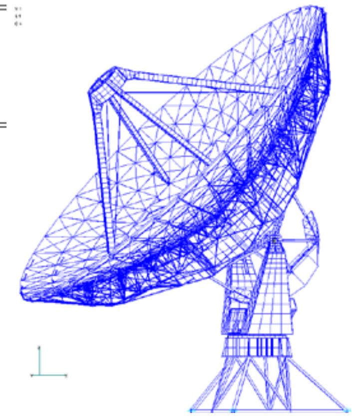
NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO



VLBA ANTENNA MEMO #93

COLD WEATHER OBSERVING

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1.0 Introduction

The original design specifications for the VLBA antenna elements stated that the antenna shall be capable of precision operation throughout the temperature range of 0 ºF to 90 ºF and normal operation throughout the range of -20 ºF to 104 ºF.

The VLBA operators historically quit observing when the temperatures dipped below 0 ºF. At cold temperatures, the Focus Rotation Mount (FRM) often failed to reach its commanded position. The failure rate of the FRM power output amplifiers also increased significantly when the temperature was below 10 ºF. Since these amplifiers are obsolete and we have a very limited supply of spares, the minimum operating temperature was changed to 10 ºF. Weather station data from over the previous year showed that raising the minimum operating temperature to 10 ºF resulted in significant lost observing time.

This paper discusses the known and potential VLBA antenna problems that must be solved in order to safely resume observation at temperatures below 10 ºF. Potential solutions to some of the known problems are also presented.

2.0 Known Problems

2.1 Ice on Structure

When the temperature drops below 32 ºF ice can form on the antenna structure. Observing with ice on the antenna can be dangerous to the structure. There are past events where ice buildup on the FRM structure had fallen onto the dish and damaged the surface. There is also an instance where ice accumulated on the antenna elevation bull gear such that when the antenna was moved in elevation, the ice broke the limit switches. This caused a condition where the antenna could move outside its safe range of motion. If not caught, this could have resulted in a catastrophic structural failure.

When even a small amount of ice forms on the FRM, the motors do not have enough power to break the ice. The ice causes the Motors to stall before they reach their commanded position. If the antenna operator continues to try and position the subreflector in the stalled condition, it causes the motor amplifiers to overheat.

The antenna operators do not receive any indication that ice is forming on the antenna. Since trying to observe with ice on the antenna can be damaging, the author recommends the installation of ice sensors similar to one shown in the appendix of this document. These sensors would drive a visual indicator in the operator's space, alerting them of the potential hazard. The operator would then be better equipped to determine the feasibility of continuing observations in the temperature conditions.

2.2 Low Temperature Performance of Grease

2.2.1 Grease viscosity at low temperature

Cold grease could be the cause of the FRM's failure to reach its commanded position. Generally, grease becomes more viscous at lower temperatures. This increase in viscosity is due to the cold weather performance of both the base oil within the grease and the soap that carries the base oil. The FRM motors might not be able to supply the additional torque needed to overcome the increased bearing stiffness caused by the more viscous grease. In order to gain a better understanding of grease subjected to cold, Engineering Services conducted a series of crude tests on several different types of cold weather greases shown in the table below.

Manufacturer, Product	Base Type	Published NLGI No.	NLGI No @ -10F estimated	Base Oil Vicosity @40C	Temperature range	Manufacturers comments
Artic Cat, Extreme Low Temperature Grease	Lithium	2	3	N/A	-40 - 302 F	High resistance to water
Jet-Lube, Artic	Calcium 12-Stearate	2	3	19.8 - 24.2 cSt	-65 - 225 F	Water resistant
Lubriplate, Mag-1 Polymer	Lithium	1	1.5	23 cSt	-60 - 300 F	Low Torque
Lubriplate, Low Temp	Anhydrous Calcium	1.5	1.5	16 cSt	-60 - 250 F	Extremely water resistant
MG Chemicals, Super Thermal II	Zinc Oxide	NA		NA	-90 - 329 F	Not suitable for lubrication. Designed for heat sinks

Table 1, Extreme cold temperature grease types tested.

A sample of each grease was placed in a Zip Lock bag and evaluated for viscosity at room temperature by squeezing between the fingers and judging their resistance relative to one another as described in Figure 1. The grease was then placed in a freezer and cooled to -5 F. After 4 hours, the frozen grease was again subjected to the same feel test to determine its increase in viscosity.

Grade Number	Worked Penetration, mm^{-1}	Approx. Yield Strength, Pa	Approx. Self-supporting Height, cm (inches)	Description
000	445 to 475			Very fluid
00	400 to 430	90		Fluid
0	355 to 385	130	1.30 (0.5)	Semifluid
1	310 to 340	180	1.80 (0.7)	Very soft
2	265 to 295	300	3.00 (1.2)	Soft
3	220 to 250	560	5.60 (2.2)	Semifirm
4	175 to 205	1,300	13.0 (5.2)	Firm
5	130 to 160	3,800	38.0 (15.0)	Very firm
6	85 to 115			Hard

Figure 1, Example of NLGI grade grease stiffness.

At room temperature all of the grease samples performed as expected by their published NLGI grades. After spending 4 hours in the freezer all of the grease samples except one increased in grade number. The Lubriplate low temp sample maintained its original consistency.

2.2.1 Ice in the grease

Another potential problem source is that water seeps into the bearings and freezes. The FRM assembly uses Teflon runners to keep dirt out of the bearings. The runner's effectiveness of sealing out water is determined by the capability of the grease to maintain its stiffness and form a barrier so water doesn't intrude further into the bearing. The bearing must be completely full of grease in order for the grease to form an effective moisture barrier. A more viscous grease is better at keeping the water out but requires more motor torque to overcome the viscosity and allow motion.

"An important property of low temperature grease is its resistance to water absorption. As lubricants absorb water they become more sensitive to low temperatures. If the temperature of grease drops below the freezing point, water trapped inside will freeze. This causes the grease to become very stiff, so that it doesn't lubricant well, even if it has a low-temperature rating. Some greases are less sensitive to water than others. Generally, in the presence of water lithium and calcium soap greases are recommended. Lithium grease does not emulsify and therefore provides good protection against corrosion at lower water concentration. Calcium sulfonate complex greases may be preferred over lithium greases because they can absorb relatively large quantities of water (3–60 wt%) while retaining their structure.” [1]

As a second part of the grease test, Engineering Services prepared samples identical to those in section 2.2.1, except for the addition of water. The samples were stirred to mix in the water and then the excess water was poured off. After 6 hours in the freezer, the water laden samples were nearly identical in consistency to that of the original frozen samples. However, after several days in the freezer, all of the water polluted grease samples had developed BB size balls of ice throughout.

2.2.3 Grease recommendation

We are currently using the Lubriplate Mag 1 polymer grease in the antenna. This grease is low torque and has acceptable low temperature characteristics. The Lubriplate Artic grease might perform slightly better as it remains more consistent throughout the temperature range and in theory it should be slightly more water resistant, but this was not seen in our crude freezer test. However, the difference between the two greases is probably marginal at best.

3.0 Potential Problems

3.1 Differential thermal expansion

One of the reasons that machinery can bind up in cold weather is differential thermal expansion between the steel and aluminum parts. After studying the drawings, Engineering Services could not identify where this could be happening on the FRM assembly.

3.2 Steel Structure

In order to maximize observing time, the antenna structure was designed to observe in very cold weather. There was some concern that the extreme cold temperatures would have a deleterious effect on the steel bearings and structure. The yield strength of steel actually increases slightly at lower temperatures. The steel however, does undergo a transition from ductile behavior at higher temperatures to brittle behavior at lower temperatures. The Ductile to Brittle Transition Temperature (DBTT) is defined as the 50% point of the top shelf of the Charpy V-notch impact curve.

The antenna components subjected to high stress and impact loading such as gears, bearings and axles are all made from high carbon steels similar to the 4340 and 4140 steels shown on the graph in Figure 2. The Ductile to Brittle Transition temperatures (DBTT) of these high carbon steels is well below our operating temperatures.

The DBTT of the A36 used for the structural members of the antenna is widely accepted to be 5 ºF. While the DBTT of A36 is within our operational parameters, the structural members are not subjected to high impact loads where ductile failures would be an issue. In summary, the steel used on the antenna will perform at temperatures as low as -20 ºF.

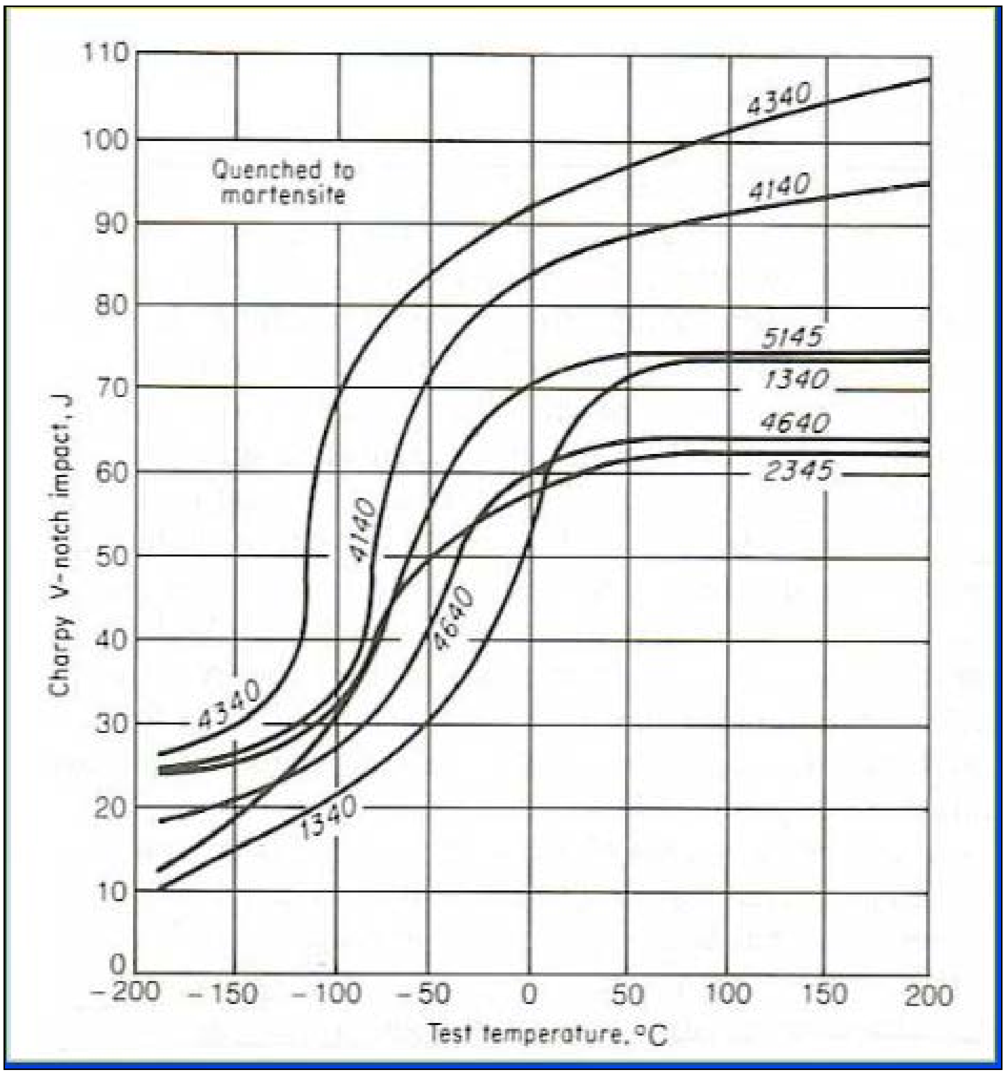
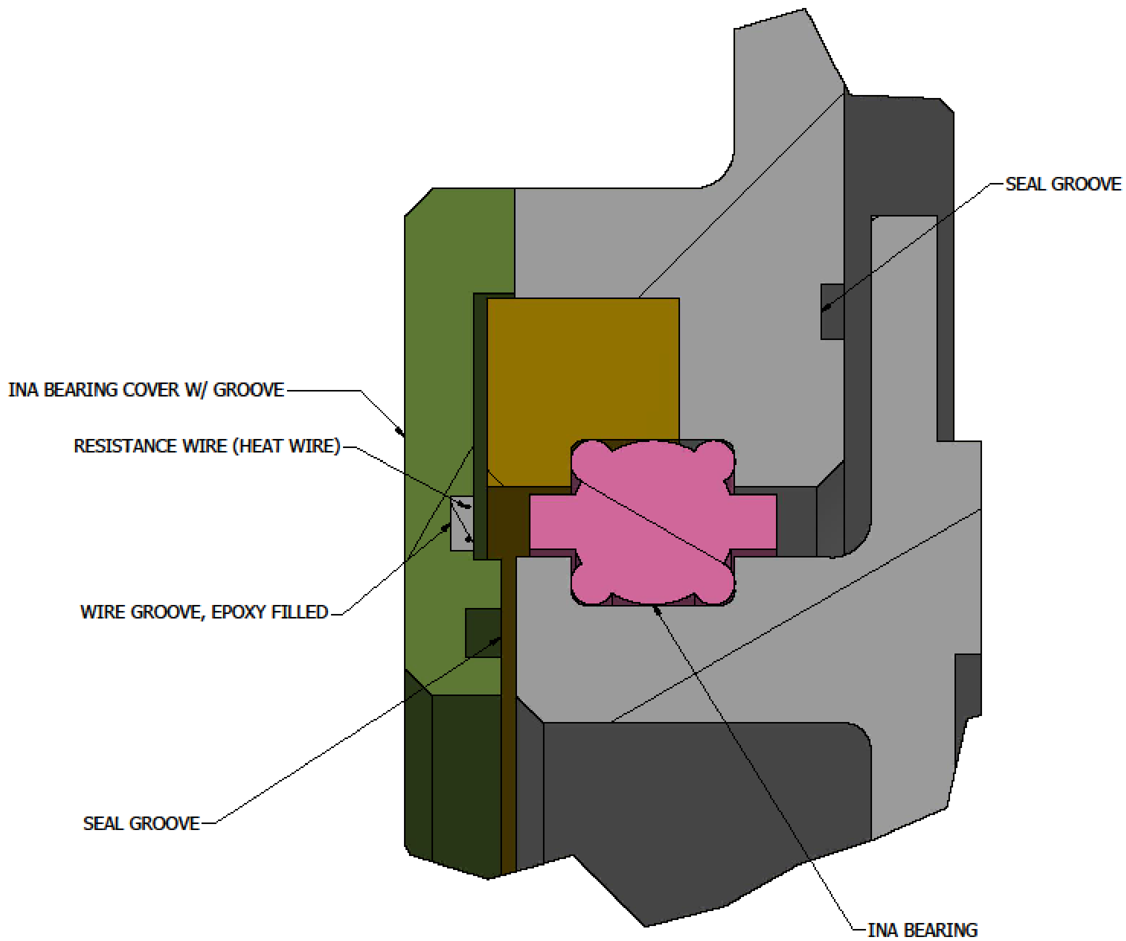


Figure 2. Dutile to Brittle Transition in Carbon Steel

4.0 Possible Solution (heaters)

NRAO has a spare VLBA FRM assembly in the VLA antenna assembly building that will be used for additional testing. One of the proposed solutions to test is to add a heater to the underside of the INA bearing cover, as shown in the figure below. The addition of heaters external to the FRM has been met with limited success in the past. By placing the heater under the bearing cover where it is in contact with the grease should allow for more efficient heat transfer into the bearing itself. The additional heat should lower the grease viscosity and prevent ice from forming within the grease. If testing proves successful, we will implement the heaters in the field.



5.0 Recommendations

The antenna structure itself is capable of handling extremely cold weather as low as -20 ºF, well below the 0 ºF operating condition. The primary concern of FRM operation occurs at temperatures below freezing. This is probably due to water in the grease forming ice pellets that impede the FRM motion, resulting in a foldback fault error. "A foldback fault is an early indication that the axis is having difficulty moving. What it means is that the axis had to go into a high torque mode (High Current) for a limited time in order to move and then folded back into the normal torque mode. The issue with amplifier burnout is simply that repeated commands will force a high torque mode without a cool-down, thus burning up the power output amplifiers. "[3] These power supply amplifiers are obsolete and we have a very limited supply of spares. There is considerable risk that we could run out of spare amplifiers resulting in the loss of considerable observing time. Therefore, we should begin a design effort to incorporate modern motors and amplifiers into the VLBA FRM drive system and eliminate this risk.

In the short term, we can mitigate the risk to the drive system by ceasing to observe when the temperature drops below 0 ºF or if there is noticeable ice on the antenna. If an FRM doesn't move when commanded, and the temperature is below 32 ºF, the operators should not try to move the FRM again until it can be inspected by a site technician, or the temperature is above 32 ºF. If the temperature is above 32 ºF and the FRM does not to move to the commanded position, the operator should wait a period of time to ensure that the ice has melted.

References

1. F. Cyriac, P. M. Lugt & R. Bosman (2016) Impact of Water on the Rheology of Lubricating Greases, Tribology Transactions, 59:4, 679-689, DOI: 10.1080/10402004.2015.1107929

2. https://www.machinerylubrication.com/Articles/Print/970, Systematically Selecting the Best Grease For Equipment Reliability. E.R. Booser, Analysts Michael Khonsari, Louisiana State University

3. E-Mail from W. Koski.

Appendix

PRODUCT

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

0871LH1

Freezing-Rain Sensor

Warns of Ice Danger

Protects roads, power lines, aircraft, wind turbines

Overview

The 0871LH1, manufactured by Goodrich, is a sensor that detects the presence of icing conditions so that appropriate actions can be taken to prevent damage to power and communication lines, to warn of road hazards, or to keep ice off wind turbine blades or a plane's wings.

Benefits and Features

- Can be used to help prevent damage to power lines, and to warn of icy road hazards, ice on planes' wings, and ice on wind turbine blades
- Automatically defrosts itself when ice accumulation reaches 0.5 mm

Detailed Description

The 0871LH1 uses resonant frequencies to determine the presence of icing conditions. Its main component is a nickel alloy rod that has a natural resonant frequency of 40 kHz. As ice collects on the rod, the added mass causes the resonant frequency to decrease. When the frequency decreases to 130 Hz (or 0.02-in. layer of ice), an internal heater automatically defrosts the sensor.

Wind Energy Applications

The 0871LH1 can detect ice on a wind turbine's blade, which is undesirable because:

- Blade can throw large chunks of ice a considerable distance —an extremely dangerous, potentially lethal situation.
- Formation of ice can cause unbalanced loading on the turbine's blades, bearings, and gear box.
- Ice reduces the turbine's power output.

The 0871LH1 can be used for wind prospecting applications by helping predict the amount of time a potential wind power site may be out of commission due to icing conditions. Additionally, the sensor lets users know when ice is preventing their wind sensors from providing data.

For comprehensive details, visit: www.campbellsci.com/0871lh1