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MACONDO WELL INCIDENT

Transocean Investigation Report

Volume I

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Drill Pipe Bows in the BOP

Once the variable bore rams (VBRs) were closed, the shut-in well pressure below the rams increased to more than 7,000 psi, and the force of the pressure pushing upward on the drill pipe exceeded 150,000 lb.[89, E] The drill pipe tool joint was restrained by the upper annular BOP packing element as well pressure forced the drill pipe upward, bowing the drill pipe in the BOP bore between the upper VBRs and the upper annular packing element.[90]

The rig lost power at 9:49 p.m., followed by explosions and fires resulting in a loss of station keeping ability.[91] As the *Deepwater Horizon* drifted off location, the drill pipe was pulled between the traveling block on the rig floor and the BOP stack. At the BOP stack, the internal drill pipe pressure at the upper annular continued to climb above 8,000 psi.[F] Within minutes, the forces ruptured the drill pipe above the upper annular where the pipe had been weakened by severe erosion.[92]

Figure 14 illustrates the rupture in the drill pipe above the upper annular BOP.

The well flow previously was contained below the VBRs but now flowed through the ruptured drill pipe above the upper annular BOP. The *Deepwater Horizon* then drifted farther off location, pulling on the drill pipe until it parted at the rupture. Inspection of the parted drill pipe and drift-off calculations indicate that there likely was sufficient tension to part the ruptured drill pipe within six minutes after power loss.

Figure 15 illustrates the moment when the pipe parted due to the tension in the drill string; the photo demonstrates the tensile failure of the drill pipe.

3.4.4 Automatic Mode Function Activation (AMF)

The *Deepwater Horizon* BOP and multiplex (MUX) control system were fully operational at the time of the incident, and the drill crew successfully operated several functions — the upper annular BOP, two sets of VBRs, and the diverter — in response to the well-control event.[93] The explosions on the rig severed the communication link between the BOP and the rig, preventing surface control of the BOP emergency disconnect system (EDS).[94] As a result, efforts to activate the EDS from the bridge were unsuccessful.[95]

The explosions and fire subsequently damaged or destroyed the BOP secondary hydraulic supply line hose and the BOP MUX control cables, resulting in the loss of hydraulic supply pressure and electrical power to the BOP. This, in turn, automatically activated the AMF system in both the blue and yellow pods. The AMF activated the high-pressure shear circuit to close the blind shear rams utilizing the stored hydraulic pressure in the accumulator bottles mounted on the lower BOP stack. Pressure from the accumulators closed the blind shear rams (BSRs) and activated the ST Locks on all of the closed rams (BSRs, upper VBR, and middle VBR). *See Figures 16 and 17*. When the BOP is operated from the surface via the control panels, the ST Locks are not automatically engaged; this is a manual function performed by the drill crew. The fact that the ST Locks were engaged on the BSRs and both VBRs confirms that the high-pressure shear circuit was activated by the AMF.[G]

E 5.5-in. drill pipe = 23.75 in.^{2} x 7,000 psi = 166,250 lb. lift.

F 5,750 psi surface pressure plus the hydrostatic pressure of seawater in the drill pipe.

G The *Deepwater Horizon* ST locks were not functioned as a standard practice when the BOP was subsea except for hurricane abandonment prior to disconnect of the LMRP from the lower BOP stack. It was unlikely that the driller/toolpusher activated the ST Lock lock function after closing the upper and middle VBRs. All functions on the MUX pods shifted to the vent position when power was lost to the pods. Closing pressure was then vented to the upper and middle VBRs. The rams stay closed with the assistance of adequate wellbore pressure. The AMF system fired the HP shear circuit locking the ST Locks behind the upper and middle VBRs moments after the power was lost to the pods. If the AMF had not fired, the rams would have had to have been held closed by only the wellbore pressure for 33.5 hours until the auto-shear pin was cut by an ROV. When the auto-shear pin was cut on April 22, 2010, at 7:30 a.m., there was no indication of fluid discharge from the control pods indicating that the BSR and the ST Locks were already in the closed and locked position. If the BSR was still open, approximately 30 gallons of fluid would visibly discharge from the open side of the BSR and ST Locks.

Condition of Yellow Pod

The yellow pod was fully functional at the time of the incident.

The yellow pod was retrieved from the BOP 15 days after the incident and transferred to the *Q4000*, the vessel used to assist with BOP intervention and other support activities.[96] The pod was inspected, tested, and prepared to operate the *Deepwater Horizon* BOP system for the post-incident response.[H] During the inspection of testing of the yellow pod, it was determined that:

- The AMF batteries registered acceptable voltage levels (8.85V for both 9V SEM battery packs and 26V for the 27V battery pack).[97]
- Solenoid 103 (for the HP shear circuit) did not function mechanically when activated with one SEM at a time (two SEMs per pod). Solenoid 103 was replaced with a spare solenoid and taken into evidence by the JIT investigation.
- Solenoid 3A (for the upper annular regulator increase) did not function mechanically when activated with one SEM at a time (two SEMs per pod). Solenoid 3A was replaced with a spare solenoid and taken into evidence by the Joint Investigation Team.
- The AMF system was re-tested and functioned as expected and designed.[98]

The yellow pod was lowered and latched to the *Deepwater Horizon* BOP on May 19, 2010. The pod was used to operate functions remotely from the *Q4000* on the rig BOP stack for 114 days up until the BOP was loaded on the barge to be sent ashore on Sept. 10, 2010.

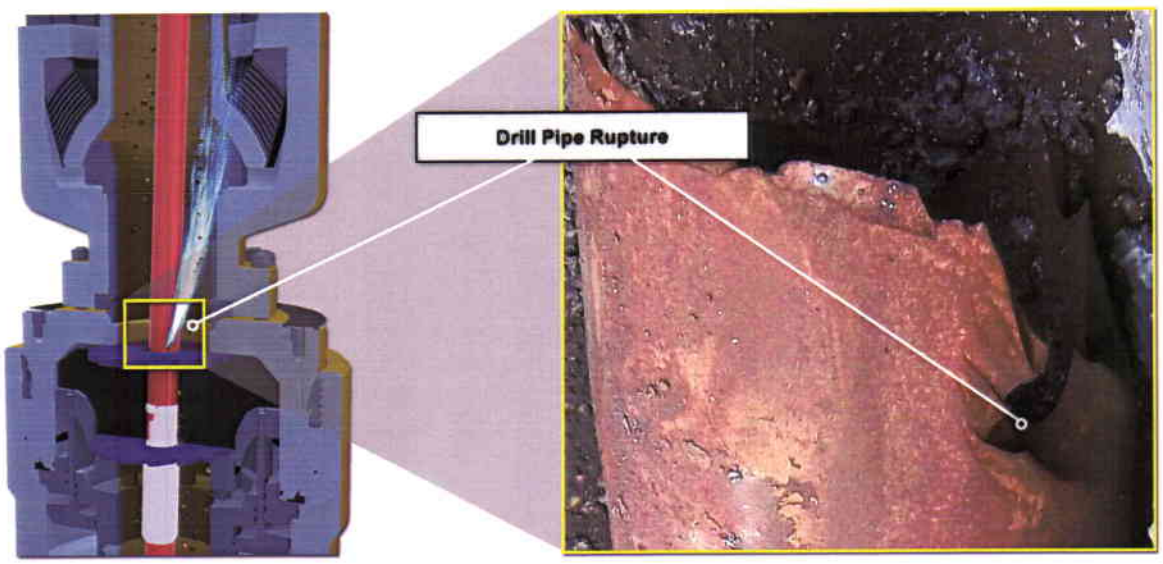

Figure 14 Rupture of Drill Pipe at Upper Annular BOP

The yellow pod AMF system was tested at NASA Michoud on March 3, 2011, with the original solenoid 103 installed. Testing of the yellow pod produced the following findings:

- The AMF batteries were still at acceptable voltage levels (8.67V for SEM A and 8.44V for SEM B 9V battery packs, and 28.15V for the 27V pod battery pack).

Original solenoid 103:

- Functioned hydraulically as designed with no leaks
- Functioned every time with both SEM A and SEM B activated (direct activation of the Portable Electronic

H At all times during the process, a representative from the U.S. Coast Guard and the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) was present to witness all work on the pod.

Test Unit (PETU) or by the AMF system)

- While technicians incorrectly described the E-cable and plug assembly as non-OEM supply, the parts were in fact made by Cameron's supplier. The E-cable and plug assembly were new when installed on the yellow pod in February 2010, prior to deploying the BOP on the Macondo well.
- Three functions of the AMF system were tested with SEM A and SEM B armed according to normal operating conditions when the BOP is subsea. The AMF functioned as expected and designed each time, functioning Solenoid 103 and pressurizing the pilot line to the HP shear circuit.[99]
- Further testing of Solenoid 103 at NASA Michoud is ongoing at the time of publication of this report.

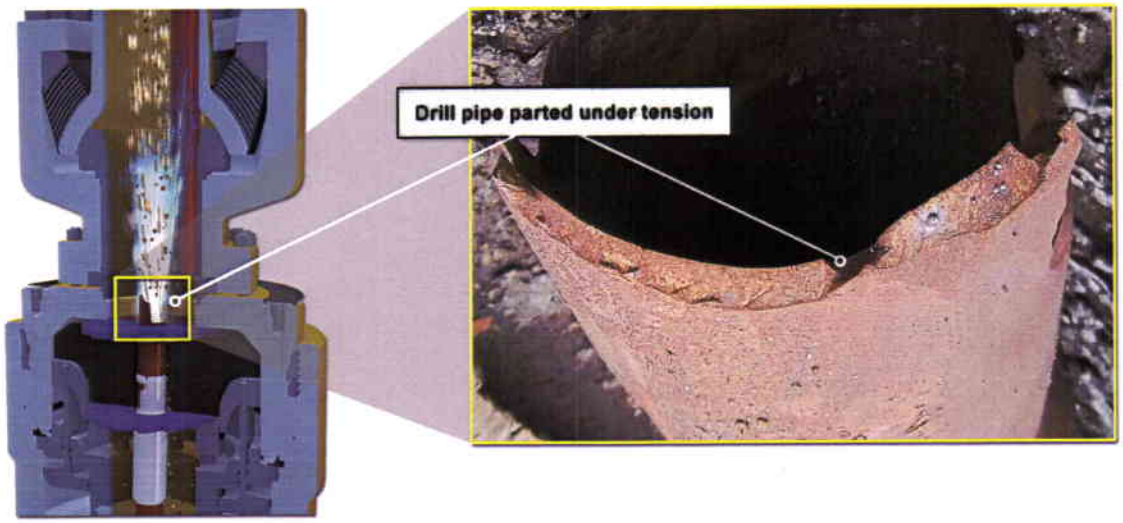

Figure 15 Tensile Separation of Drill Pipe at Upper Annular

Investigation Team Findings

Testing performed on the yellow pod at NASA Michoud confirms the AMF system activated solenoid 103, and solenoid 103 activated the HP shear circuit to close the BSRs at the time of the incident.[100]

Condition of Blue Pod

The blue pod was fully functional at the time of the incident.

The blue pod was retrieved from the BOP 74 days after the incident and loaded onto the *Discoverer Enterprise,* a Transocean drillship on site to assist with post-incident activities.[101] The pod was inspected, tested, and prepared to operate the *Deepwater Horizon* BOP for the post incident response.[l]

During the surface inspection and testing of the blue pod, it was found that:

- The AMF battery voltage levels were recorded at 8.87V for SEM A 9V, 0.142V for SEM B 9V battery pack, and 7.61V for the 27V battery pack.[102]
- The blue pod AMF system was tested and did not initiate the sequence (i.e., solenoid 103 was not activated due to low 27V battery power).[103]
- When 230V power was re-applied from the PETU to the pod, the AMF system initiated and completed the sequence and activated solenoid 103.[104]

l At all times during the process, a representative from the U.S. Coast Guard and the BOEMRE was present to witness all work on the pod.

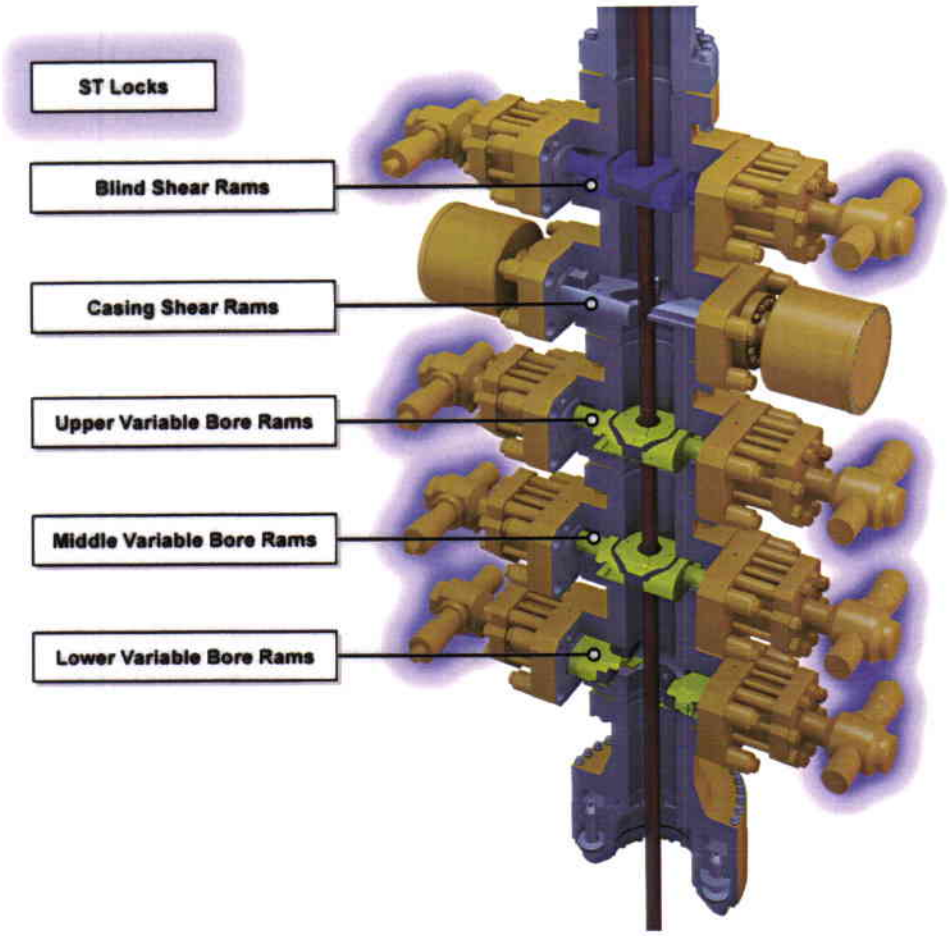

Figure 16 Position of Blind Shear Rams and VBRs Following AMF Activation.

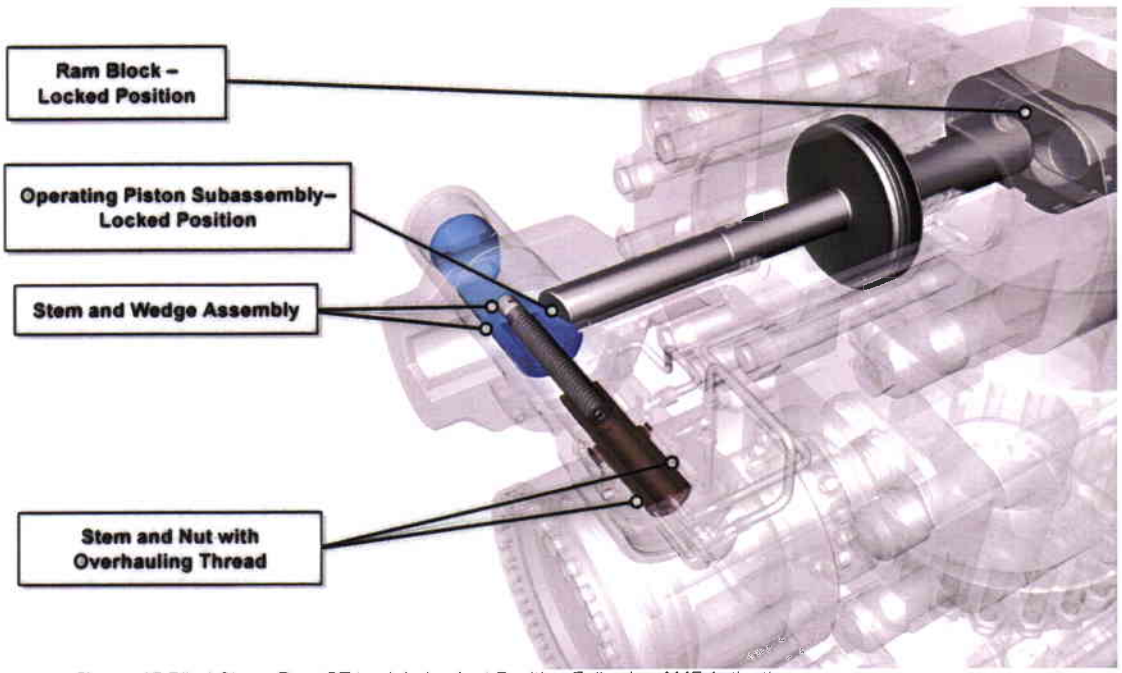

Figure 17 Blind Shear Ram ST Lock in Locked Position Following AMF Activation

The blue pod was lowered and latched to the *Deepwater Horizon* BOP on July 9, 2010. The pod was ready but not used for the incident response. It was recovered with the BOP in September 2010.

The blue pod AMF system was tested at NASA Michoud on March 3, 2011, with the following results:

- The AMF battery voltage levels were recorded at 8.90V for SEM A 9V battery, 8.61V for SEM B 9V and 0.71V for the 27V battery pack.[105]
- It was determined by the NASA engineer at Michoud that the initial battery voltage readings taken in July 2010 on the *Discoverer Enterprise* were incorrectly measured by the technician. The readings taken on the pod at Michoud were verified three times and are correct.
- The AMF system was tested and did not initiate the sequence.[106]
- When 230V power was re-applied from the PETU to the pod, the AMF system completed the sequence and activated solenoid 103.[107]
- SEM A AMF processor was inactive, confirming that it had completed the sequence and shut down as designed.
- SEM B AMF processor was active, confirming that it had not completed the sequence due to a low amperage 9V battery pack.
- Further inspection of the blue pod AMF system is ongoing at NASA Michoud at the time of publication of this report.

Voltage measurements taken on the blue pod 9V AMF batteries showed that they were at satisfactory voltage levels; however, voltage tests alone are not indicative of the battery condition. The batteries must be tested under load to determine whether sufficient energy remains to operate the AMF processor.

Investigation Team Findings

The 9V battery for SEM B in the blue pod did not have sufficient power to boot the AMF processor, which triggered a cycle that attempted activating the process every three minutes, reducing battery charge each time. The AMF cards have a "low voltage drop out" feature that prevents the 9V battery from powering the Programmable Logic Controller (PLC) when voltage is less than 5V. This allows the 9V battery to rest and regenerate; however, a higher voltage reading is not indicative of the remaining stored energy. The investigation team demonstrated this phenomenon in the lab where a 9V battery was drained to 0V at 32°F. The voltage readings increased as the battery returned to room temperature but tested near 0V when put under load, indicating that voltage readings alone are not a valid indicator of battery condition.

Once the AMF is armed at the surface control panel, upon loss of power from the rig to the BOP, the 27V battery will power the subsea transducer module (STM) that measures surface hydraulic and subsea hydrostatic pressures that are parameters used to activate the AMF sequence. The 27V battery remains connected to the STM while both SEM PLCs boot, execute, then reset and disconnect the 27V battery from the STM. In the case of the blue pod, SEM B PLC did not boot or reset (indicating low 9V battery power). From the time of the incident until the blue pod was recovered 74 days later on the *Discoverer Enterprise,* the SEM B AMF card continued to cycle the 27V battery power to the STM transducers each time the AMF card initiated the restart process, thus draining the 27V battery pack. The "dead" 27V battery combined with SEM B not re-setting during the AMF test at the NASA Michoud facility indicates the blue pod AMF activated on SEM A at the time of the incident.

Testing performed by the investigation team is further explained in *Appendix N,* and testing performed on the blue pod at NASA Michoud indicated that the AMF system activated solenoid 103 on SEM A, and then solenoid 103 activated the HP shear circuit to close the BSRs at the time of the incident.[108]