InterLink Systems, Inc.
5116 Bissonnet #341, Bellaire, TX
77401
Telephone and Fax: (713) 663-6361
jamesmcadams@alumni.rice.edu

Cameron SEM Automatic Mode Function Tests

James P. McAdams, PE
Interlink Systems, Inc.
Texas Registered Engineering Firm F-8069

Deepwater Horizon Incident Investigation – CF3-NTF20 AMF card electrical characteristics test results

Status:	**FINAL**	**APPROVED: Fereidoun Abbassian**
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		AMF card electrical characteristic test result - BP
Persons Interviewed:		
Reference document/s file name/s:		
Interlink Systems Cameron -63 Cameron SEM Automatic Mode Function Tests		
Note to File		

Introduction:
This Note to File identifies the results of a test performed by Interlink Systems characterizing the Cameron SEM (Subsea Electronic Module) AMF (Automatic Mode Function) function tests. That report is attached.

Executive Sumary:
A series of tests were conducted on a Cameron Mark I SEM with an AMF version 1.6 installed. The tests were conducted to better understand electrical characteristics of the AMF, the pressure transducers and solenoids with respect to the 9 volt and 27 volt battery supplies.

The tests show that the AMF card uses the 27 volt batteries to not only power the tranducers and relays on the AMF board but also to supply SEM transducers and solenoids. Testing determined that the 27 volt battery would need to produce a minimum of 15.7 volts to successfully operate an AMF sequence. The finding also conclude that with inadequate voltage on the 27 volt circuit, the 27 volt batteries are capable of discharging all the way to 0 due to open circuits in the solenoid.

When the AMF card is armed the 9 volt battery pack supplies the Central Processing Unit (CPU) chip, which in turn signals the system that the card is armed and available to function. Testing determined that the minimum voltage required for CPU operation is 3.5 volts. When the battery reaches that level, the CPU stops fucntioning and ceases to demand power from the battery, closing the circuit. Therefore, it is unlikely that the AMF card will function as designed at battery output lof 3.5 volts or less.

Conclusion:
The Cameron AMF function testing revealed that the AMF system would not work with a 9v battery with less than 3.5 volts, and that the system needs a minimum of 15.7 volts on the 27 volt batteries to complete an AMF sequence.

Further Testing:
The investigation team has conducted additional testing on the SAFT bateries to determine discharge characteristics and how they affect the votage monitoring with and without current applied. These findings can be found in CF3 NTF31.

Rev.	Date	Description	Origin.	Check.	Approv.
05	12 Sept 2010	Second reading with corrections of grammar and clarifications of wording.	JPM		
04	1 Sept 2010	All sections filled out for initial draft.	JPM		
03	26 Aug 2010	Drafts of all sections except the test details finished and edits included per suggestions from Andy Garnett	JPM		
02	24 Aug 2010	Expanded after an initial review, still incomplete text and no test data	JPM		
01	19 Aug 2010	Begin initial outline and text.	JPM		

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Introduction

The Cameron Mark I and Mark II BOP control pods can be supplied with an Automatic Mode Function (AMF). The purpose of the AMF is to execute an emergency well shut in upon a catastrophic loss of the riser (specifically, complete loss of hydraulic pressure and electrical power to the BOP). After being armed and charged with fluid, the AMF does not depend upon the surface equipment for electrical or hydraulic power, having its own hydraulic accumulators and batteries.

The Macondo BOP was fitted with an AMF system at the time of the incident. There are independent AMF systems in the Blue and Yellow Pods and it appears that neither of them functioned properly. Soon after the incident, the Yellow Pod was retrieved to the Helix Q4000 for modifications to allow it to be put back in service and it was found to be electrically functional but with a faulty solenoid valve that kept the high pressure shear function from operating. Later, the Blue Pod was retrieved to the Transocean Discoverer Enterprise for similar modifications and was found to have low battery voltage.

The purpose of this series of tests is to examine whether the batteries in the Blue Pod could have executed an AMF sequence at the time of the incident and to estimate what the state of the Blue Pod batteries was at the time of the incident.

Summary

The AMF system normal operation

The electronic control system in each pod is shown schematically in Figure 1. For the purpose of this report, the control system consists of a set of dual coil solenoid valves operated by redundant Subsea Electronic Modules (SEM's), A and B. Each SEM has an associated AMF circuit board. Also, each SEM generates a heartbeat signal that consists of a series of pulses applied to a single wire that is shared between the two pods. The heartbeat of all SEM's is monitored by all four AMF circuits. All of the electronics for a pod is sealed inside of a nitrogen-filled pressure vessel.

Before starting to drill, the operator arms the AMF system by sending a signal to the AMF circuit board via the SEM. This turns the AMF board on and it then operates from the 9V battery and sends a continuous active signal to the SEM. In operation, the AMF board monitors the SEM heartbeat, 24V from the AC supplies, the conduit pressure, and the hydrostatic head pressure. If all of those inputs are normal, the AMF circuit does nothing.

If an armed AMF circuit loses the SEM heartbeat (meaning that all 4 SEM's are inoperative), the 24V, and conduit pressure, it applies battery power to its SEM. The SEM, as it is booting up, sees the AMF active signal and executes the AMF sequence. At the end of the sequence, the SEM disarms the AMF circuit, thereby removing all battery power from the SEM and the AMF circuit.

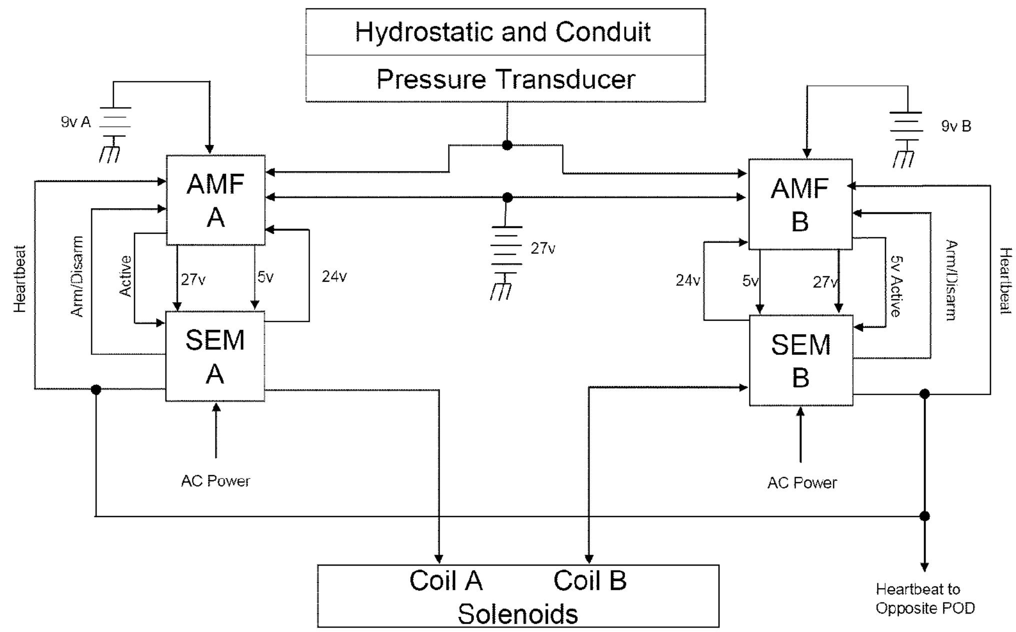


Figure 1 - Simplified AMF system schematic

Blue pod condition when recovered

There are three batteries in each pod electronic module: 9V A, 9V B, and 27V. The 9V battery operates one AMF circuit and is used to operate one SEM when an AMF sequence is triggered. The 27V battery is used by both the A and B electronics. It operates relays on the two AMF circuit boards and the solenoid valve drivers in each SEM.

When the Blue Pod was retrieved from the BOP stack, the voltages of the batteries were measured using a high impedance voltmeter and were recorded (and photographed) as follows:

9V A = +8.78 volts   9V B = -0.14 volts   27V = -7.61 volts

The batteries were not measured directly since the cover was not removed from the pressure vessel. Instead, they were measured by way of a pie connector that is wired to the batteries specifically for the purpose of testing the batteries without removing the cover. The sign (±) of the voltages is significant and is discussed in the section *Measured the batteries using incorrect common pin.*

At the time that the voltage measurements were made, attempts were made to run an AMF sequence. For both the A and B SEM's, the AMF circuit was successfully armed via the PETU and the proper active signals were returned by the SEM's and displayed on the PETU. When the AC power was removed, the AMF sequence should have been triggered, but was not. Then, when AC power was restored, the AMF sequence did trigger and ran to completion.

Questions Originally Posed

- Given the observed state of the batteries, what was their state at the time of the incident?
- At the time of the incident, could the Blue Pod have run an AMF sequence?
- At the time of the incident, would the AMF circuit have detected the low conduit pressure?

Most likely conditions at the time of the incident

Battery State

The outcome of these tests suggests strongly that the battery voltages measured after the incident were confused. The voltages reported are probably correct, but attributed to the wrong batteries.

When measured on deck, the 9V B battery was reported to be 0.14 volts but that cannot have been the case. First of all, in order to have an active signal on the PETU, the AMF circuit computer must be operating, which requires at least 3.5 volts from the 9V battery. The active signal was observed on the PETU for both SEM's, so the 9V B battery voltage for each SEM had to be at least 3.5 volts.

In addition, the AMF circuit pulls almost no current if the 9V battery is less than 1.5 volts so there is no obvious mechanism for discharging the 9V battery to 0.14 volts. Finally, there is an easily demonstrated mechanism for discharging the 27V battery to 0.14 volts. Therefore, it is reasonable to conclude that the voltages of 9V B and 27V were swapped in the after-incident test.

The most likely states of the batteries are shown in the following table.

Time	9V A	9V B	27V
Measured Upon retrieval	8.78 volts	7.61 volts	0.14 volts
Estimated for the time of the incident	8.78 volts	7.61 volts	< 14 volts

Could the Blue Pod have run the sequence?

Regardless of whether the 9V and 27V battery voltages are swapped, the Blue Pod could not have run an AMF sequence at the time of the incident. The argument for this is as follows.

In order to operate the relays on the AMF circuit board and the solenoid valves, the 27 volt battery must be able to deliver more than 14 volts. If the AMF sequence completes, the SEM disarms the AMF circuits, removing the load from the batteries. If this had happened, the 27V battery would have been found with more than 14 volts. No battery was found with more than 14 volts.

Furthermore, if an armed AMF detects an AMF condition, it tries to actuate relays to apply power to the SEM, transducers, and solenoid. The relays get their power from the 27V battery. If the 27V battery is less than 14 volts (which apparently was the case), the relays do not pull in, the SEM gets no power, and the sequence cannot run. As long as the 9V battery stays above 3.5 volts, the AMF circuit will stay in this state, draining what power is left in the 27V battery.

These tests suggest strongly that, due to the 27V battery being low at the time of the incident, both AMF circuit boards were trying, unsuccessfully, to run the AMF sequence for the 75 days the Blue Pod remained on the stack following the incident, draining the 27V battery completely. If this is correct, then it would be extremely unlikely that the AMF in the Blue Pod could have successfully completed an AMF test prior to being deployed at Macondo.

Could the AMF Circuit detect the low conduit pressure?

The original purpose of this question was to determine if SEM A could have run the AMF sequence. The idea was that with a low 27V battery, the pressure transducers may not have worked well enough at the time of the incident for the AMF circuit to detect the low conduit pressure and trigger the AMF sequence.

To the contrary, the direct answer to the question is that the AMF circuit could and would have detected the low conduit pressure. In fact, even with a dead 27V battery the AMF circuit will interpret the lack of transducer voltage to be "low conduit pressure" and try to trigger the AMF sequence. But, as explained above, the relays required to connect power to the SEM did not have enough voltage to operate, so the sequence could not run. Any voltage from the 27V battery that can operate the relays will also operate the transducers.

Test Objectives

Understand AMF normal operation

What, for sure, are the conditions required to trigger an AMF sequence? The conditions of the batteries certainly affect the ability of the equipment to operate correctly. The tests should confirm or define the conditions under which the AMF will trigger.

Examine transducer operation at low battery voltage

What is the definition of "low conduit pressure"? The tests should define this and examine the effects of low voltage in the 27V battery.

Examine conditions that could deplete the batteries

A normal AMF sequence draws a small amount of energy from the battery and then turns all of the electronics off, stopping further depletion of the battery. Yet, at least one of the batteries was found almost totally drained. The tests should examine ways that this could have occurred.

Examine other ways that the conditions when recovered could occur

The test program should remain flexible enough to recognize and examine any other unforeseen conditions that would shed light on the conditions at the time of the incident.

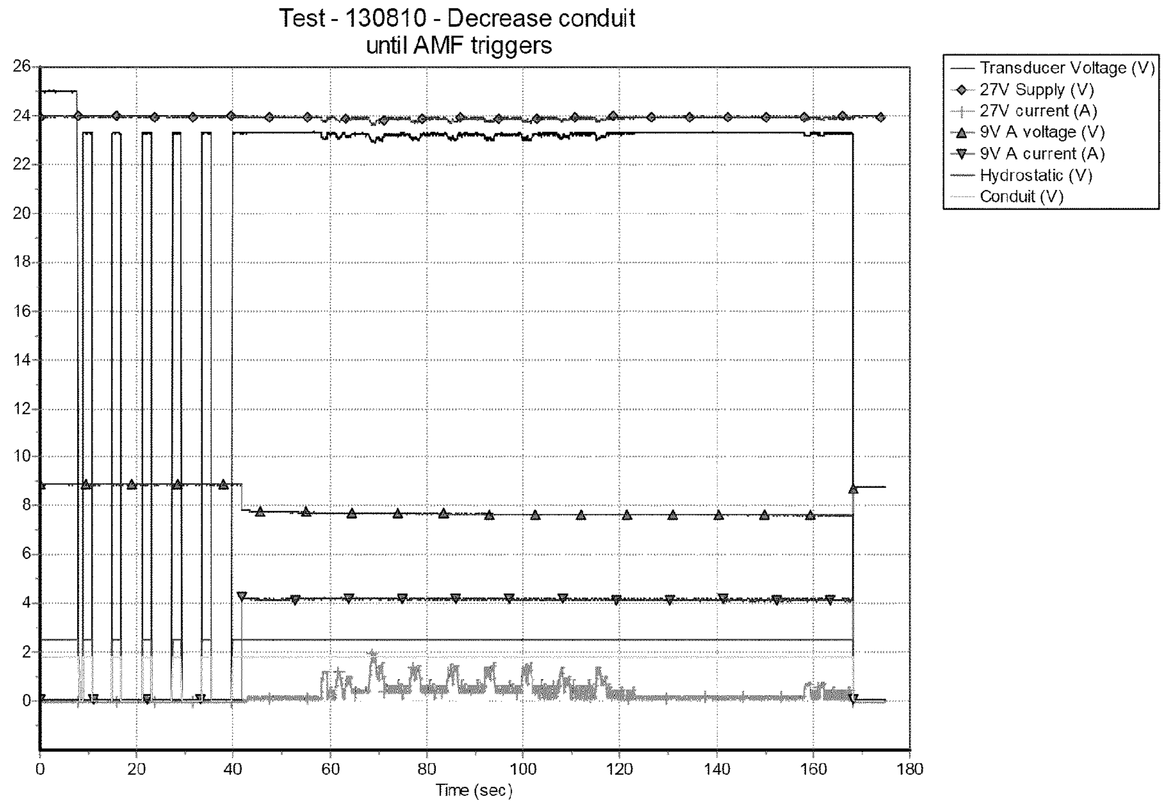
Tests in Chronological Order

Test results that relate to the data in this report appear in this section. All tests were done in August 2010. Most tests were recorded by a data acquisition system (DAQ). Test numbering is based on the DAQ file name and consists of the day, hour, and minute. Not all test files are reproduced here since some were redundant, had errors, or were irrelevant.

Test 130810 – AMF conduit pressure trigger point

This is **Test 1 in** the hand notes of **Appendix 1**. The purpose was to measure how close the conduit pressure has to be to the hydrostatic pressure for the AMF to trigger. The AMF triggered with the conduit about 750 psi above the hydrostatic pressure (conduit = 2784 psi, hydrostatic = 2028 psi). The hydrostatic was set to approximately the same depth as Macondo.

The last stage of lowering the conduit pressure and the complete AMF sequence that resulted are recorded in the following plot from the DAQ. The PETU was turned off at about 8 seconds, resulting in the loss of voltage to the transducers.



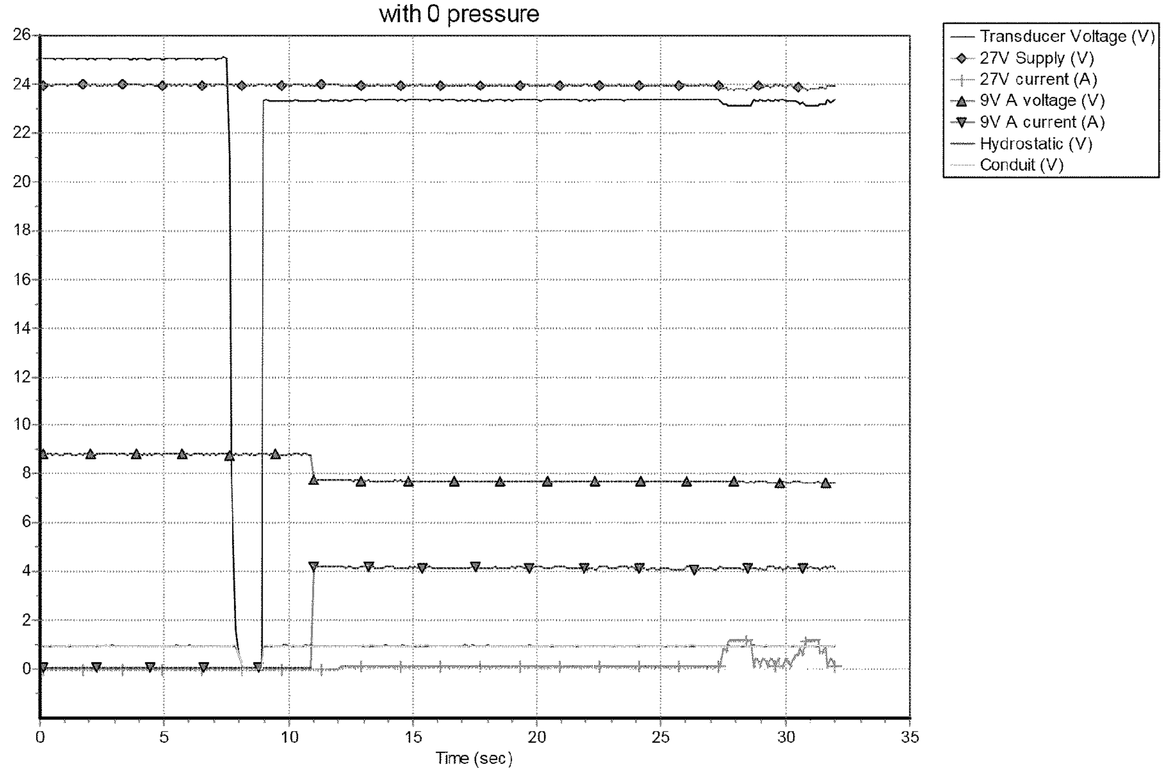
These traces are recording the voltage at the analog inputs of the AMF circuit. The conduit voltage is less than the hydrostatic voltage in the plot because the conduit pressure transducer is 850 bar full scale, while the hydrostatic pressure is 350 bar full scale. Both are 4-20 ma transducers and the voltage is developed across a 240 ohm shunt. So, to convert plot voltage to pressure, you use the following relations:

Conduit Pressure (psi) = 3210 * (Volts – 0.96)
Hydrostatic Pressure (psi) = 1322 * (Volts – 0.96)

Test 130822 – AMF test simulating zero pressure

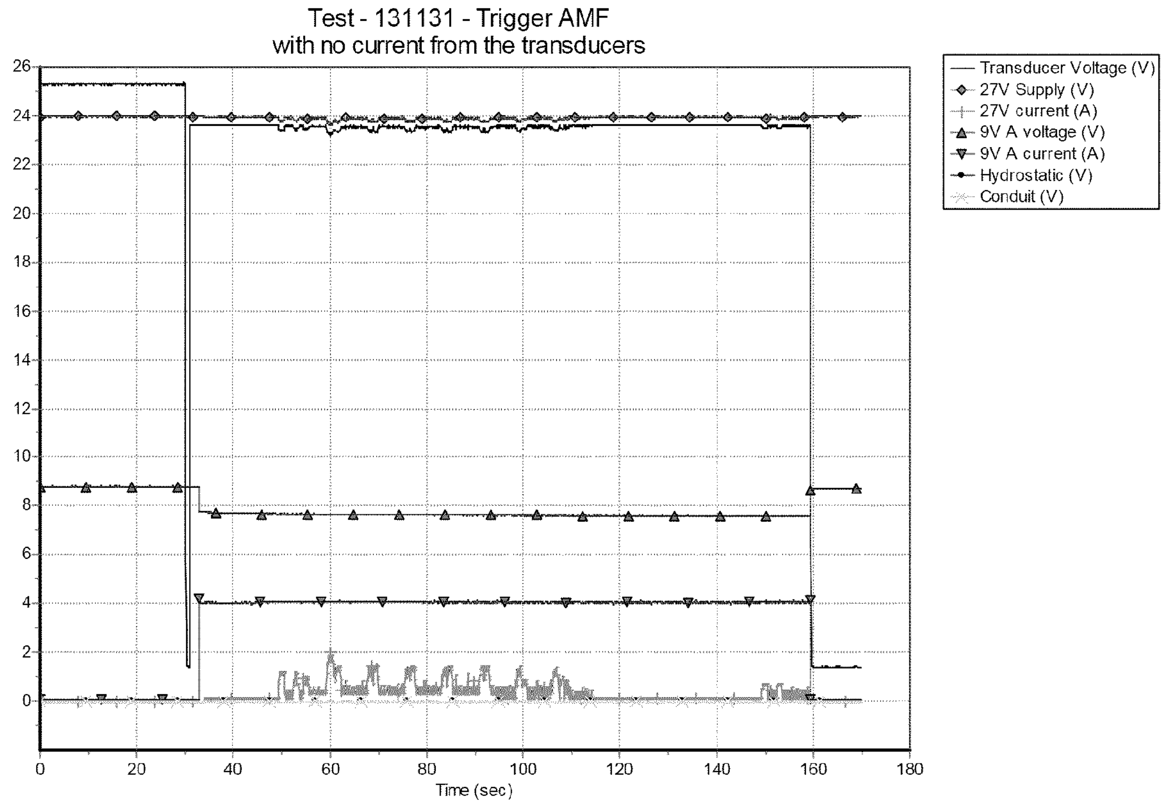
Test 2 in Appendix 1 approximates an AMF test as it would take place on deck, with atmospheric pressure on the conduit and hydrostatic transducers. Both analog inputs are set to 4 ma for this test. The PETU was turned off at about 7.5 seconds and it can be seen that the AMF triggers at about 9 sec. The AMF circuit boots up the SEM at 11 sec, and the small (almost invisible) step in the 27V current at 12 sec is the current in the solenoids driver circuits when the solenoid relay pulls in. Only part of the AMF sequence is shown.

Test - 130822 - AMF test
with 0 pressure



Test 131131 – No current from the conduit or hydrostatic transducers

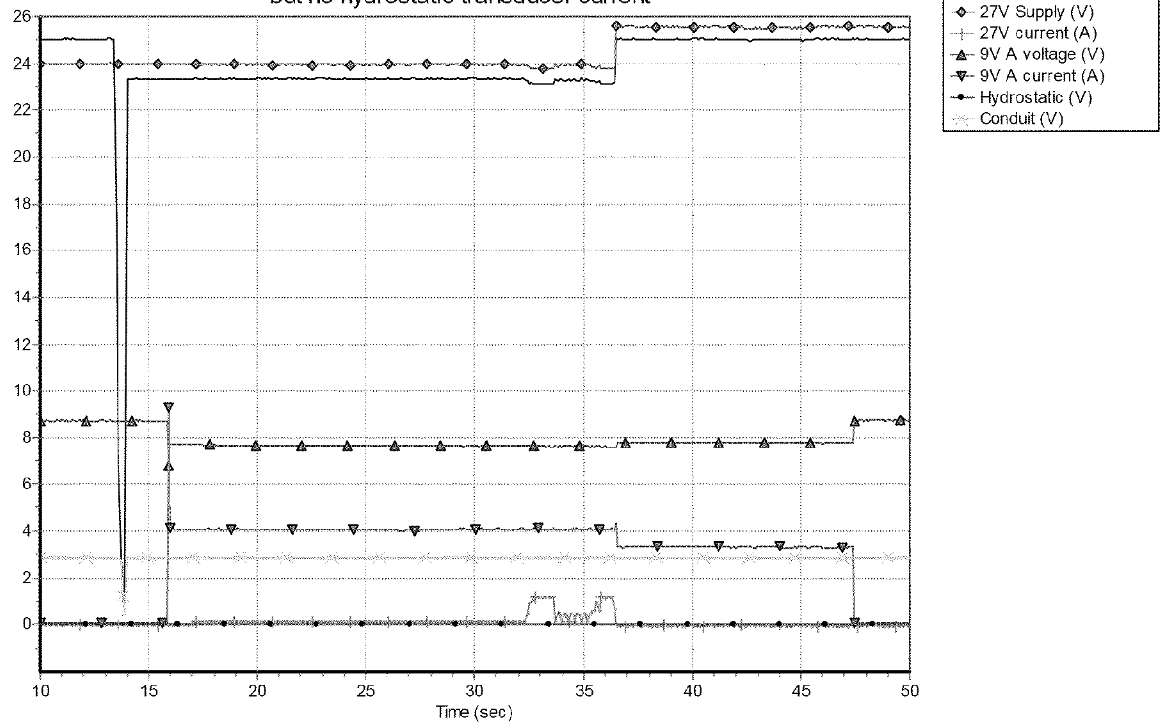
Test 3 in Appendix 1 examines what the AMF system will do if current from the transducers is simply missing. The transducers were turned off, leaving 0 ma on the conduit and the hydrostatic inputs. When the PETU was turned off, the AMF sequence was triggered.



Test 131157 – Trigger AMF with conduit pressure, then failure to disarm

Out of curiosity, we decided to see what the AMF would do having conduit pressure but with no current on the hydrostatic channel. The conduit was set to 12 ma (6171 psi) and the hydrostatic current was set to zero. This test yielded two surprises.

The first surprise was that the AMF was triggered when the PETU was turned off, in spite of the pressure on the conduit channel. My guess is that the internal arithmetic uses unsigned integers and the hydrostatic head being below 0 psi is somehow messing up the comparison between it and the conduit pressure. This is not relevant to the incident and is hard to examine without the software source code. So the matter was not investigated further. The DAQ record of this test follows.



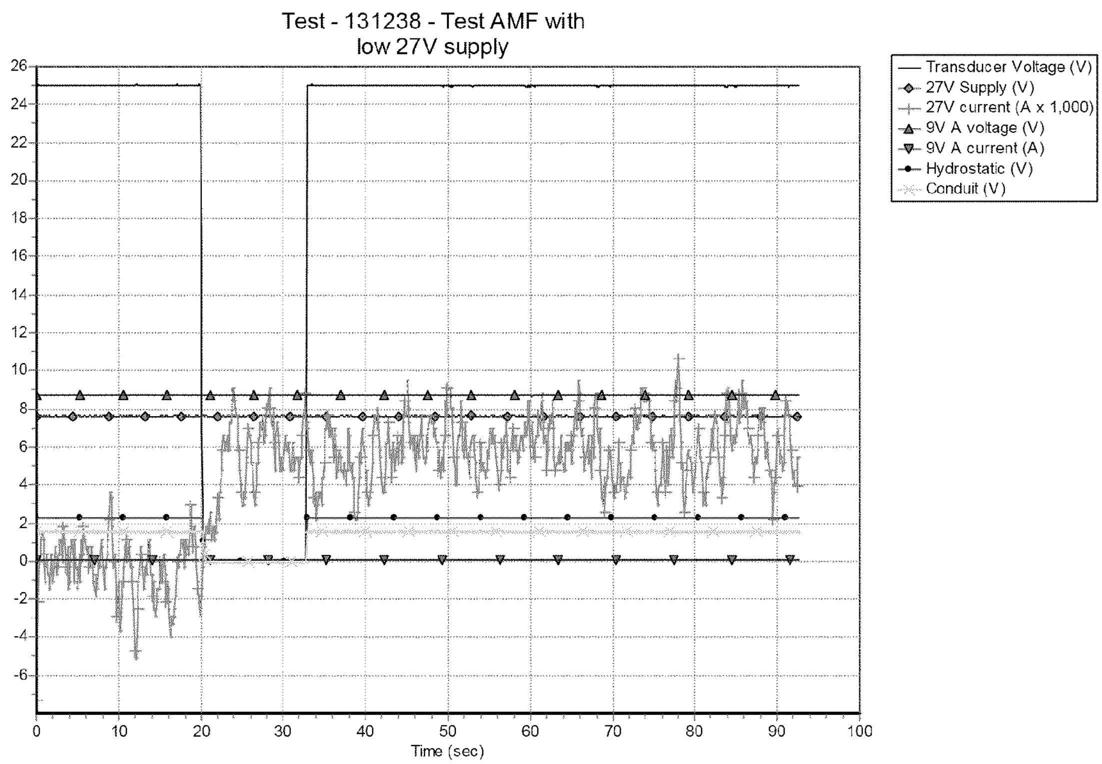
The second surprise in this test is that the sequence armed when it should have disarmed. That is not apparent in the plot. Here is the sequence of events.

At about 13.4 seconds the PETU was turned off and the AMF triggered normally as a result. Then, at 36.5 seconds, before the AMF sequence finished, the PETU was switched back on. At that point, the 24V internal supplies took over and current no longer came from the battery. Also, the 9V battery current dropped as the internal supplies took over part of the 5 volt SEM power.

At 47.5 seconds, the AMF circuit was disarmed and the current in the 9V battery went to zero. Everything to this point was expected. The SEM continued to run the AMF sequence. Then, at the end of the sequence (not visible on the plot), when the SEM should have disarmed the AMF card, it rearmed it instead. This is potentially of significance to the final conditions of the batteries. How this can happen is discussed in sections titled *Test 171531 - Arm/Disarm Waveform* and *Failure to Disarm*.

Test 131238 – AMF test with low 27V supply

Test 4 in Appendix 1 simulates a very low 27V battery and a virtually dead 9V B battery. The A and B AMF circuits were both armed and the analog inputs set for "low conduit pressure" (conduit = 2073 psi, hydrostatic = 1729 psi). It was confirmed that the B SEM never received an active signal from its AMF circuit, even though the AMF circuit card was armed (the relay could be heard when the AMF was armed and disarmed). Below are DAQ recordings of the sequence.



In the DAQ record, the 27V current is magnified by a factor of 1000. Though noisy, it can be clearly seen that a couple of seconds after removing the PETU power, the current from the 27V supply increases by about 6 ma. This is due to the A AMF circuit actuating its 3 relays in an attempt to trigger the AMF sequence. But in this case, the voltage is too low and nothing happens.

Nothing happens, that is, until the PETU power is restored at 32.7 seconds. It cannot be seen in any of the data in the plot, but at that time, the A SEM rebooted, ran its AMF sequence, and disarmed its AMF card. The 27V current does not change when PETU power is reapplied because 1) the relays get current only from the 27V battery, so the relay current does not go away and 2) the SEM 24V supplies power the solenoids and transducers so their current does not come from the 27V battery connection.

Test 131249 – AMF test with low but increasing 27V supply

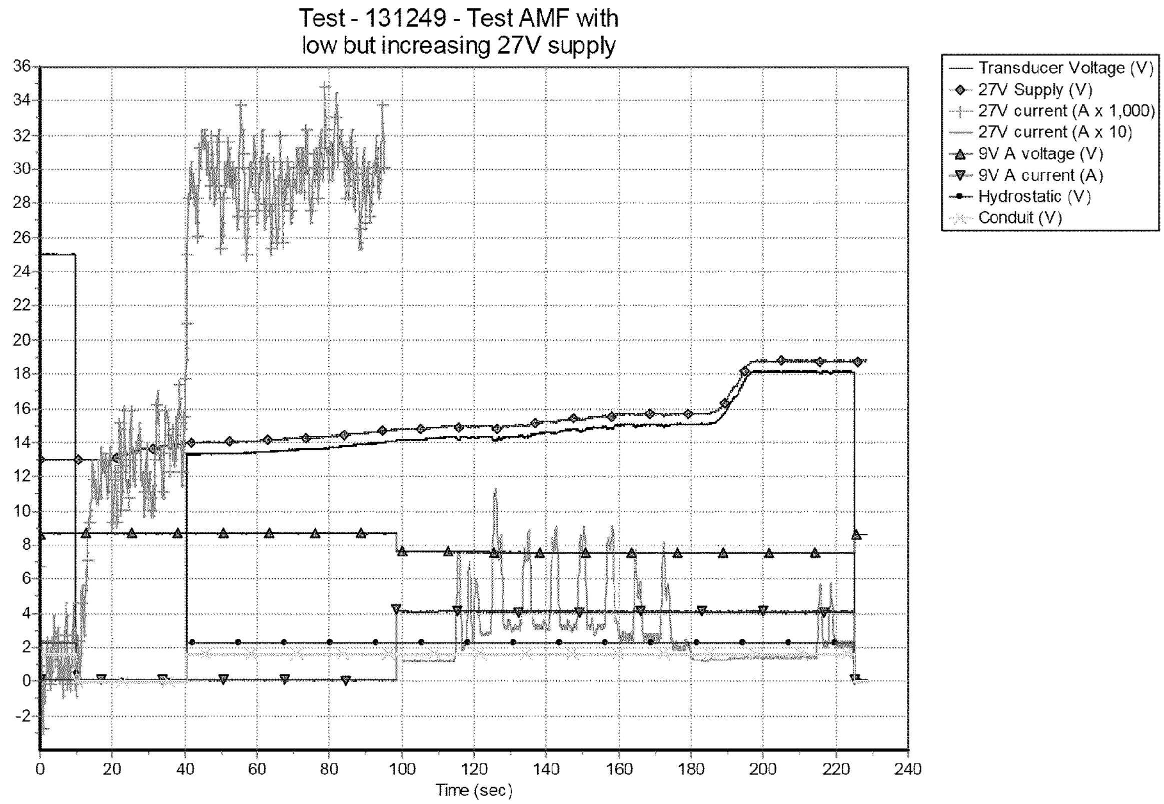
This test starts out just like 131238, with an armed AMF circuit, low conduit pressure, and a low 27V battery supply. Again, the AMF tries to trigger the AMF sequence but cannot pull in its relays. In this case, the 27V supply is raised until the relays, and then finally solenoids, operate.

As in Test 131238, the 27V current is magnified by a factor of 1000 for the first 95 seconds so that small currents can be seen. In this case, you can see the current increase due to the relays being turned on at about 13 seconds. Then, nothing more happens until about 40 seconds when the transducer solenoid pulls in. At that point you can see the additional current pulled from the 27V supply by the transducers.

The 27V supply continues to increase and at about 90 seconds is high enough that the relay pulls in to apply 9V A battery power to boot the SEM. At this point, the A SEM boots up and starts running the AMF sequence. In the plot, the scale of the 27V current is multiplied only by a factor of 10 so that the solenoid currents can be displayed at a reasonable scale.

At about 115 seconds, it is obvious that the solenoid relay has pulled in because you can see solenoid current. But no solenoids were actually heard pulling in until the voltage reached 15.7 volts at about 165 seconds. After that, the 27V supply was ramped up more quickly and the sequence finished and disarmed the AMF circuit at about 225 seconds.

As well as can be judged from the data, the transducer relay pulled in first at 14.0 volts. That was followed by the 5V relay at 14.7 volts, the solenoid relay at 14.9 volts, and a solenoid at 15.7 volts. All of these pull in points vary from relay to relay. The relays may well pull in a different order on a different AMF circuit board.



Test 131305 – "Chattering" Relays

Three tests were done adding 0.2 to 0.3 ohms in series with the 9V A battery. A plot is not included because the plots are hard to interpret and the tests represent an artificial situation. But the test is related to something that could occur with real batteries, so the description below is worth considering.

When the AMF applies 5V to the SEM, the SEM draws a large initial surge of current as it charges various filter capacitors. This surge would cause a drop in the 9V supply. When that drop is large enough, it causes the AMF board to reboot. All of the relays drop out, allowing the 9V supply voltage to increase. The AMF circuit then detects the AMF condition again and tries to boot the SEM causing another current surge. The whole cycle then repeats 10 times per second causing a chattering sound to come from the relays.

There is no way out of this state except for the 9V or 27V battery to discharge low enough to not be able to pull in the relays.

I call this an artificial condition because a low battery does not act just like a resistor. If the battery has been sitting with no load for a while, it can supply a brief surge better than it can supply a continued draw. So a real battery would be able to deal with the surge better than a battery in series with a resistor. Still, there is the possibility that the SEM could start the AMF sequence, draw the 9V battery down too low and either reboot itself or the AMF circuit. This was not tested for, nor was anything like this observed in other tests.

Test 131549 – Test effect of a dead 9V battery

Two tests similar to 131238 were performed to confirm the effect of a dead 9V battery. In the first test, SEM A had a good 9V battery, while SEM B did not have a 9V battery. The 27V supply was set to 7.6 volts.

Both SEMS could be armed. But without the 9V battery, SEM B reported the AMF as "inactive" to the PETU. Temporarily connecting a 9V B battery caused the signal to change to "active" for the B AMF on the PETU. This confirmed that the AMF was really armed. The 9V B battery was then removed.

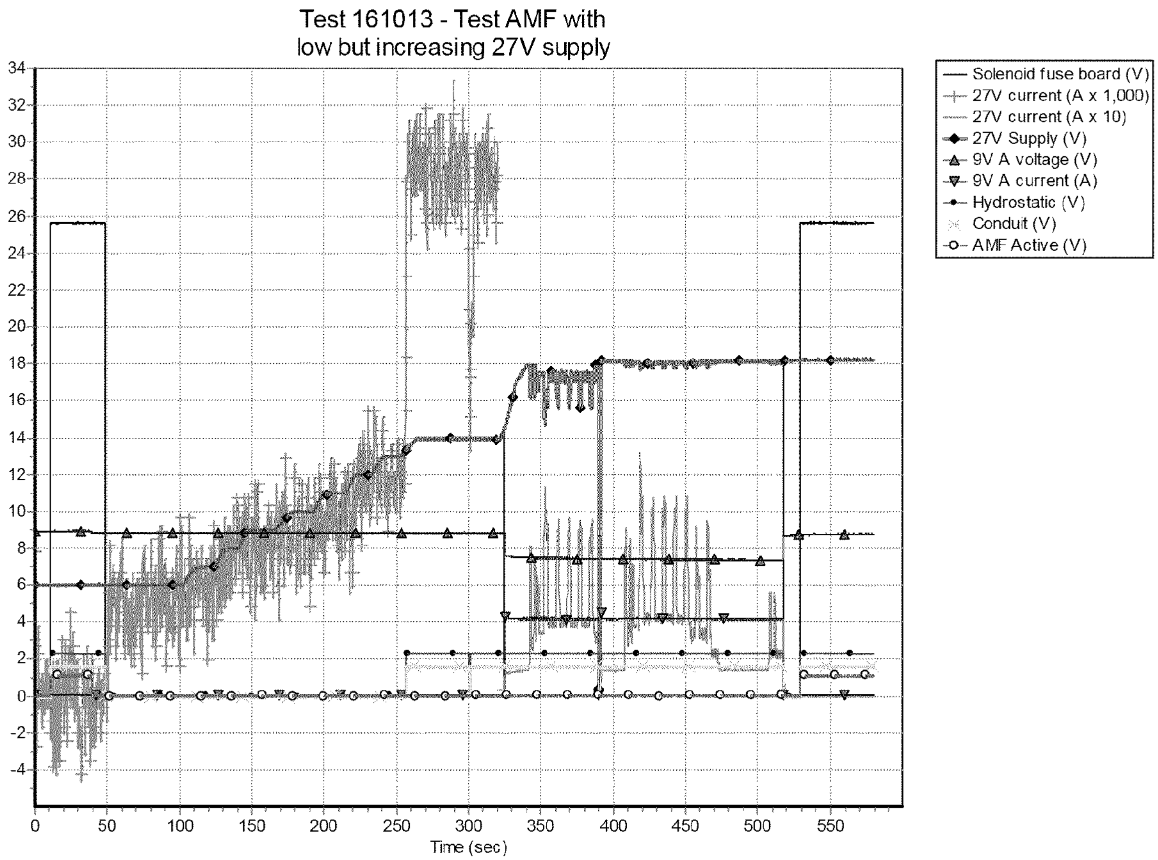
Turning off the PETU did not result in an AMF sequence since the AMF circuit could not pull the relays in (due to low 27V). But turning the PETU back on allowed SEM A to run the sequence and disarm the A AMF circuit. SEM B did not run the sequence and temporarily applying the 9V B battery showed AMF "active" on the PETU proving that the B AMF circuit was still armed. SEM B never ran the AMF sequence because the AMF "active" signal has to be present at the time the SEM runs its boot up routine.

A really low 9V battery (less than 2V under load) completely inhibits the operation of that AMF circuit.

Test 161013 – 27V current vs voltage for entire sequence

This test is a more detailed version of Test 131249, in which an AMF condition is set up with low 27V supply voltage, and the 27V supply is then increased until the sequence can run. In this case, the AMF active signal is recorded.

This test is an excellent record of the current that will be drawn from the 27V battery in various situations. To see low currents, the 27V current is multiplied by 1000 for the first 320 seconds, which results in a noisy signal since it is near the lower limit of the DAQ. The various events in the test are described following the plot below.



The PETU was turned on at about 10 seconds with the AMF inactive (1.1 volt on the active signal). The AMF was then armed at 38 seconds (AMF active goes to 0 volts) and the PETU turned off at 48 seconds.

Up until the PETU is turned off, there is no current being drawn from the 27V battery. When the PETU is turned off, the 27V current jumps up as the relays are energized by the AMF circuit. As the 27V supply voltage increases over the next 200 seconds, the current follows the voltage with the 3 relays looking roughly like a 1000 ohm resistor.

At 257 seconds, the 27V supply voltage is high enough to actually pull in the transducer relay. This causes a jump in the 27V current as it supplies the transducers as well as the relays.

At 324 seconds, the rising 27V supply pulls in the relays for the SEM 5V and solenoids and the SEM then boots up and starts pulling about 4 amps from the 9V A battery. At this point the magnification of the 27V current is changed to keep the scale reasonable to display the pulses in the solenoids.

At 390 seconds the SEM rebooted. I did not note what happened, but it is clear from the data that in the period between 340 and 390 seconds, either there was a poor alligator clip connection for the 27V or the 27V power supply was current limiting. This is indicated by the relatively large voltage swings in the 27V supply voltage. At 390 seconds, something was done that fixed the condition (as evidenced by the smaller voltage swings that follow), but the 27V was also briefly disconnected causing the relays to drop out, rebooting the SEM.

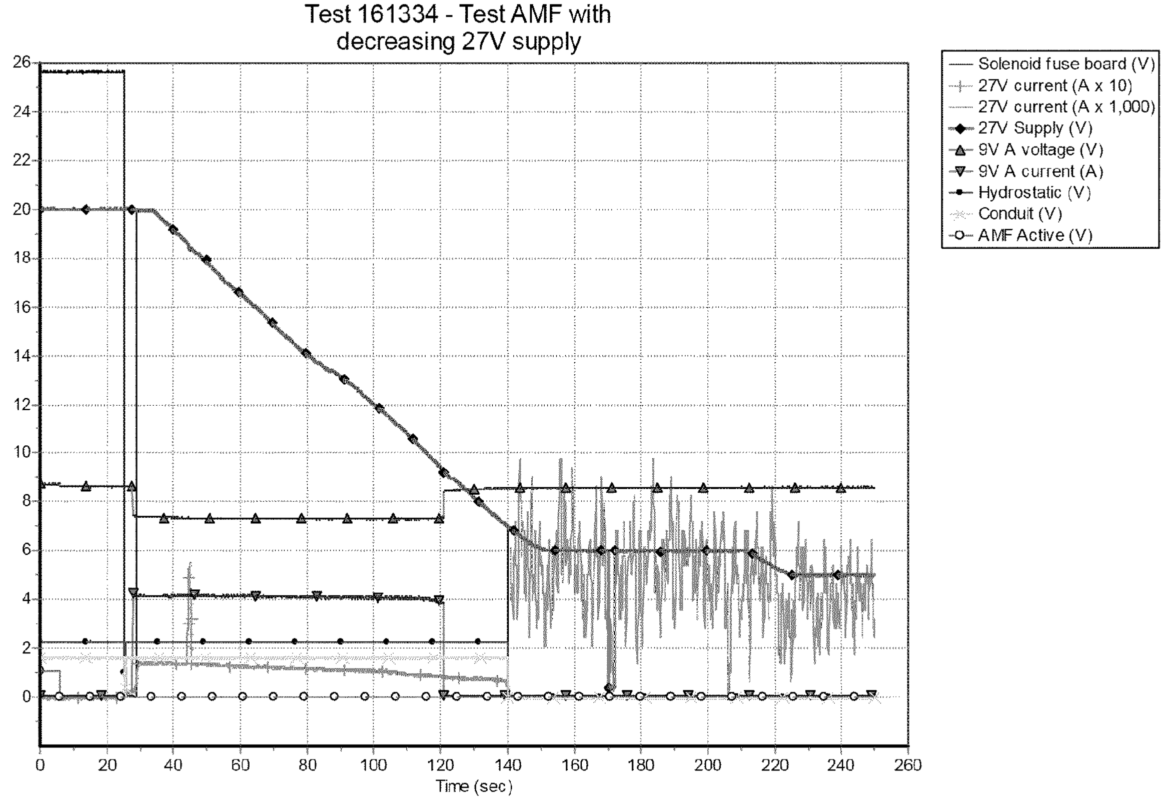
After 390 seconds, the AMF sequence ran normally and disarmed the AMF at 517 seconds. The PETU power was restored at 529 seconds at which time the AMF active signal confirms that the AMF is disarmed.

Test 161334 - AMF test with decreasing 27V supply

Test 161334 is the opposite of 161013; it starts with an elevated 27V supply which is then reduced until the AMF relays drop out. The AMF sequence in this test is different from 161013 in that it actuates one solenoid for a second, waits 100 sec, and then actuates the solenoid for one more second before disarming the AMF.

In this test, the AMF is armed via the PETU at 6.4 seconds, and then the PETU is turned off at 25 sec. In this test, one DAQ channel monitors the fuse board that supplies the solenoid drivers. You can see that the AMF card actuates the solenoid relay about 1 second after booting the SEM.

In this test, SEM operation terminates prematurely at 121 seconds when the 5V relay drops out. The solenoid relay is still pulled in and supplying the solenoid drivers because the 27V current is still around 75 ma. The solenoid relay drops out at about 140 seconds. Since the SEM is not running, the AMF sequence is not finished and the AMF is not disarmed. This test result is included as a matter of completeness, but is not obviously related to the incident.



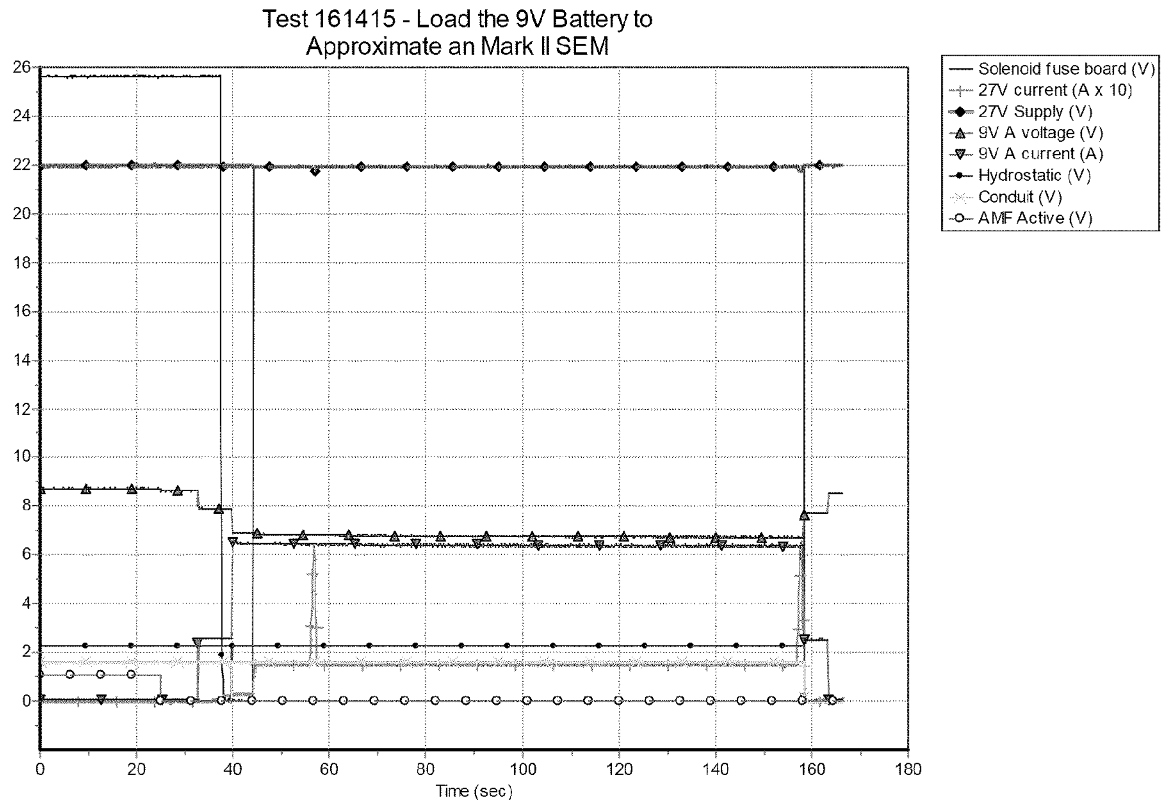
Test 161415 – Approximate a Mark II SEM

The Mark II SEM used on the Horizon is larger than the Mark I used in these tests. Test 161415 approximates the operation of a Mark II SEM by adding 2 amperes to the 9V A battery. The internal 5V supply for the SEM is too small to supply the extra current, so a 3 ohm resistor was applied to the 9V battery. This test is only significant in its effect on the battery.

The AMF sequence in this test actuates one solenoid for a second, waits 100 sec, and then actuates the solenoid for one more second before disarming the AMF.

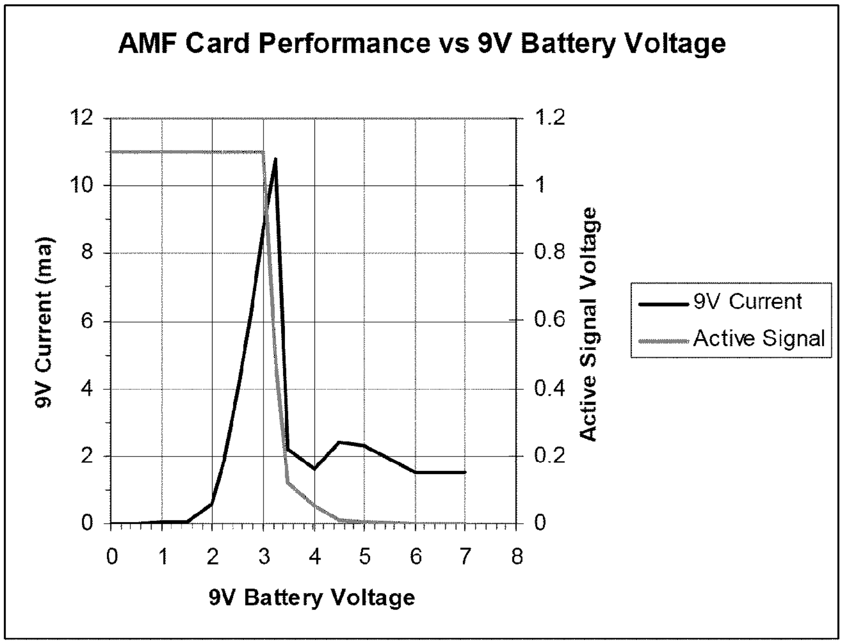
The AMF is armed at 25 seconds and the 3 ohm load is applied at about 32 seconds. The PETU power is removed at about 38 seconds, starting the AMF sequence and increasing the 9V A current to about 6.5 amps. The sequence ends normally at about 158 seconds and the 3 ohm resistor is removed shortly after. The battery in use here is one that had been removed from a SEM for normal battery maintenance. It had been used in this series of tests to run several AMF sequences, so it is nearing the end of its life. The more discharged the battery is, the lower will be its voltage when loaded. In this case, the battery drops to about 6.8 volts with the 6.5 amp load.

In the AMF circuit board there are voltage drops in wiring and other components. It is necessary to supply 6.25 to 6.5 volts to the connector on the front of the AMF circuit board for the 5V output to the SEM to be proper. A 9V battery that drops to 6.8 volts under load is marginal for the operation of the AMF sequence. This limit is demonstrated in Test 160303.



Test 171500 - AMF 9V Battery Current vs Voltage

The current drawn by an armed AMF circuit was measured as a function of voltage. The current was, in general too low to measure with the DAQ so it was measured with a hand held meter. The results are shown in the following plot.

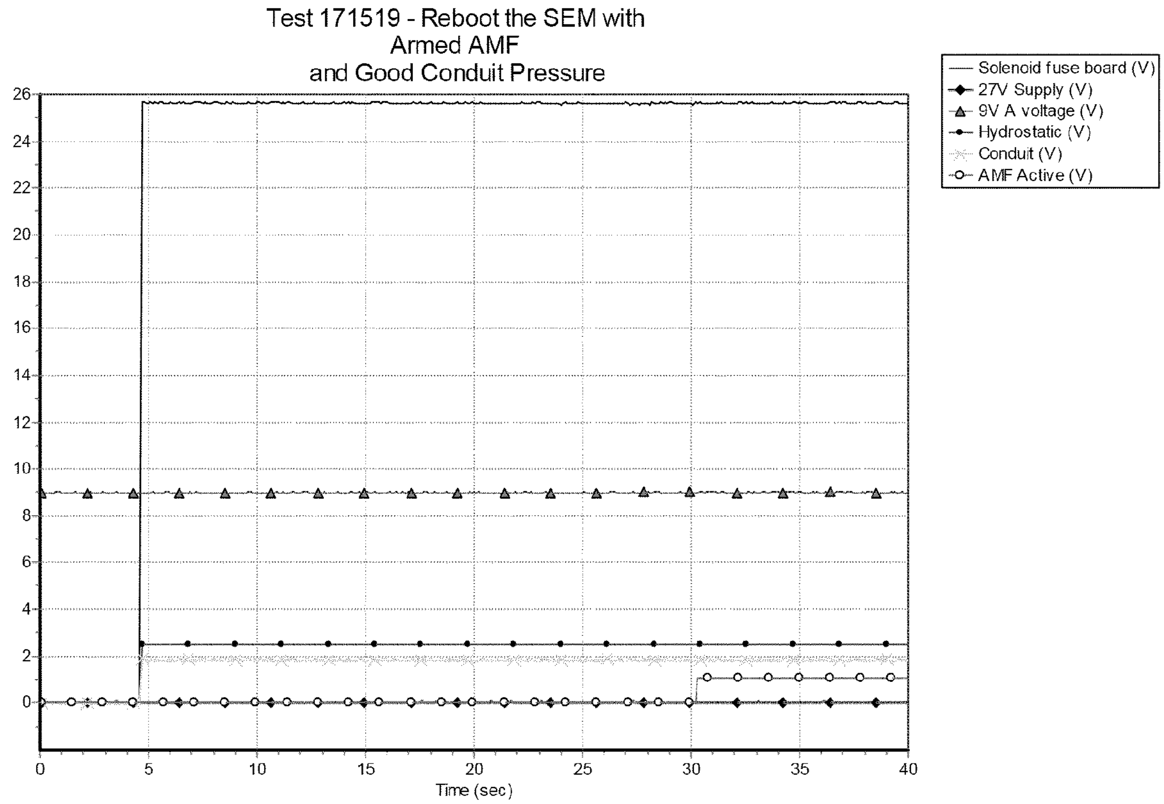


Below about 1.5 volts, the AMF circuit current is essentially zero. The current meter indicated a noisy signal of about ±150 microamperes. Below about 3.5 volts, the AMF circuit is not functioning properly and pulls excessive current. At 3.5 volts and above, the AMF circuit begins to function with completely proper operation starting at 6 volts and above. The current draw when properly functioning is 1.5 ma.

Test 171519 – See if the SEM looks at the transducers

This test was set up with a conduit pressure of about 900 psig (10.4 ma on the hydrostatic channel, and 7.8 ma on the conduit channel). The 27V supply was removed to make sure that the AMF circuit could not reboot the SEM.

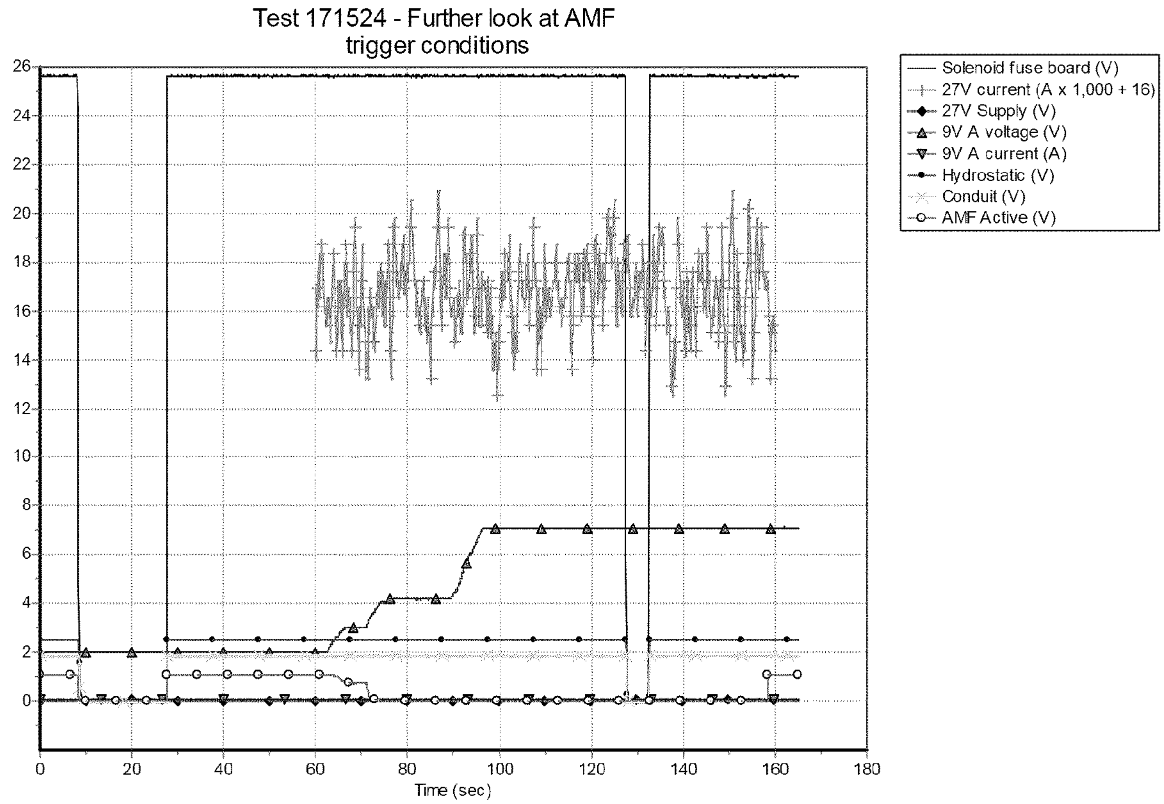
The DAQ data starts with the AMF armed and the PETU off. At 4.5 seconds, the PETU power is restored. At that time, the SEM boots from AC power and runs the AMF sequence. The sequence ends and disarms the AMF circuit at 30 seconds.



The simulated conduit pressure is equivalent to 900 psig (conduit = 2928 psia, hydrostatic = 2030 psia). This test raises but cannot answer the interesting question of whether the SEM checks the conduit pressure before running an AMF sequence. In retrospect, it would have been good to clarify two questions: 1) Would the SEM have run the AMF sequence with a higher conduit pressure? and 2) Would the 27V supply have inhibited the AMF sequence somehow? Unfortunately these questions did not surface at the time of the tests and were not investigated. They are not particularly significant for the Horizon incident, but are significant for normal AMF operations in general.

Test 171524 – Further look at AMF trigger conditions

This test starts with good conduit pressure as in Test 171519 and with the AMF unarmed. The 9V A supply has been reduced to 2 volts. PETU power is removed at about 8 seconds. As expected, the AMF is not triggered.



At about 27 seconds, the PETU is turned back on, and again the AMF sequence is not triggered.

At about 63 seconds, the 9V A supply is increased to 3 volts. At this voltage, you can see the AMF active signal starting to go low, but it is still not low enough to actually be interpreted as "armed".

At about 72 seconds, the 9V A supply is raised to 3 volts, and later on to 7 volts. The AMF active signal goes essentially to zero (armed) as expected.

The only way to know that the AMF circuit tried to start an AMF sequence is to look for a jump in the 27V current when it tries to actuate the relays. The plot shows the 27V current multiplied by 1000 and offset by 16 ma. so that 0 current is at 16 (to get the noisy signal away from the other traces near the bottom of the plot).

If the AMF circuit tried to start an AMF sequence, you would see a jump in the 27V current similar to the one that happened at 50 seconds in Test 161013. There clearly is no jump in current in this test, with the middle of the noise at about 1 ma (17 on the vertical scale), which is consistent with the normal current for the AMF circuit. So, the AMF circuit does not try to start the AMF sequence. And it should not since the conduit pressure reading is above 750 psig.

At 128 seconds, the PETU power was removed and then returned at 132 seconds. At that time, the SEM booted from AC power and ran the AMF sequence even though the conduit pressure is OK and the AMF circuit has not tried to turn on its relays.

It appears from these tests that all that is necessary to cause the SEM to run the AMF sequence is for the AMF circuit to be armed when the SEM boots up.

Test 171531 - Arm/Disarm Waveform

To arm and disarm the AMF, the SEM uses a solenoid driver to actuate a magnetic latching relay. A positive pulse latches the relay (arming the AMF circuit) and a negative one unlatches it. But the solenoid driver cannot put out a negative voltage. Instead, the driver is used in a particular way to drive the circuit shown in Appendix 2 (see pin 18 (Arm/Disarm) on the connector at the bottom of the figure).

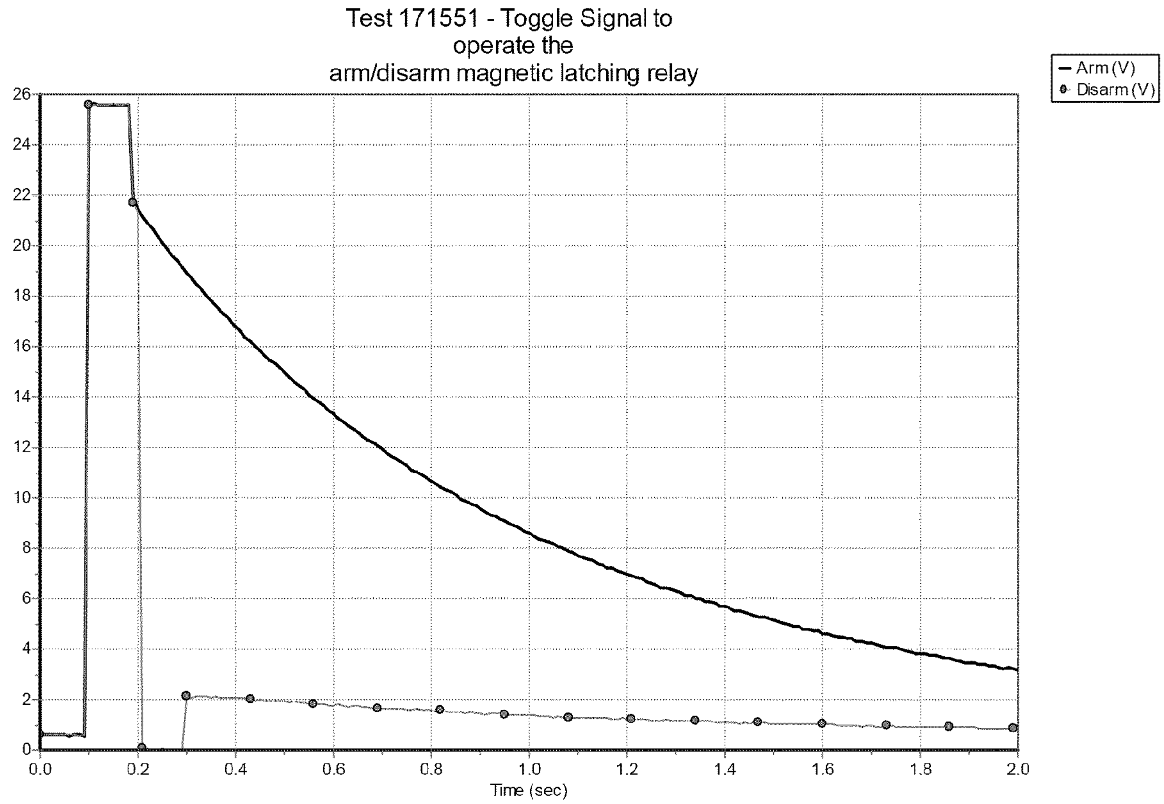
The circuit consists mainly of a 47uf capacitor in series with the relay coil. The solenoid driver consists of two driver transistors that can be operated independently. The high side driver pulls the output to the 24V supply. The low side driver pulls the output to the 0V common. When they are both off, the output is in a high impedance state and pulls no current at all.

In order to arm the AMF, the high side driver is turned on for 91ms and then turned off again. While it is ON, a positive current surges through the capacitor and relay, latching the relay. When it is turned OFF, the current in the relay stops, and the 100K resistor and other resistors not shown discharge the capacitor gradually back to 0 volts.

In order to disarm the AMF circuit, there is a two step process. It starts off just like the arm waveform, with the high side driver putting a positive pulse on the relay coil, latching it (if it is not already latched). This leaves the capacitor charged up to about 85% of the supply voltage at the end of 91ms.

Then, when the high side driver is turned off, the low side driver is turned on, shorting the positive end of the capacitor to the 0V common. This drives the end of the capacitor attached to the relay to a negative voltage and the capacitor discharges into the relay in a negative direction, unlatching it. So the relay ends up in the unlatched condition. After 91ms, the low side driver turns off and the capacitor discharges its remaining voltage slowly to 0V.

Below is a plot of the arm and disarm waveforms, measured at pin 18, superimposed on one another to show the relative shape and timing.



The fact that the wave form is not zero for the first 0.1 sec is that neither driver is on and the DAQ inputs float at a small positive voltage when not actively driven.

According to the relay data sheet, the voltage across the coil must be at least 8.4V to operate the relay. It also takes a finite time for the relay to switch states. That required time is not given, but it will take less time to actuate the relay when the voltage is high compared to the time it will take when the voltage is marginal.

The voltage across the coil is created by the charging and discharging of the capacitor. The voltage available for the unlatch cycle is always less than the voltage available for the latch cycle. Finally the time that the voltage is above 8.4V depends on the supply voltage. The more voltage, the longer the voltage will be above 8.4V.

The result is that as the 27V battery voltage goes down, the pulse time across the coil will go down, but the needed time will be increasing due to the reduction in voltage. So as the 27V battery voltage goes down, there is an increasing likelihood that the unlatch signal will actually leave the relay latched. This was observed to happen in one of the tests. We did not test to see at which voltage this would become a serious problem.

In terms of the Horizon incident, the effect of leaving the relay latched after completion of the AMF sequence is to discharge the 27V battery, potentially all the way to zero. It would also seriously discharge the 9V battery, but not take it to zero.

Other Possible conditions

These are conditions that were considered as reasons or factors contributing to the state of the system at the time of the incident. Their relations to the incident are discussed below.

Failure to disarm

The magnetic latching relay that arms the AMF system is armed and disarmed via a single wire. The waveform applied to that connection determines if it arms or disarms. This is described in the test section (section 0 Test 171531 - Arm/Disarm Waveform).

There are many places in this report where it is assumed that if the AMF sequence runs, it leaves the AMF disarmed. But it is possible for the disarm signal to actually leave the AMF armed, or to arm it when it was previously disarmed (the latter was actually observed in one test). If the 27V battery is low, the likelihood of the disarm signal failing and leaving the AMF armed increases.

This is a possible, but unlikely failure mode, the result of which would most likely resemble the "Most Likely Scenario" except that the 9V battery could be more depleted by it.

Leakage in the test pie

Water intrusion into the pie connection could furnish a conduction path that would drain the battery(ies). This could be a reason for batteries being low or dead at the time of the incident. The problem with considering this is that it is impossible to estimate the magnitude of the leakage. It could range from tiny (due to minor condensation or other fault inside the SEM) to major (salt water intrusion in the connectors).

It can be difficult to even measure this leakage because as soon as you remove the pie plug and insert the test connector, you alter or destroy the leakage condition in the connector. To confirm leakage in the pie connector for sure, you would have to leave the connector intact, remove the pressure vessel cover, disconnect the battery, and then measure the wires going to the pie socket. But removing the cover could alter the state of any leakage originating within the SEM.

Due to the uncertainties and the fact that none of these tests were done, it is impossible to make a meaningful comment on leakage and its effect on the incident.

Batteries were too old

A year of operating the AMF circuit board (AMF being armed for a year) depletes about half of the 9V battery capacity. The batteries also lose capacity due to self discharge over time, especially at high temperatures. It is hard to calculate self discharge precisely since it is so dependent on temperature history and storage conditions. At 30°C and below, the self discharge rate is very low. But at 50°C the battery will lose about 5% of its capacity in a year, with the rate approximately doubling for each 10°C rise in temperature[1].

Even if the AMF system spends 2/3 of its time armed, it is hard to see how age would be a problem if the batteries are changed each year. Even storage at a nearly impossible 80°C (30% loss per year) would still result in over 30% of 9V battery capacity remaining at the end of a year.

On the other hand, if the 9V batteries were 2-3 years old, and stored or operated at 60°C, it is possible that much of the capacity of the battery was consumed.

A complicating factor when considering age is that there is no continuous drain from the 27V battery, even with the AMF armed. So self discharge and AMF tests are the only obvious source of discharge of the 27V battery.

At least two of the batteries were found in a state of low charge. Even if the 7.61 volt reading is attributed to the 9V B battery, that voltage could indicate a battery with little remaining charge. Age could account for weak batteries at the time of the incident, but it does not seem to be enough by itself to account for the battery at 0.142 volts. So age, though possibly a contributing factor, is not likely to be the whole explanation for the final state of the batteries.

Errors in the Post-Incident Tests

The obvious way to measure the battery voltages is to put the negative meter lead on the common pin of the battery pie connector, and then probe the 3 battery voltages with the positive lead. That would result in 3 positive numbers. Pictures of the post-incident test show, instead, two negative values and one positive value. For this to happen, either the wrong pin was used as the common, or the meter polarity was ignored, or both. These tests were made by a technician standing on a ladder outside so it is not unreasonable to imagine either condition happening.

This section examines the most likely ways that measurement errors in the post-incident test could have yielded the observed results.

Measured the batteries using incorrect common pin

The case of an incorrect common occurs when the common and one of the battery connections are reversed. This is not a likely explanation for the observed voltages.

[1] Rayovac OEM/Technical Products Reference Guide, Application Notes and Product Data Sheet, Lithium Carbon-monofluoride (BR) Coin Cells and FB Encapsulated Lithium Coin Cells. This sheet contains reference to $LiMnO_2$ coin cells, comparing them to other technologies. While they are a completely different size and package from the AMF batteries, the chemistry is similar to the AMF batteries so, perhaps, the discharge rate may be similar as well. Better data could not be found.

Incorrect Common – Case 1

Assuming that the negative lead was consistently used as the common reference, then one of the 9V batteries must have been mistakenly used as the common. That is the only way to have both positive and negative measurements. The observed voltages would result from the following actual battery voltages:

9V used as common = 7.61 other 9V = 7.47 27V = 16.39.

16.39 volts is almost certainly enough voltage to operate the relays[2], but not enough for all solenoids. Also, the 9V batteries are low. This battery state would result in either the sequence running to completion (maybe without any solenoids actuating), or an oscillation caused by the following cycle: 9V drops too low due to initial surge current in the SEM, AMF circuit detects low voltage and reboots, AMF detects AMF condition and actuates its relays, repeat.

If the AMF sequence ran to completion, then the AMF Circuit would have been disarmed and the batteries would have been left sitting in the state shown above. In the post-incident test, the AMF circuit was still armed when the power was reapplied from the PETU. So it is very unlikely that the AMF sequence ran to completion.

In the case of the oscillation, the AMF sequence is not allowed to run to completion due to the constant rebooting. This condition would not have been noticed in the post-incident test. But, if it happened during the test, it would have most likely done it during the incident as well. In that case, it would remain in this state until either the 9V battery dropped too low in voltage to run the AMF circuit, or until the 27V battery dropped too low in voltage to operate its relays. The assumption of Case 1 is that at the time of the post-incident test the 27V battery was at 16.39, which should operate the relays. Also, the 9V battery is well above 3.5 volts, so it should be capable of operating the AMF circuit. This suggests that the AMF system was not oscillating.

From the above, it seems most likely that Case 1 did not exist.

Incorrect Common – Case 2

As in Case 1 above, if the positive lead was consistently used as the common reference, then one of the 9V batteries must have been mistakenly used as the common. The observed voltages would result from the following actual battery voltages:

9V used as common = 8.78 other 9V = 8.92 27V = 16.39.

16.39 volts is almost certainly enough voltage to operate the relays, but not enough for all solenoids. But the 9V batteries are fine. This battery state would result in the sequence running to completion. As in Case 1 above, the fact that the AMF circuit was still armed when the PETU power was turned back on, suggests that Case 2 did not exist.

[2] The relays are guaranteed to operate at 16.8 volts, and in our tests they all operated (pulled in) below 15 volts.

Polarity was ignored

Standing on a ladder on deck trying to handle leads from the meter, and given that the goal was simply to get the magnitude of the battery voltage, it is reasonable to assume that the technician would have not paid much attention to the polarity of the leads.

Even ignoring polarity, the observed voltages are not supported by the other facts if you assume that the batteries are correctly identified and the correct terminals were used. As argued elsewhere, the test results do not support a 9V battery voltage of 0.14 volts.

But it is possible to produce the observed voltages by the combined errors of ignoring polarity and choosing one of the 9V batteries as the common pin. This results in actual battery voltages of:

9V used as common = 8.78 other 9V = 8.92 27V = 1.17.

This condition is quite possible and similar to the error of attributing the voltages to the wrong batteries as described in the next section. For reasons described below, the "wrong battery" explanation is taken as more likely to have occurred.

Voltages are attributed to the wrong batteries

This error is conceptually similar to using the wrong pie connection as the common, except that the voltages measured are actually the voltage of the batteries. This situation requires that polarity of the test leads was ignored and that the identity of two of the batteries was swapped. Swapping the batteries could happen as a result of the technician making an error, or by a wiring error in the SEM, a situation that would not have caused any malfunction and could conceivably never have been noticed. The actual battery voltages would be as shown in Section 0 Battery State above.

In this scenario, the 27V battery voltage could have been as much as 13-15 volts at the time of the incident and still resulted in incomplete AMF sequences. The incomplete AMF sequence would have drained the 27V battery completely over time.

Conclusions

These conclusions are based upon the results of the tests performed and, in some cases, are an informed judgment based on the information available. Additional information could, in some cases, change the conclusions.

AMF Normal Operation

The AMF circuit triggers if AC power to the SEM is lost and there is low conduit pressure.

When the AMF triggers, it applies power from the batteries to reboot the SEM. It is actually the SEM that runs the sequence.

When the SEM boots up, it checks the AMF active signal. If it is active (the AMF is armed) it executes the AMF sequence and then shuts the AMF system down.

Definition of low conduit pressure

Low conduit pressure is found to be either a conduit pressure less than about 750 psi above the hydrostatic pressure, or the inability to measure conduit pressure due to a bad transducer signal.

Absence of power for the transducers or even absence of the transducers themselves is treated as "low conduit pressure".

The 9V battery is not likely to discharge to near zero

During an AMF sequence, the SEM gets its 5V power directly from the 9V battery by way of a voltage regulator on the AMF circuit board. For the SEM to get power from the 9V battery, the AMF circuit computer has to command its relays to energize. The AMF computer will not operate below 2 volts and the transistors that turn the relay on cannot operate properly below about 3 volts. So the SEM cannot get any power from the 9V battery if the battery is below 2-3 volts. This leaves the AMF circuit board as the only load in that case. Below 1.5 volts the AMF circuit current drain falls to practically zero. This makes it very unlikely that any circuit operation could discharge the 9V battery below about 1.5 volts in the time available after the incident.

The 27V battery can easily discharge to near zero

If the AMF circuit is armed and an AMF condition occurs, the AMF computer will command three relays to turn on. They all draw power from the 27V battery. Normally, the AMF sequence operates, the AMF is disarmed, and the load is removed from all of the batteries. But, if the 27V battery is too low in voltage to actually pull in the relays, then the sequence will not run and the load will be on the 27V battery for an indefinite length of time, as long as the 9V battery can operate the AMF computer. Since, by definition, it is low to begin with, the 27V battery would very likely discharge to near zero volts in the time since the incident.

The AMF active signal cannot happen without a good 9V battery

The AMF computer has to operate to issue an active signal that the PETU can display. Since it takes more than 3.5 volts for the AMF circuit to issue that signal, and since the signal was observed on the PETU, it is not possible that the 9V B battery was discharged all the way to 0.142 volts.

A 27V battery with enough charge to run relays and solenoids will also operate the transducers.

In order for the battery to operate the AMF circuit relays and solenoid valves, the 27V battery must supply more than 14 volts when loaded. But 14V is sufficient to operate the transducers in a completely normal manner. So transducer voltage is not a limiting factor in AMF operation.

Most likely scenario

It is most likely that at the time of the incident the AMF system was armed and appeared to be operating normally, but the 27V battery was already discharged to the point that it could not operate the relays on the AMF circuit boards. At some time during the incident, hydraulic and electrical power to the BOP failed. The AMF circuits then commanded the relays to pull in. But, due to the low voltage in the 27V battery, the AMF sequence did not happen, the AMF circuits were not disarmed, and the 27V battery was completely discharged over the next 75 days.

Further work – Battery Testing

An important addition to the tests done for this report will be tests of the $LiMnO_2$ cells used in the AMF batteries.

Many of the conclusions in this report are based upon the batteries delivering a particular voltage when they are needed. All of the voltages measured in the field and used for this report were measured with a high impedance volt meter and an open circuit (no load) on the batteries. But the open circuit voltage of a battery is not a reliable indication of its ability to supply a load, so some of the batteries may have failed to deliver useful voltage under a load.

Similar cells should be tested for loaded voltage and open circuit voltage as a function of their charge state, especially when nearing complete discharge to get a better idea of what the no-load field measurements actually mean.

Equipment

Equipment under test

The equipment that was tested did not come from the Deepwater Horizon. Pride International, through the efforts of Danny Fugate and others, made a Cameron Mark I SEM and several "-63" solenoids available for this test. The solenoids are the same kind as those used on the Horizon. But the Horizon pods used Mark II SEM's. The difference between the Mark I and the Mark II is simply size. The Mark II has more solenoid outputs and more analog transducer inputs. The AMF circuits and batteries are identical in the Mark I and Mark II SEM's.

Due to having more input and output capability, the Mark II draws more power from the batteries than does the Mark I. Test 161415 simulated the additional 9V battery current drawn by the Mark II just to show that the battery in use for the tests could supply a Mark II SEM.

Test Equipment

The various pieces of test equipment used to take measurements during the tests are listed in the first part of Appendix 1. All of the meters were either certified or cross checked to make sure that they were accurate enough for the purposes of the test.

REFERENCES

Documents

Transducer tests

CF3-NTF17 – Stress Engineering – AMF Sensor Testing

Yellow SEM tests when retrieved

CT3-NTF11 – Yellow pod test results
CT3-NTF12 – Yellow pod PETU screen shot on startup
CT3-NTF13 – Yellow pod AMF test

Blue SEM test when retrieved

CT3-NTF14 – Blue pod test results
CT3-NTF15 – Blue pod PETU screen shot on startup
CT3-NTF16 – Blue pod AMF test

Solenoid tests – no pressure

CF3-NTF18 – Solenoid valve energization test in air

Solenoid tests – with pressure

CF3-NTF19 – Solenoid valve energization test with hydraulic pressure

Personnel

James P. McAdams, PE

Worked for Cameron Iron Works in the 70's doing electronic design and programming of subsea production control systems. Worked as a consulting engineer since 1980 for a wide variety of medical, geophysical, and oilfield clients. From 1997 to 2004 worked closely with Cameron Controls on the design, programming and debugging of deep water drilling control systems of the type used on the Deepwater Horizon. He also publishes software to do hydraulic simulation of subsea drilling and production systems, and worked with API to provide accumulator sizing software to accompany the latest revision of API 16D.

Gavin Starling

Joined Global Marine drilling company in 1999 as an Electronic Technician aboard the Celtic Sea Semi-Submersible. Was promoted to the Subsea Operations support team at Global Marine in 2001 with the primary responsibility of assisting the Rig based personnel with hands on and planning of maintenance and upgrades on the Cameron and Hydril MUX electronic and hydraulic control systems and Blow Out Preventers.

2006 Became independent and worked contract for FMC technologies in project management responsible for delivery of several production related subsea systems for BP and Shell.

2008 Worked for C-Mar Americas as the North American Manager providing technical support, management personnel and hands on technicians to support several drilling contractors world wide in the Subsea engineering discipline.

Glossary

AC	Alternating current – The SEM gets its internal 5V and 24V DC power from power supplies that operate from 110 or 220 volt AC current.
Active	An armed AMF circuit transmits an active signal back to the SEM via one of the SEM's analog input channels.
AMF	Automatic Mode Function – a system to detect that the BOP is completely isolated from surface control and to supply electrical and hydraulic power to operate a predefined sequence of valve operations designed to close the BOP and disconnect the riser.
Arm	Turn the AMF circuit on and make it active. The SEM does this by activating a magnetic latching relay in response to a command from the surface equipment.
Armed	When it is armed, the AMF circuit board computer monitors its inputs for an AMF condition and will command an AMF sequence when it is needed. When disarmed, the AMF system will not function.
Boot	The sequence of steps that a computer goes through to load its program or operating system when it is initially turned on. The term originated as a reference to pulling one's self up by one's own bootstraps.
BOP	Blowout preventer
DAQ	Data acquisition system, a means of recording voltages and currents from several different sources at a selectable number of samples per second.
DC	Direct current such as the power from the batteries.
Trigger	When the AMF triggers, the AMF circuit board applies electrical (battery) power to the SEM and indicates to the SEM that an AMF sequence is required. The AMF sequence is run by the SEM as part of its boot up sequence.
Heartbeat	A pulsing signal put out by each operating SEM and monitored by each AMF circuit board. This signal pulses continuously as long as even one SEM is powered and working normally.

Horizon	The Transocean, Deepwater Horizon drilling rig
PETU	Portable Electronic Test Unit – A test unit to provide power and communications signals to operate the SEM's in a pod. When combined with a laptop computer and the right software, you can completely operate and monitor the pod.
Pie conn.	The solenoids connect to the SEM via a set of circular connectors on the bottom. Each circular connector receives 6 wedge-shaped plugs resembling pie slices. Each plug has 4 pins and goes to one dual-coil solenoid valve.
SEM	Subsea Electronic Module – AC operated power supplies, a computer, solenoid driver circuits, and analog transducer circuits that are used to control and monitor the BOP. Used alone, "SEM" refers to the whole electronics module contained in the Blue or Yellow pod. Used with a letter as "SEM A" or "SEM B", it refers to each of the redundant controllers that are contained within one electronics pressure vessel.

Appendix 1 – Hand Notes from Initial Tests

SEM Dead-Man testing

Purpose:

The scope of work defined in this document is to collect additional data to determine the operation of the Cameron dead-man system.

Equipment needed for dead-man testing:

1. Cameron PETU with Cables. (Pride)
2. Laptop with WinTSIM and Kermit loaded on it. (Pride)
3. Three 24 volt Power supplies (2 rental & 1 James)
4. Three calibrated and certified DC voltmeters. Record serial numbers, model numbers and calibration dates. (Rental)
5. Two 4-20 mA simulators. (Gavin or Pride)
6. Assorted wires and clips. (Gavin & James)
7. Assorted electrical tools (solder, cutters, crimpers.etc) (Gavin & James)
8. Extension cords and power strips (Gavin)
9. USB 6009 Data Acquisition device with laptop (James)
10. Camera /Video recorder. (Gavin)
11. SEM on stand with Cameron Dead Man (Pride)
12. Five Cameron -63 solenoid valves

Procedure:

Preparation:

1) Remove the cover from the SEM. Initial [initials] Cover removed by Burton /Pride before we started

2) Identify all the equipment that is being used for testing: Including labels, part numbers, serial numbers photograph all the parts in detail for the record.
Initial [initials]

Multimeter1 Fluke 87V Serial number 94400249
Cal Certificate - 1403822010787??10244 Cal ??? ?1
TRS Rentelco April 12, 2011
Multimeter2 Fluke 87V SN/94400124 Certificate 1403822010787?7102 4
Cal due date 4/1/2011

Multimeter3 Fluke 87V [illegible] SN/94400081
Certificate 14038220107873210728 Cal due July 30 2011

DAQUSB6009 National Instruments NI USB-6009
No cert Verified output with Multimeter 2 above

PowerSupplies AT/6032 A;A Certificate 1403822096??010715
Serial # US38522927 cal due July 30, 2011
AT/6030A SN/2380A00111 Certificate 140382201109?6710712
PETU Cameron PN 223190-49 SN/ 4286 0003

SEM Cameron PN/2020722-03 [illegible] F03 [illegible]
SN/ 1143649??01-02

4/20 Sim A+B equipment
Fluke 787 SN/71570002
Cal due 12/1/2010
Cert No 2492 by TK
4/20 Sim 2
Fluke 787 SN/1886008?
No Cert
Verified output
with certified
meter Above. [initials]

A - Deadman (AMF) Cameron
V1.6 chip Deadman12.Hex
B - Deadman (AMF) Cameron
V1.6 chip Deadman12.Hex

3) Power down the PETU and put a 4-20ma loop simulator on the Hydrostatic head transducer connections and the Conduit pressure transducer connections (refer to the Electrical Schematics to determine the correct connector and pins to use.) The device should be set to "loop powered" or "Passive" do not inject any voltage into the SEM. An instrument capable of slowly reducing the current is needed. (DAMAGE to the dead-man card is possible. It is EXTREMLY important that the power to the SEM is off and there are no shorts between pins or wires, the use of a Seacon connector with a loom terminated to it is highly recommended) Initial [initials]

4) Connect the channels of the USB 6009 DAQ to the following points:

Install a .02 ohm shunt between the A 9v battery and the dead man card. measure voltage across the resistor.

9v supply voltage A system
5v back plane voltage A system
27v battery current ✓
Analog input for conduit transducer ✓
Analog input for hydrostatic transducer ✓
Analog input for deadman armed. N/A

5) Install a Cameron -63 solenoid valves on each of the functions used by the dead man (refer to the electrical schematics to determine the pie connections).
Initial [initials]

Sol 1 4A Riser Stinger Seals
Sol 2 6B Riser Stinger Extend
Sol 3 6C 3000psi work pressure HP Shear
Sol 4 10B Ram #1 Shear
Sol 5 10A Deadman System Active
Sol 6 12C Stack Stinger Seals Energize
Sol 7 12A Stack Stinger Extend

6) Using the Laptop and Kermit. Open the shutdown.asc file and determine the current dead man sequence. If the sequence is appropriate for the following tests then close out of Kermit. If the dead man sequence is not appropriate for the testing then rename shutdown.asc to shutdown.old. Using the desired Dead man sequence make a new shutdown.asc and save it to the OS9 directory. Initial [initials]

7) Connect the DC power supplies to the 9vDC inputs on the A and B card and 27vDC volt input for the dead man batteries. NOTE: pay close attention to proper polarity before turning power on. Initial [initials]

Test 1: To determine the maximum difference between the Hydrostatic pressure and Conduit pressure and still meet the loss of conduit dead man condition.

1) Power up the PETU and check the status of the dead-man card by looking at the raw data on the analog channel #29 for the dead-man in WinTSIM. Record the Raw data value on the analog channel. Armed 0-30 and dis-armed (900+/- 60)
Initial___

A 913

2) In the Pod valve commands section of WinTSIM send the command to dis-arm the dead-man cards (both A & B). Raw data should be high 900 +/- 60. Record the Raw data on the analog channel: Initial___
A 913
B NA

3) Power up the SEM and put 10.4mA on the Hydrostatic head transducer. Put 7.8mA on the Conduit pressure transducer. Check the inputs on the PETU. Initial___

Conduit Ch 9
Hydrostatic Ch 10

A: Conduit 2739.1 psi Hydrostatic 2025 psi
Conduit 7.8 mAHydrostatic 10 mA
Conduit 1599 raw Hydroststic 2127 raw

4) Arm both dead-man cards and verify that they are armed by checking the analog value. Record the raw data value. Should be 1-30. Initial___

A 8.0
B NA

5) Power down the PETU. Initial___

6) Listen for any relays pulling in and out and watch the loop generator meters. (Dead-man system should not fire) Using the voltage measurements from the USB 6009 record the polling time on the transducers (how often do the dead-man cards apply power to the transducers). Record the duration that the transducers are powered up. (How long do they stay "on" and how long are the "off") Check the current on the 27v battery circuit. Check the current on the 9v battery circuit. Initial___

Recorded on DAQ

ON____sec
Off____sec
27v Current____

See DAQ

7) Slowly decrease the Conduit pressure by .01mA increments. Record the mA value on the meter of the Conduit when the Dead man fires. Note: **Do not** continue adjusting the simulator after the dead man fires. Initial___

mA 7.605

Repeated 2x
Same Result

1st time Started at 7.8mA on Conduit
2nd time Started at 7.610mA Conduit and let the card.

8) Power up the PETU and check the analog values for the dead-man card and determine if either one is still armed. Also record the psi value for the Hydrostatic and Conduit transducers.

A 913
A: Conduit 2734 psi Hydrostatic 2028 psi   Δ = 756 psi
Conduit 7.605 mAHydrostatic 10.4 mA
Conduit 1560 raw Hydroststic 2124 raw

9) Check the raw data and determine if the cards are dis-armed. Record the raw value

A 913

10) This test may have to be run several time to accurately determine the maximum difference between the Hydrostatic pressure and Conduit pressure and still meet the loss of conduit dead man condition. If additional tests are needed use the test sheets at the end of this procedure to capture the data. Sheets are labeled: Test 1A, Test 1B...

Test 2: To determine if the dead man will fire with a 0 scale input on the Hydrostatic.

1) Power up the SEM and put 4mA on the Hydrostatic head transducer. Put 4mA on the Conduit pressure transducer. Check the inputs on the PETU. Initial___

A: Conduit 3.8 psi Hydrostatic 0.0 psi
Conduit 4.00 mAHydrostatic 4.00 mA
Conduit 819 raw Hydroststic 819 raw

2) Arm the A dead-man card and verify that it is armed by checking the analog value. Record the raw data value. Should be 1-30. #29 Initial ____

A 8.0

Power down the PETU. Initial ____

Does the dead man fire? Initial Yes

NOTE: Recorded event on DAQ

Test 3: To determine if the dead man will fire with no input from the transducers.

1)Power up the SEM and put 0mA on the Hydrostatic head transducer. Put 0mA on the Conduit pressure transducer. Check the inputs on the PETU. Initial ____

A: Conduit Break psi Hydrostatic Break psi
Conduit Break mAHydrostatic Break mA
Conduit Break raw Hydroststic Break raw

2)Arm both dead-man cards and verify that they are armed by checking the analog value. Record the raw data value. Should be 1-30. Initial ____

A 7.0
~~B~~ NA

3) Power down the PETU. Initial ____

Does the dead man fire? Initial Yes

NOTE: Recorded on DAQ

Test 4: To determine how the dead man reacts to a varied state of battery condition.

1) Power down the PETU and adjust the DC power supplies to: Initial ____
A dead man: ~~8.27~~ 8.73 from actual Battery
B dead man ~~142~~ OV
27: 7.61

2) Power up the PETU and check the status of the dead-man cards by looking at the raw data on the analog channel for the dead-man in WinTSIM. Record the Raw data value on the analog channel. Armed (0-30) and dis-armed (900+/- 60) #29 Initial ____

A 7.0
B 912 - no Battery, F/indicated

3) Simulate ~~4~~mA on the Hydrostatic head transducer. Put 6.8mA on the Conduit pressure transducer. Check the inputs on the PETU. This should be 2225 +/- 100 psi. Initial ____

A: Conduit 2073 psi Hydrostatic 1729 psi
Conduit ~~[illegible]~~ (6.62) mAHydrostatic 9.44 mA
Conduit 1370 raw Hydroststic 1935 raw
B: Conduit 2066 psi Hydrostatic 1726 psi
Conduit 6.68 mAHydrostatic 9.44 mA
Conduit 1368 raw Hydroststic 1932 raw

4) Arm the dead man. Initial ____

5) Power down the PETU. Note any anomalies. If necessary repeat this step several times to collect all the data on A an B system. Initial ____

Does the dead man fire? no

Does the dead man attempt to poll the tranducers? no

Note any difference between A&B: Nothing

6) Power the SEM back up and immediately check the analog signal for each dead man card to determine if the cards are still armed. Record the value. Pay attention to the SEM and note if the dead man fires. Initial ____

A 7.0 - then 914
B NA
NOTE: The deadman fired when PETU started up. The entire sequence ran then dis-armed the card.

Test 5: Determine if there if there is a possibility that the dead man card can still draw current if there is not enough voltage to complete a sequence for an extended period of time.

1) Power down the PETU and adjust the DC power supplies to: Initial ____
A dead man: ~~9V~~ 8.73 from Battery
27: 7.61

2) Power up the PETU and check the status of the dead-man cards by looking at the raw data on the analog channel for the dead-man in WinTSIM. Record the Raw data value on the analog channel. Armed (0-30) and dis-armed (900+/- 60) Initial ____

A 8.0

3) Simulate ~~11~~ 9 mA mA on the Hydrostatic head transducer. Put ~~6.8~~ 6.68 mA on the Conduit pressure transducer. Check the inputs on the PETU. Initial ____

A: Conduit 2073 psi Hydrostatic 1729 psi
Conduit 6.68 mAHydrostatic 9.44 mA
Conduit 1370 raw Hydroststic 1935 raw

4) Arm the dead man Initial ____

5) Power down the PETU. Note any anomalies. Immediately reduce the A 9v power supply to a point at where the VSBC4 processor and Dead man processor start to malfunction. If necessary repeat this step several times to collect all the data on A an ~~B system~~. Initial ____

Does the dead man complete its sequence? No

Does the dead man attempt to poll the tranducers? no

6) Power the SEM back up and immediately check the analog signal for the dead man card to determine if the card is still armed. Record the value. Pay attention to the SEM and note if the dead man fires. Initial ____

A 8.0

NOTE: Deadman fired whe Pots was powered up.

No Solenoids in sequence - want to measure how much current the internal circuitry will draw, when activated with 6v voltage on the 27v battery then increase to 22vdc 1v increments.

Appendix 2 - Partial Schematic of the AMF Circuit Board

The following is a partial schematic of the AMF circuit board assembled by visually tracing the circuits on the board. The circuits that are significant in terms of the SEM AMF tests are shown. Rel 1, 2, and 4 are 24V relays. Rel 5 is a magnetic latching relay with a 12V coil. The operation of the circuit is given in the text.