Failure Analysis of SN3 Digitized AFM

Peter Ruggiero
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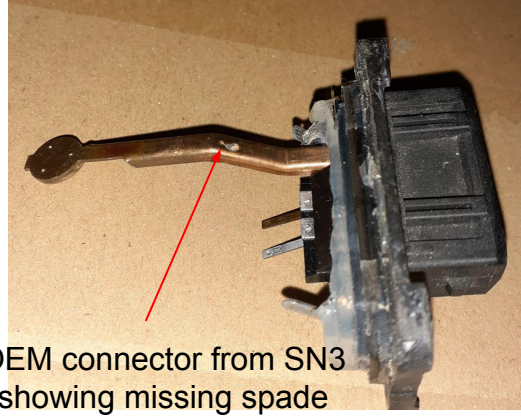
Bottom Line Up Front

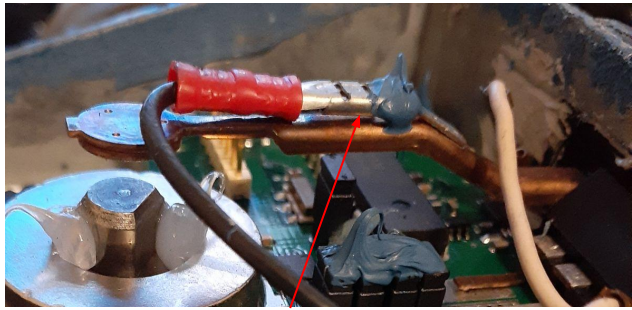
- During testing of SN3 with Jeremy Lucas (Mid-Ohio April 23-24 2021) the vehicle began running poorly and was ultimately traced back to the AFM
  - Verified by both fitting a stock AFM on the vehicle, fixing the problem as well as putting the suspected digitized AFM on another vehicle which then exhibited the same issue
- Unit was subsequently returned for evaluation and determined that a damaged jumper was the root cause of these issues.
- This damage is suspected to have initially occurred during an earlier shipment of the AFM and didn't materialize until further handling, thermal excursions were presented
- Currently (5/7/21) the jumper was replaced and thermal testing (oven at 75C/167F) showed normal operation of the unit
  - No other components were replaced
- Plan is to return the unit back to the NASA Great Lakes division to continue testing

SN3 Life History

- SN3 was built on 01/03/2020 and was the first Digitized AFM to have all the latest circuitry upgrades and has been passed around to multiple SE30 racers for evaluation.
  - Initially tested on Scott McKay's 100 car in paddock (not in a race)
  - Given to Carlos Mendez for evaluation (ran in car at his shop)
  - Handed off to Sandro Espinosa who ran it in multiple races as well as performed dyno testing
  - Finally making its way to the NASA Great Lakes division where it was tested at NCM (March 27-28 2021) and Mid-Ohio (April 23-24 2021)
- During shipment from Sandro to myself (GA to FL) the unit was damaged, ripping the terminal spade off of the copper arm (OEM parts).
  - Up to this point, the plastic cover on the AFM was only taped on, this cover fell off during transport allowing the shipping materials to make contact and ultimately breaking the arm as well as damaging the jumper
  - This component is OEM and undergoes **no** changes during "digitization"; The OEM wire is removed and a different wire is attached.
- At the time, the damaged component was replaced and the unit was functionally tested on the bench and was working fine
- Testing at NCM (March 27-28) was successful as the unit was put on three different SE30s with the only noticeable differences being that one of the cars looked to have a faulty AFM and the driver picked up 2 seconds a lap with the digitized version
  - Dyno testing was performed at the track on Brian Edmunds car showing results in line with stock unit
- It wasn't until the following race, Mid-Ohio (April 23-24) that the unit began exhibiting issues
  - Cars were reported to run fine in the early sessions but had issues with later session, pointing to a temperature related issue



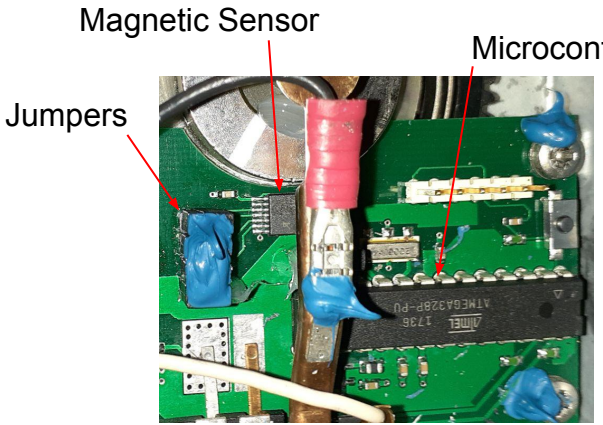
OEM connector from SN3 showing missing spade connection

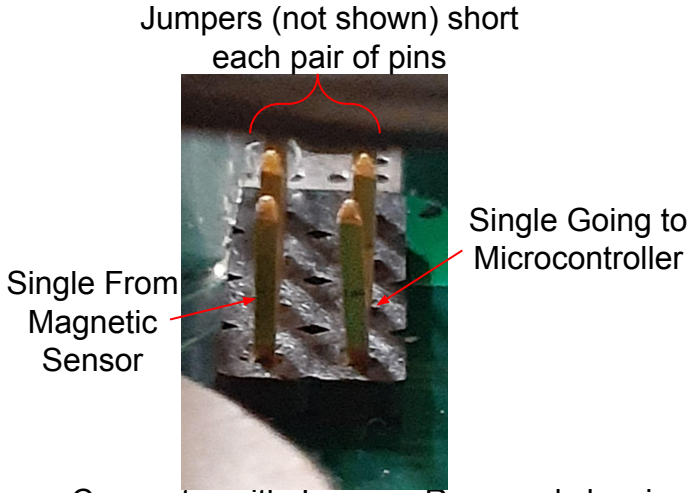


Picture of SN3 after replacement of OEM connector

SN3 Failure Analysis

- SN3 was tested on the bench (77°F) environment) and showed normal behavior
- The unit was then placed in a temperature controlled environment (75°C/167°F) where it started to output a fixed value instead of varying with the door flap - Condition that would explain the poor running behavior
    - It was also noted that the unit would show this same mis-behavior on the bench (77°F) at times but was very inconsistent.
- Oscilloscope probing showed that one of the SPI bus signals (MISO) between the magnetic sensor and microcontroller wasn't present on the microcontroller side but oddly was present at the magnetic sensor side
    - For programming reasons, these SPI bus signals travel through a set of jumpers between the two devices
    - The jumpers literally short two pins of a connector together to allow the signal to pass
- While running the sensor, the RTV (shown in blue in the picture) was removed to allow inspection of the jumpers. Once the RTV was cut, the sensor immediately began to function
- Inspection after removal of the jumpers showed a bent pin corresponding to the signal of interest. In addition (not shown) the jumper itself exhibited similar deformation
- This bent pin is most likely to have occurred at the same time the damage to the copper arm was done (shipping)
- Additionally, it is believed the the RTV on top of the jumpers (intended to lock them in place) was a poor choice as during thermal excursions this would place undue stress on the connections

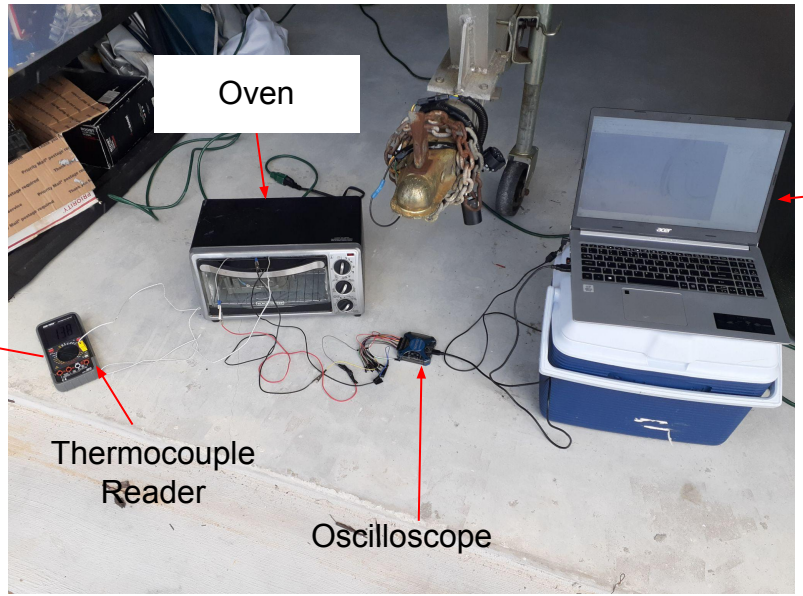




Connector with Jumpers Removed showing bent pin (corresponding to MISO signal)

SN3 Repair and Test

- The bent pin was reformed using special tooling and new jumpers were placed in all four locations
- Testing was performed at temperature over a few hours and the AFM performed as expected



Recommended Path Forward

- SN 3 Path Forward
  - Test on Tom Panzarella’s car on the weekend of 05/08/21 to verify the unit is functional on a vehicle
  - Send AFM back to Jeremy Lucas the following week (5/10/21) to continue testing
- Design Updates
  - Remove RTV from top of jumpers and place at the base of the jumper to reduce the moment arm and thus load the RTV can impart onto the jumper/connector during thermal transients
  - Increase output wire length and utilize smaller gauge wire to reduce stress on copper arm
  - Ensure AFMs are fully bubble wrapped and packaged well prior to any further shipments as well as notifying customers to do the same