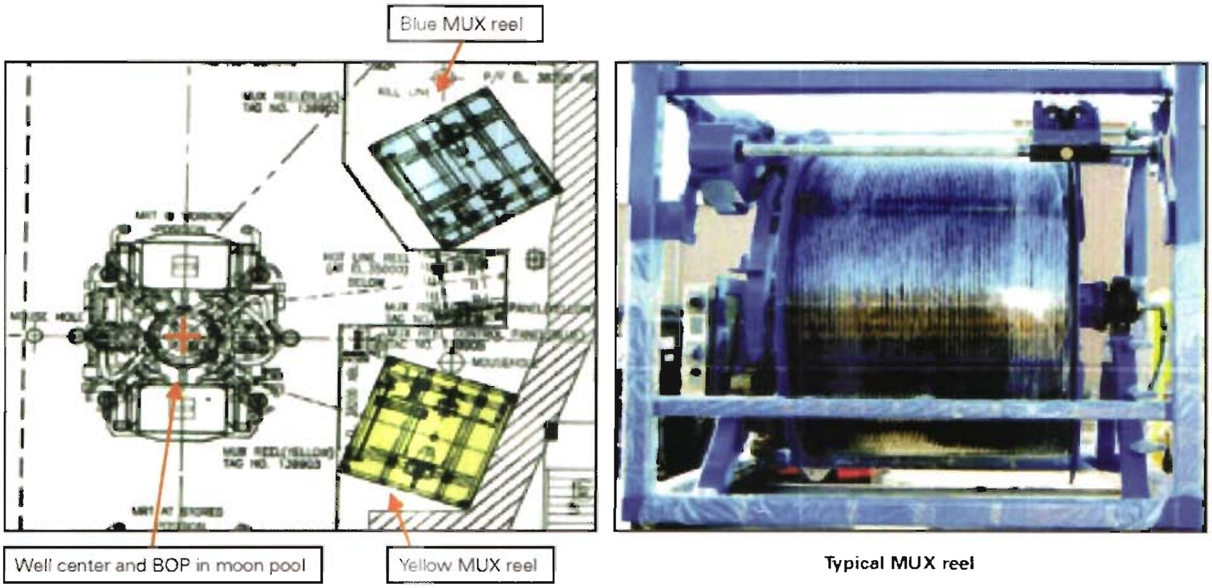


Figure 6. Moon Pool Layout Showing the Location of Blue and Yellow MUX Reels.

The subsea supervisor testified during the MBI hearings on May 26–29, 2010, that the TCP had a low accumulator alarm indicating loss of hydraulic power. The witness testified, "I hit the EDS button. Everything in the panel did like it was supposed to at the panel, but it never left the panel. I had no hydraulics." This account suggests that the EDS did not initiate. Both methods, high-pressure BSR and EDS, would have required communication with the BOP control pod through MUX cables.

The MUX reels were located in the moon pool area within the explosion and fire zone. (Refer to Figure 6.) Since the MUX cables were not protected against explosions or fire, it is very likely that the early explosion and fire damaged the MUX reel slip rings and the cables to the extent that the communication line and electrical power required to initiate the high-pressure BSR and EDS functions were no longer available.

3.2 Automatic Mode Function Performance

The AMF sequence is initiated when electrical power, communications and hydraulic pressure are lost to both pods. To initiate an AMF, all three services must fail (i.e., after damage to the MUX reels or cables and to the hydraulic conduit, caused by explosions and fire). As indicated in *3.1* of this analysis, the MUX cables, which carry electrical power and communications, were vulnerable to explosion and fire damage. Though the hydraulic conduit flexible hose was less vulnerable to damage than the MUX cables, it was located close to the MUX cables in the moon pool and could have been damaged by the explosions and fire. (Refer to Figure 7.)

As described in *3.1* of this analysis, the TCP displayed a low accumulator alarm, indicating a loss of surface hydraulic power at the time the EDS button was pressed. Combined with the damage to the MUX cables, the conditions for the AMF sequence would very likely have been met at the time of the explosions and fire or soon afterward.

However, the AMF very likely failed to activate the BSR. The examination and tests conducted by Transocean and Cameron on the blue and yellow pods following their retrieval after the accident found a faulty solenoid in the yellow pod and low charge batteries in the blue pod. The investigation team has determined that these conditions very likely prevailed at the time of the accident. If so, neither pod was capable of completing an AMF sequence that would have closed the high-pressure BSR in the event of hydraulic and electrical power supply and communications failure on the rig.

3.2.1 Solenoid Valve 103 Condition

During the yellow pod test performed by Transocean and Cameron after the accident, both coils on solenoid valve 103 failed to energize, suggesting electrical coil faults. The investigation team found no evidence that this failure occurred after the accident; rather, the team concluded that this failure condition very likely existed prior to the accident. (Refer to *5.1 Maintenance* of this analysis.) A faulty solenoid valve 103 would mean that the yellow pod could not have performed the AMF sequence, as no pilot

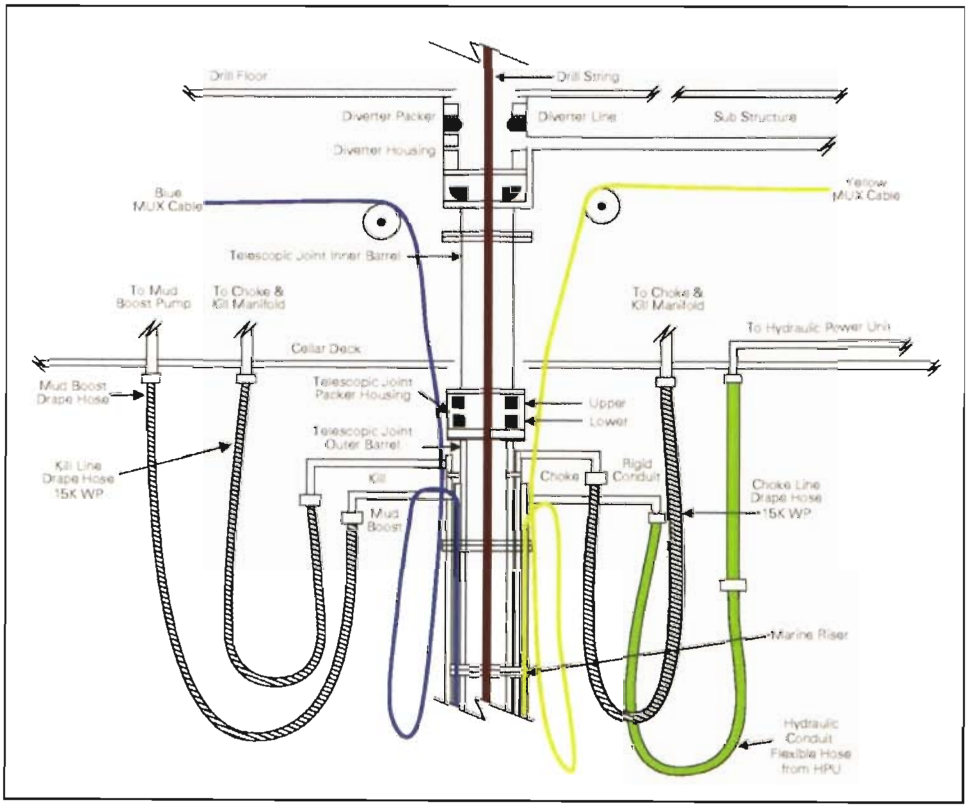


Figure 7. Typical Configuration of Flexible Hoses in the Moon Pool. (Hydraulic conduit flexible hose is shown in green).

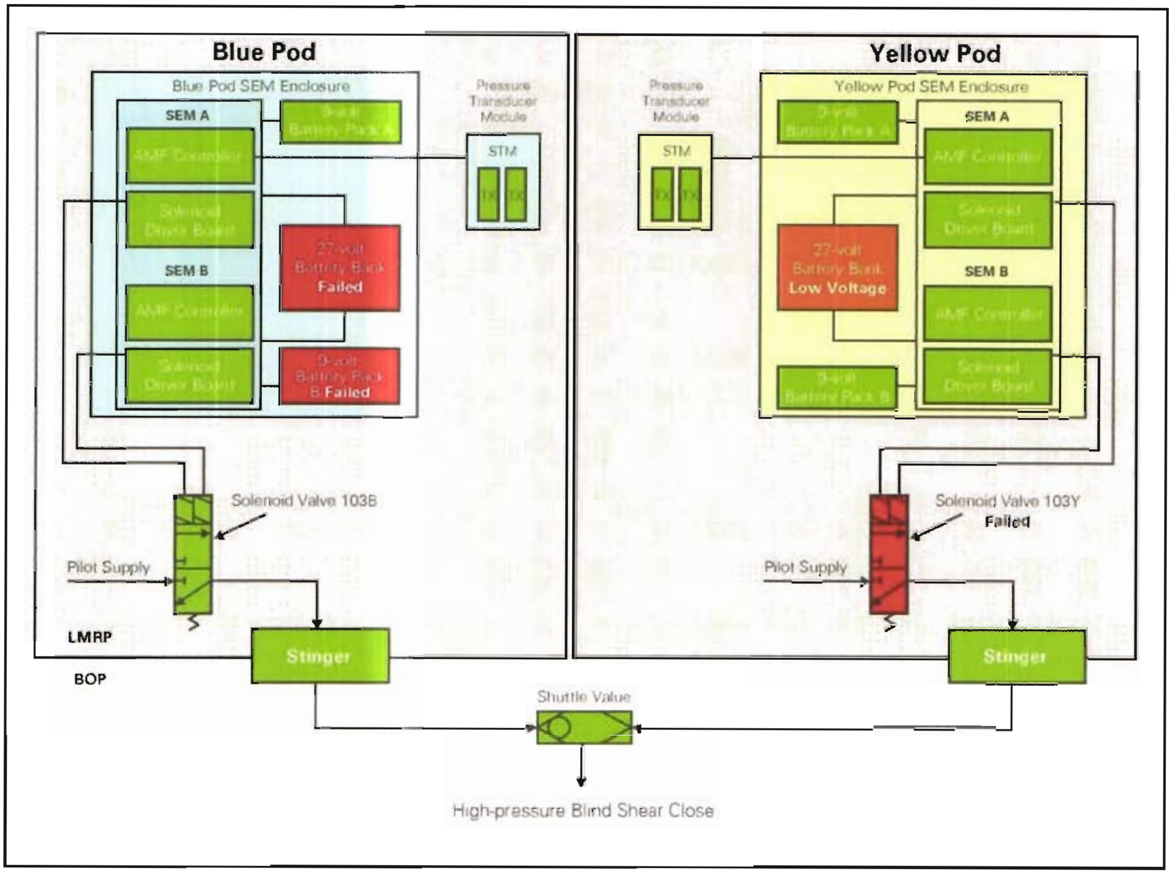


Figure 8. Simplified Schematic of the AMF Control System.

signal could have been sent to the pilot-operated control valve to activate the high-pressure BSR close function. As described in *5.5 Monitoring and Diagnostic Capability* of this analysis, the rig's BOP control diagnostic system should have been capable of remotely detecting the faulty solenoid valve and recording it on the system event logger.

3.2.2 AMF Battery Condition

Figure 8 shows a simplified schematic of the AMF system. There were two 9-volt battery packs and a 27-volt battery bank (made up of 3 packs of 9-volt batteries connected in series) in each pod. These batteries were not rechargeable. The 9-volt AMF battery packs were used to power the AMF card processors. When the AMF was enabled, these batteries provided continuous power to the AMF cards. The 27-volt battery bank was used to provide power to the 24-volt rated AMF card relays, the pressure sensors and the solenoid valves that were used in the AMF sequence, including solenoid valve 103.

The batteries would power the sensors only when the AMF card detected a loss of electrical power and communications. If the AMF card subsequently determined that the hydraulic fluid supply had failed by comparing the measurements from the two pressure sensors, the AMF card would have switched the 27-volt battery bank to operate the solenoid valves. Upon completion of the AMF sequence, the AMF card would have been powered down, and the 9-volt battery packs and the 27-volt battery bank would have been isolated, preventing further discharge.

The examination of the control pods by Transocean and Cameron when the pods were retrieved after the accident (yellow pod on May 5–7, 2010, and the blue pod on July 3–5, 2010) revealed potential problems with AMF batteries in both pods. The more significant problem was found in the blue pod, where only 0.142 volts remained in the subsea electronic module (SEM) B 9-volt battery packs and 7.61 volts remained in the 27-volt battery bank.

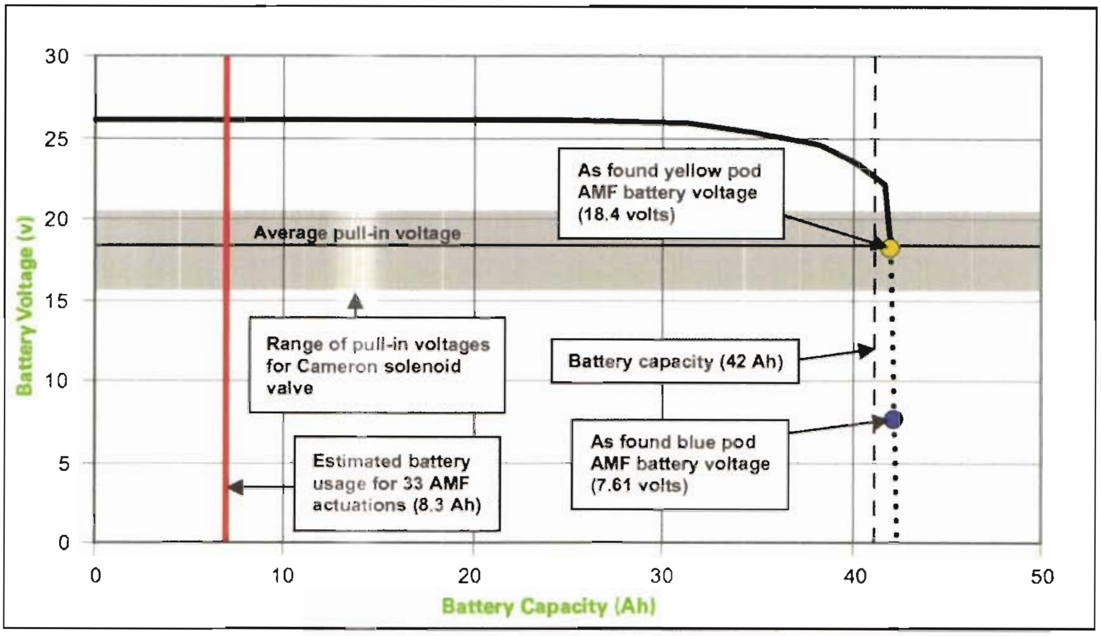
Following the findings from the examination of the control pods, the investigation team conducted a number of tests on a representative Cameron AMF card. The tests established that a minimum of 14.9 volts was required to energize the relays on the AMF card. The tests also established that under 3,000 psi supply pressure, a typical Cameron solenoid valve requires between 15.8 volts and 20 volts to energize. Based on these tests, the investigation team concluded that the charge on the AMF batteries in the blue pod at the time the pods were examined by Transocean and Cameron would have been insufficient to successfully complete an AMF sequence.

In 2004, Cameron, the BOP manufacturer, issued an engineering bulletin, *EB 891D*, recommending that battery banks be replaced after one year of operation or when the number of actuations exceeds 33 for that year, whichever comes first. The discharge curve for a 27-volt battery bank indicates that after 33 actuations, the battery bank would have expended only 20% of its expected life, as measured in ampere hours (Ah). The measured charge of 7.61 volts on the 27-volt battery bank was past the expected annual usage and was beyond the design life of the battery bank. (Refer to Figure 9 and *Appendix X.* Deepwater Horizon *Blue Pod AMF System Batteries.*)

If the AMF sequence had been successfully completed, the AMF pod would have been powered down isolating the 27-volt battery bank and stopping further battery discharge under load. Under such circumstances, the 27-volt battery bank would have had to have been in a charged condition at the time of the examination.

The investigation team considers that it is very likely that the charge at the time of the accident would have been insufficient to activate the AMF.

The available maintenance records from 2001 to 2010 indicate that during this period, the AMF batteries were changed at a frequency less than the manufacturer's recommendation. The BOP control diagnostic functionality did not include measuring the charge on the AMF batteries. Transocean maintenance records for AMF batteries are discussed in *5.1* of this analysis.



Source: SAFT LM33550 Battery Data Sheet (Data is scaled from a C/120 discharge rate at 68°F [20°C])

Figure 9. Discharge Curve for a 27-volt AMF Battery Bank.

3.3 ROV Hot Stab Intervention to Close the BSR

Several attempts were made to close the BSR by ROV hot stab intervention after the accident. The investigation team has concluded that it was unlikely that these efforts closed the BSR.

These attempts are summarized below:

- In the initial ROV intervention period, several ROV hot stab attempts to close the BSR were made, but none were effective, as no pressure was developed at the ROV hot stab port. These attempts were unsuccessful because of ROV pump failure and because the available ROV pumps, with their low flow rate output, were not able to operate shuttle valves or overcome a leak that was subsequently discovered in the hydraulic system. (Refer to the third bullet below.)
- After these attempts failed, an ROV cut the autoshear rod to initiate the high-pressure BSR close function. In the 3-hour period between the cutting of the autoshear rod and the sinking of the rig, an additional ROV hot stab attempt was made to close the BSR, but the ROV was unable to build pressure in the BOP hydraulic system.
- After the rig sank, ROV hot stab intervention revealed a leaking fitting in the ST lock close hydraulic circuit. After this leak was repaired, another attempt was made to close the BSR. The resulting sudden pressure increase indicated that the BSR was already closed, supporting the proposition that the autoshear function had already closed the BSR.