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Safety Core Insulator Failures Reliability Analysis

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EXECUTIVE SUMMARY

OBJECTIVE

Perform reliability analysis for safety core insulators.

APPROACH

Known incidents of safety core insulator failure (for Navy and non-Navy installations) since 1970 were identified and categorized. Three major categories (or types) of failure included (1) improper installation, (2) manufacturing defect or design flaw, and (3) unknown or part of the normal risk of operation. Mean time between failures (MTBF) was estimated for all safety core insulators (based on Austin Insulators Inc. estimate of insulators in service) and for Navy insulators (based on the history of Navy insulators installed at the Navy's VLF/LF sites).

RESULTS

When properly installed and "burned in," the Austin Insulator safety core insulators are very reliable. They have an experienced MTBF of at least 167,000 insulator years. For a typical umbrella top loaded monopole installation with 100 insulators, this implies a failure rate for the insulators of 1 every 1670 years, assuming no insulator remains in place past its service life. If data from the Navy VLF antenna installation at Cutler, ME, are eliminated, the Navy experience is consistent with the Austin Insulator experience. The MTBF experience for the individual insulators at Cutler is much less, about 108 years for all failures and twice that for type 3 failures.

The Cutler experience is due to the different configuration of the Cutler antenna and insulator, combined with the occurrence of large lightning strikes in that area. The insulators have a radio frequency (RF)-driven structural failure mode that occurs after an electrical failure (belt tracking) if RF operation is allowed to continue. This can happen in an active antenna installation that has more than one insulator in series to ground. This has been the predominant mechanism of structural failure of the safety core insulators. At Cutler, a lightning strike near the insulator results in a very large, fast wave front, voltage pulse appearing across the insulator. This fast wave front (high dV/dt) pulse combined with the ring configuration results in (1) a large peak voltage appearing across the insulator prior to flashover, (2) flashover along the insulator surface, and (3) possible penetration of the arc into the interior of the insulator. The high voltage can track or puncture internal components. The high current on the surface or inside the insulator can damage or destroy the insulator.

RECOMMENDATIONS

For any application using safety core insulators where structural failure of a single insulator would result in serious damage, it is strongly recommended that there be at least two independent structural supports. When safety core insulators are installed in locations where they are exposed to lightning, the corona rings should be designed to mitigate the lightning-induced damage as well as RF voltage withstand. The design of rings for lightning mitigation requires further study. Preliminary efforts have yielded some insight into the design problem for lightning protection of insulators using corona rings, but further efforts are required to develop confidence in the design.

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BACKGROUND

Austin Insulators Inc. is the successor of the A.O. Austin Insulator Company started in Barberton, Ohio, in 1933. Arthur Austin, who was Chief Ceramist, left the Ohio Brass Insulator Company to start his own company, with a primary emphasis on the production of radio insulators. The company was bought by the Decca Navigator Company of the United Kingdom in 1969 and moved to Toronto, Canada, as the Decca-Austin Insulator Company. Since then, the company has changed names a few times (Racal-Decca Canada, Litton Marine, and now Austin Insulators Inc.)

The general safety core insulator design was developed by A. O. Austin before the move to Toronto. There were probably thousands of these insulators installed prior to 1969, but the records prior to the move are not available. Since then, the company has produced approximately 800 of the oil-filled safety core insulators per year. As of today, there are more than 25,000 of these insulators in service, including several hundred at U.S. Navy VLF/LF operational transmitters around the world [1].

FAILURES

Austin Insulators is aware of several incidents involving these types of insulators since 1970. These incidents include failures of various types, including combinations of electrical, mechanical, and structural failure. All of the known incidents are described in Appendix A. These failures have been divided into three different categories (or types) as follows.

Category 1 includes failures that are a result of improper installation. Examples of failures in this category are given below:

1. Improper installation
    a. Installed upside down. Air bubble exposes belt in high field area (Haiku)
    b. Installed with inadequate articulation. Porcelain cracks, allowing oil to leak out (Crimmond, Bafa Lake, La Regine)
    c. Installed with inadequate suspension hardware, allowing insulator to fall (Jim Creek)

Category 2 includes incidents or failures that are due to a manufacturing defect or a design flaw. This type of incident or failure tends to happen early in the life of an insulator. This category is similar to the burn-in phase for solid-state equipment in that once the design flaw is corrected and/or the insulators with defects are discovered and replaced, then the probability of failure drops to the long-term expected value. Examples of failures in this category are given below:

2. Manufacturing defect or design flaw
    a. Leaking seal allows oil to leak out (Cutler, Fort Collins)
    b. Casting flaw allows oil to leak out (Cutler, Fort Collins)
    c. Design defect. Low angle allows air bubble to expose belt to high field (Cutler)

Category 3 includes “true” failures of installed insulators where the cause of the failure is unknown or is part of the normal risk of operation. Examples of failures in this category are given below:

3. “True” Failures
    a. Cyclone damage (Decca Navigation Transmitter Site Western Australia)

b. Other (Cutler lightning damage)[1]

The failures are further described by the type of failure. Mechanical failure (M) involves the porcelain cracking and the oil leaking out. Electrical failure (E) involves the tracking of the fiberglass belt, turning the insulator into a resistor. Structural failure (S) involves the structural failure of the fiberglass belt.

Table 1 summarizes all the known failures. Note that two of these failures were the original Austin Company safety core type. This design used smooth-sided porcelain, an impregnated cloth belt as a tension-bearing element, and a preload higher than the maximum recommended working load, thus continuously subjecting the tension belt to very high loads. Subsequently, Austin Insulators improved the design by incorporating shedded or rippled porcelain, a continuous wound fiberglass belt, and a redesigned configuration that significantly lowered the preload on the linkage assembly. Thousands of the old Austin Company design safety core insulators were supplied, but no records are available that can be used for a reliability estimate; consequently, they are not included in the mean time between failures (MTBF) estimation.

Note that for the new Austin safety core insulators there are only three failures that fall in category 3. They are the cyclone-induced structural failure in the Western Australia DECCA Navigation transmitter and the last two lightning-induced failures at Cutler. All the others can be attributed to improper installation or design flaw. Although every attempt was made to obtain accurate and complete records, it should be noted that there might be other unrecorded or unknown failures.

[1] The probability of lightning-induced failure can be reduced but not eliminated by modifying the corona ring design [2]. Thus, given new rings, the last two failures at Cutler might be considered as type 2. However, they have been retained as type 3 in this report, which gives a conservative MTBF estimate.

Table 1. Summary of known safety core insulator failures.

Site	No.	Type	Cause	Insulator Type
Crimmond, UK	1	M-3	Unknown	Old Austin
Matola, Sweden	1	S-3	Tower lost, cause unknown, speculation includes vibration and/or lightning.	Old Austin
Jim Creek, WA	2	S-1	Span lost, breaking two insulators when they hit the ground. Cause – improperly installed spelter socket.	New Safety Core
Haiku, HI	1	EM-1	Down lead dogleg counterweight insulator exploded. Cause – improper installation (upside down exposing belt to air pocket), corona ring installed backwards, plus lightning.	New Safety Core
Decca Navigation Site, West Australia	1	S-3	Cyclone-blown debris cut insulator, causing tower to fall.	New Safety Core
Decca, Scotland	3	S-1	Mechanical overload caused fiberglass links to tear. Installation of a larger (stronger) insulator eliminated problem.	New Safety Core
La Regine, France	1	MES-1	Inadequate articulation between series pair insulators caused the porcelain in one insulator to break, oil to leak, and the insulator to fail electrically. Continued operation resulted in burning and structural failure.	New Safety Core
Bafa Lake, Turkey	2	MES-1	Top load insulators failed structurally. The insulators as originally installed do not have adequate articulation so vibration causes the oil to leak out, allowing burning of the fiberglass.	New Safety Core
Bafa Lake, Turkey	4	M-1	Same as above (Bafa Lake 2), but oil leak discovered prior to burning.	New Safety Core
Cutler, ME	2	E-1	Fiberglass belt tracked following lightning storm. Main cause attributed to design flaw in that the air bubble exposed the fiberglass belt to high electric fields.	New Safety Core
Cutler, ME	1	EMS-3	Lightning tracked a modified insulator belt. Operation of second array caused continued burning and eventually explosion and structural failure.	New Safety Core
Cutler, ME	1	EM-3	Lightning caused electrical failure and porcelain to explode.	New Safety Core
Cutler, ME	3	M-1	Three insulators have been discovered to have oil leaks.	New Safety Core
WWVB, Ft. Collins	1	M-1	One insulator was discovered to have an oil leak prior to installation.	New Safety Core

MTBF ESTIMATE

All Safety Core Insulators

An estimate for the MTBF of the new safety core insulators can be obtained by taking the number of operating insulator years and dividing by the number of failures. Austin Insulators Inc. provided an estimate of the total number of insulators in service for this calculation.

There are 25,000 new Safety Core insulators that have been in operation for an average time of 20 years or 500,000 insulator-years. There were three type 3 failures, counting the two latest failures at Cutler. All other failures are due to manufacturing defects, design flaws, or improper installation. The manufacturing defects all involve very slowly leaking oil and all were discovered early in the life of the insulator prior to any electrical or structural failure. Consequently, the long-term MTBF is based on only type 3 failures.

MTBF Type 3 Failures = 500,000 Insulator Years/(3 insulator failures) =>
MTBF = 167,000 years.[2]

This is an astounding reliability figure. As an example of application, the VLF/LF antenna at Aguada, PR, has ~125 insulators in it. For a particular site, the overall expected time between failures is given by dividing the insulator MTBF by the number of insulators installed. Using the individual insulator MTBF above gives an overall MTBF for Aguada of 1333 years. This implies that it is more likely that an insulator will be destroyed by natural forces (i.e., earthquake, cyclone, hurricane, tornado, etc.) or war than by failure.[3] Even if there were 10 times the number of known failures, the MTBF for the individual insulators would be more than 16,000 years and the overall estimate for the MTBF of Aguada would be 133 years.

Note that this reliability estimate applies to insulators that have been "burned in" i.e., manufacturing defects and design flaws have been discovered and eliminated. It applies to the time after "burn in" until ageing starts to be a factor. Austin Insulators gives a conservative estimate for the lifetime of the safety core insulator of 25 years, meaning no age-related failures prior to that time. No age-related failures have yet been observed, and the actual lifetime prior to the start of age-related failures is probably greater than 25 years. The implication in the case of Aguada is that the probability of failure during the manufacturer's stated lifetime is equal to 25/133 = 0.189, or less than a 20% chance of a failure during the service lifetime of the insulators.

Navy Safety Core Insulators

Another estimate of the MTBF for the Navy's application can be obtained from the history of the insulators installed at the Navy's VLF/LF sites. The number of insulators and time in operation has been estimated by the use of Austin Insulators' records of sales to the Navy. Table 2 gives the details for the various U.S. Navy sites. This estimate was based on 5% of the order being for spares and the installation date being ½ year after delivery.

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[2] If the last two failures at Cutler are moved to category 2, then the experienced MTBF is 500,000 years. In either case, the sample size is too small to provide statistically significant data. Normally a sample size containing at least 10 failures would be required to get accurate values of MTBF. Hence, the term "experienced" or "estimated" MTBF is used in this report.

[3] Similarly re-categorizing the last two failures at Cutler would mean that the only type 3 failure in Austin Insulators' experience was caused by a cyclone (Decca Navigation site West Australia).

The MTBF experienced for all U.S. Navy insulators in service is 7977.5 insulator years divided by four failures, or 1994 years. The experienced MTBF for type 3 failures is double that, or 3989 years.

Table 2. New safety core insulators installed at U.S. Navy sites.

Site	Number – 5%	Years Service	Failures	Insulator Years
Adak, AK	74	7	0	518
Aguada, PR	125	15	0	1875
Awase, Okinawa	85	14.5	0	1232.5
Cutler, ME	24 24	10 8	4	432
North West Cape, Western Australia	24	9	0	216
Grindivik, Iceland	91	14	0	1274
Jim Creek, WA	22	17	0	374
LaMoure, ND	16	20	0	320
Niscemi, Sicily, Italy	112	15.5	0	1736
Total	597	130	4	7977.5

Note that this is a factor of 34 less than the estimate based on all the insulators Austin has in operation. The reason for this is that the data from Cutler have been included in this calculation. All the type 3 failures experienced by the Navy have been at Cutler. Cutler is unique because of its configuration and the large lightning strikes that occur in that area. If Cutler is eliminated from the calculation, then 7548 insulator-years have passed **without a failure,** indicating that the U.S. Navy (except for Cutler) has experienced a MTBF greater than 7548 years. This number is a MTBF that is a factor of 22 times less than the 167,000-year estimate based on Austin Insulator records. However, since there have been no failures in the Navy experience (except for Cutler), this is consistent with the Austin Insulator experience.

The reliability experienced at Cutler has been poor. In this case, the experienced MTBF for the safety core insulators including all failures is 432/4 = 108 years. The MTBF experienced for type 3 failures is double that or 216 years. There are 48 insulators in operation at Cutler and the overall failure rate experienced there has been about 1 every 2 years. The expected failure rate now that the initial design flaw has been eliminated is about 1 every 4 years. Since the last failure, a standard operating procedure (SOP) has been initiated for the station forces to turn the transmitter off when a lightning storm is in the vicinity, which only happens 2 or 3 times a year. There have been no failures at Cutler since that SOP was initiated, which supports the conjecture that lightning is attracted to the antenna panels when they are energized at high voltage.

This failure rate at Cutler could be significantly reduced by modifying the corona rings to provide lightning protection by making them symmetrical and moving them closer together [2]. There are two problems with this. The first is that the design process for using corona rings operating at high voltage to also provide lightning protection needs to be developed. The second is that the modified rings will reduce the RF voltage rating, and the modified insulators may not meet the requirement for operations at Cutler.

The antennas at Cutler and the North West Cape are nearly the same Tri-Deco design. There are two of these arrays at Cutler and a single, slightly larger, array at the North West Cape. The Tri-Deco design is different from the other antennas in the U.S. Navy inventory, which are umbrella top loaded monopole (UTLM) antennas, with the exception of Jim Creek, which is a valley span. Each array of the Tri-Deco antennas has six diamond-shaped horizontal top loads made up of cables suspended from an array of towers.

The reason Cutler experiences lightning-induced failures involves several factors. First, there is only one insulator between the high voltage on the top load and ground. Second, this insulator is located at the highest part of the high-voltage top load and thus most likely to be struck by lightning. Third, the design RF operating voltage for the insulator is quite high, and for that reason the gap between the corona rings is nearly the full length of the insulating body, enabling flashover along the surface of the insulator for high dV/dt impulses. In addition, it seems that lightning is attracted to the active portion of the antenna near the insulators when it is energized.

A lightning strike near the insulator results in a very large, fast wave front, voltage pulse appearing across the insulator. This fast wave front (high dV/dt) pulse combined with the ring configuration results in (1) a large peak voltage appearing across the insulator prior to flashover, (2) the flashover path along the insulator surface, and (3) possible penetration of the arc into the interior of the insulator. The high voltage can track or puncture internal components. The high current on the surface or inside the insulator can damage or destroy the insulator. If the oil is low, the resulting voltage can reach levels that can initiate tracking of the fiberglass belt even if the arc path is not along the insulator surface.

It is interesting that no failures have been experienced for the safety core insulators installed in the Tri-Deco antenna located at the North West Cape in Australia. One reason for this is believed to be a result of the fact that there is very little lightning in that area [3]. Another possible reason relates to the fact that Cutler arrays differ slightly from the one at the North West Cape in that Cutler has a 60-Hz deicing system to heat the wires by running current through the antenna conductors. When icing conditions occur, one array is transmitting while the other is deicing. The deicing system requires insulators in the top panels to isolate the 60-Hz current paths. The isolated panel sections have a larger surge impedance than that of the entire array, which will increase the peak voltage resulting from a given lightning strike.

The WWVB antennas at Fort Collins, CO, are similar to a single panel of a Tri-Deco antenna, although considerably smaller. There have been no failures in the Fort Collins antennas. The lightning statistics, in terms of the number of strikes per square km, at Fort Collins are similar to those experienced at Cutler [3], but because they are smaller the antennas have much less probability (~1/12) than Cutler for a direct strike. The transmitters there do kick down at times during lightning storms but it is not known if that is due to direct strikes. Other factors may contribute to the fact that there have been no failures at Fort Collins. The panel configuration at Fort Collins is such that the grounded towers provide more protection to the panel corners, the duty cycle of the signal is approximately 50%, and the operating voltage is considerably less than at Cutler. All of these factors may contribute to a reduced probability for a direct strike to the panels.

STRUCTURAL FAILURES

Structural failures of insulators are the most costly and dangerous. Depending on the configuration, they can put the entire structure at risk. There are three failures listed in Table 1 and also in Appendix A (Bafa Lake, Cutler, and La Regine), where structural failure followed electrical failure (belt tracking). All of these structural failures resulted from RF current burning the fiberglass belt because the configuration allowed transmitter operation after the insulator was tracked. There are two modes of track initiation: (1) a lightning-initiated track, which can be completed by the lightning or RF, and (2) RF tracking following oil leakage.

UTLM Failures

The structural failures at Bafa Lake, Turkey, involved the top load radial insulators in a UTLM antenna. These are the insulators most likely to fail electrically in a UTLM because they have the most voltage across them and because they are highest and so most exposed to lightning. However, RF voltage probably initiated the tracking at Baffa Lake because the oil had leaked out of the insulator due to improper installation (limited articulation). Structural failure occurred following electrical failure because the breakup insulators below the main top load insulator were still intact, allowing RF operation to continue. The RF current flowing through the carbon-tracked fiberglass belt caused the burning and eventual structural failure.

The failures at Bafa Lake did not result in damage to the tower for two reasons. First, the top load radials are highly redundant structurally. Second, that antenna was designed such that the active portions of the top-load radials are longer than the tower height so that the failed insulators and hardware hit ground before reaching the tower.

The structural failure at La Regine, France, was similar to structural failures at Bafa Lake in that it involved the main top load radial insulators. At La Regine, two insulators were put in series as an expedient to increase the voltage capability. Improper installation (limited articulation) of the second insulator resulted in mechanical failure, allowing the oil to leak out. When one insulator tracked, the other held off the RF voltage, allowing continued operation with subsequent burning of the fiberglass band and eventual structural failure.

The U.S. Navy has several UTLM antennas that have top load radials shorter than the tower. Most of these have been in operation for several years without incident, and there is a remote chance that one of these insulators could track, either from an oil leak or from a large lightning strike. In that event, structural failure of a main top-load insulator could occur by the mechanism described above and the insulator and associated hardware would swing in and hit the tower, potentially causing significant damage.

Tri-Deco Antenna Failures

The structural failure at Cutler (failure #3) was caused by RF current, induced from continued operation of the other array, burning the tracked fiberglass belt. Since that failure, an SOP has been put in place to cease operation of both arrays if one array goes down with symptoms of an insulator failure. Operations are not allowed to resume until the failed insulator has been located and isolated. This SOP was used effectively immediately following failure #4 and structural failure was averted [4].

One proposed method of eliminating the lightning-induced failures at Cutler involves placing two safety core insulators in series, which would nearly halve the slope (dV/dt) of the lightning-induced voltage waveform across the insulators. That reduces the likelihood of damage to the insulator from a direct lightning strike. It means that the peak lightning current required to initiate surface flashover would nearly double. The problem with this configuration is that if one of the insulators tracks, the other would hold off the RF, allowing continued operation and resulting in **certain** structural failure. The structure at Cutler is too valuable to take this risk. Consequently, the concept of two series safety core insulators is strongly discouraged at Cutler.

CONCLUSIONS

In normal service, when properly installed and "burned in," meaning all manufacturing defects have been eliminated, the Austin Insulator safety core insulators are very reliable. They have an experienced MTBF of at least 167,000 insulator years.

For a typical UTLM installation with 100 insulators, this implies a failure rate for the insulators of 1 every 1670 years, assuming no insulator remains in place past its service life. Since the manufacturer's recommended life expectancy for these insulators is 25 years, the expectation is that no insulators would fail during that time for this type of antenna. In fact, for "burned in" insulators it is more likely that the insulators will fail from natural forces or war than from anything else.

The MTBF experience for the individual insulators at Cutler is much less, about 108 years for all failures and twice that for type 3 failures. The reason for this has to do with the different configuration of the Cutler antenna and insulator, combined with the occurrence of large lightning bolts in that area. Modifying the corona rings by making them symmetrical and moving them together will reduce but not completely eliminate the probability of lightning-induced failure. This modification will also reduce the RF voltage rating and the modified insulators may not be adequate for Cutler. Preliminary efforts have yielded some insight into the design problem for lightning protection of insulators using corona rings, but further efforts would be required to develop confidence in the design [2].

The Austin Insulator Inc. new design safety core insulators have extremely high reliability after "burn in." However, these insulators are not the classic fail-safe design. The new insulators have an RF-driven structural failure mode that follows an electrical failure (carbon tracked belt) when RF operation is allowed to continue. This failure can happen in an active antenna installation that has more than one insulator in series to ground. This has been the predominant mechanism of structural failure of the safety core insulators.

If the fiberglass belt of one of these insulators becomes tracked, the other insulators in series can hold off the voltage, allowing operation to continue, usually without the operator's knowledge of the failure. This allows RF current to flow in the tracked belt, burning it to structural failure. The belt can be tracked by lightning or by RF if the oil leaks out of the insulator. Thus, for any application using safety core insulators where structural failure of a single insulator would result in serious damage, it is strongly recommended that there be at least two independent structural supports. For example, the U.S. Navy policy is that all towers using safety core insulators in the guy wires must be double guyed.

RF burning of an already tracked belt can also occur in an inactive antenna if there is a nearby active antenna. In this case, burning is much more likely if there is a single insulator between the active antenna and ground, like the Cutler configuration. For closely coupled antennas, both design and operational considerations must take into account the possibility that coupled energy could burn an already tracked insulator.

When safety core insulators are installed in locations where they are exposed to lightning, the corona rings should be designed to mitigate the lightning-induced damage as well as RF voltage withstand. The design of rings for lightning mitigation, while simple in concept, has not yet been thoroughly studied. An important aspect of this study is to consider the tradeoffs between RF withstand voltage and lightning protection.

Every application having multiple insulators in series to ground should take into account the possibility of structural failure of one of the insulators. For example, the structural failure of a single top load insulator failure does not in itself put the tower in jeopardy because of the other top load radials. However, if the top load radial is shorter than the tower, the insulator and associated hardware can swing into the tower and damage it. This type of antenna should be designed such that if one of the main top load radial insulators fails it does not hit the tower causing further damage. Similarly, failure of a single guy will result in loss of the tower. Thus, each guy point should have two independent insulated guys.

One possible exception for the rule of having two independent insulator supports would be antennas that have a single insulator between the high-voltage structure and ground. In this case, if an insulator becomes tracked, operation of the antenna is no longer possible, thus informing the operators of the problem and precluding the RF burning the fiberglass belt. An example of this type of antenna would be the valley span antenna at Jim Creek, the panel antennas at Fort Collins, and the Tri-Deco antennas at Cutler and the North West Cape. This type of antenna should have the corona rings configured for lightning protection. If safety core insulators are used for this application, they must be configured as a single insulator only. If two or more insulators are put in series, then the RF burning failure mode becomes possible, with the resulting risk of serious structural damage.

REFERENCES

[1] Chavez, J. L. and P. M. Hansen. "Very-Low-Frequency (VLF) Cutler, Maine Replacement Insulator Analysis, Technical Report 1773, SPAWAR Systems Center San Diego, San Diego, CA, July 1998.

[2] Hansen, P. M. "Impulse Flashover Tests at Edgar Beauchamp High Voltage Test Facility Dixon, California – In support of Cutler Insulator Failure Investigation, Technical Report 1943, SPAWAR Systems Center San Diego, San Diego, CA, July 2006.

[3] Hansen, P. M. "Probability of Lightning Strike to VLF/LF Antennas," Technical Report in Process, SPAWAR Systems Center San Diego, San Diego, CA.

[4] Zueck, R., P. Warr, and E. Nezic. "Panel Insulator Failure on 21 August at Naval Computer and Telecommunications Area Master Station Atlantic Station (NCTMSLANT) Detachment Cutler, Maine," NFESC SSR-3045-SHR, Navy Facilities Engineering Service Center, Port Hueneme, CA, June 2005.

APPENDIX A:
KNOWN INSULATOR FAILURES
(AS OF AUGUST 2006)

1. *Crimmond, UK.* MOD LF site in Scotland, UTLM antenna, failure ~ 1977-1980. The insulator that failed was an original Austin A-8040 (smooth sided). The original Austin safety core design uses very large permanent pre-load. In this case, the ceramic cracked and upon inspection, oil was found to be leaking. 47- model A-8040 insulators were installed in 1974 and they are still in operation, plus 13 more A-8056 size. The MOD is proposing a program to replace all of the old style safety core insulators with the new style safety core.

2. *Matola, Sweden.* Broadcasting station, antenna configuration unknown. The only information is a file indicating that the insulators were tested in August of 1957 and a couple of pictures of the tower crumpled and lying on the ground. These insulators were the old type with the large pre-load manufactured by the original Austin Company. The implication is that a guy insulator failed structurally. Pat Warr (Austin Insulators CEO) was told by his predecessors that lightning was involved.

3. *Jim Creek, WA.* Valley span antenna. Two span suspension insulators failed when they hit the ground following the failure of an improperly installed spelter socket.

4. *Haiku, HI.* Valley span antenna (Dec 1996) AST -6018/3849 in down lead. Supplied (12) AST6018/3878 in 1989 insulators for the valley spans plus one more for the down lead. The down lead was configured as a dogleg with the corner held in place using a safety core insulator attached to a counterweighted halyard. The porcelain of the insulator exploded following a lightning storm. The operators attempted to bring up the transmitter three times during which time outside observers saw the belt glowing red. The fiberglass belt was burned such that most of the epoxy was gone. The remaining fiberglass belt twisted up but retained its structural integrity. The insulator was later shipped to the factory and pulled to destruction. It failed at a level above its specified working load. Examination of the insulator indicated it had been installed upside down so that the air bubble exposed the fiberglass belt to the high field area. The corona rings were also improperly installed (inverted) which increased the field on the belt. The failure occurred approximately 7 years after installation.

5. *Decca Navigation Transmitter Western Australia.* A Decca tower (300' UTLM typical) on the North West coast of Australia was lost during a cyclone when flying debris cut through a safety core guy insulator.

6. *Decca Navigation Transmitter Scotland.* (300' UTLM typically) Three safety core insulators failed structurally on a Decca tower in Scotland. The damage occurred at a single location in successive insulators that were installed there. The fiberglass links failed by tearing at the same location where they failed during a pull to failure test. There was no indication of electrical failure (burning). The problem was solved by using a larger insulator in this location. Pat Warr thinks the problem was caused by unusual vibration at this particular insulator location.

7. *La Regine France.* UTLM Antenna. One of the main top load radial insulators failed structurally. The original arrangement was with single A-S0078L insulators, supplied in 1992. The station transmitter power was subsequently increased in 1996 and they suddenly wanted AST's but since they were not available quickly they opted to take a second 'L" which was unfortunately connected directly to the original with a couple of link plates. Quoting Pat Warr, Austin CEO, "I understood from John Molloy-Vickers, at the time, that he recommended an articulated connection

but the customer clearly had their own ideas." The cause of the failure is attributed to the fact that there was no articulation between the two main top load insulators. The torque transmitted through the connection caused the bottom insulator porcelain to crack and allowed the oil to leak out. The belt in this insulator tracked but the transmitter was able to continue operations because the other insulator in the series pair remained intact. This resulted in significant current flow in the second insulator, which eventually failed structurally. The resolution of the problem is unknown as repair was completed without a report provided.

8. Bafa Lake Turkey. 2-UTLM Antennas. Two of the main top load radial insulators have failed structurally. This antenna was designed such that if the top load insulators failed they hit the ground not the tower, so the failures have not resulted in extensive damage. The cause of the problem is similar to the number 7 above in that the articulation on the insulators is inadequate. In addition, the tension in the top load radials is low and there are no vibration dampers or spoilers. This may allow large displacement Aeolian vibration (galloping) that exacerbates the problem. The evidence is off center worn hardware on the ends of the failed insulators and asymmetrical compression of the gaskets. It appears that the gaskets are being squeezed on one side and eventually the oil leaks out. The transmitter continues to operate tracking the belt, which fails electrically first and eventually burns through failing structurally. Several other insulators have been discovered with missing gaskets or displaced porcelains that would have failed structurally had they been left in place. A repair and replacement program was undertaken by Austin Insulators to stiffen and support the gaskets between porcelains in conjunction with a change in the articulation hardware by the prime contractor.

9. Cutler ME. Two Tri-Deco panel top loaded monopoles. The diamond shaped panels have a single insulator between the halyard and the panel. Four of these insulators have failed during operations and three other insulators have been discovered to have very minor oil leaks.

The first two insulators that failed had a design flaw that allowed the air bubble to expose the belt to the high fields outside of the end cap. Both of these failures were associated with lightning. The failures are therefore attributed to the combination of the exposed belt plus that additional voltage induced by a nearby lightning strike. These insulators failed electrically in that a carbon track was formed along the length of the insulator shorting the antenna to ground so it can no longer be operated directly. At the time of both of these failures, the other antenna was disabled for painting and could not be operated. The insulator electrical failure precluded further operation so that the belts were not burned to structural failure.

There are 48 insulators installed at Cutler plus 4 spares. All of these insulators were modified by the addition of a larger top end cap to completely contain the air bubble. In addition, 4 more of these insulators were purchased for spares as a part of this modification.

Failure 3: Following installation, one of the modified insulators failed both electrically and structurally. The electrical failure occurred shortly following a reported large lightning strike to the South Array. That array became immediately inoperable. The North Array was operable and the standard procedure at the time was followed, which was to ground the South Array and operate on the North Array. The coupling between the antennas resulted in RF current flowing through the damaged insulator in the South Array, which burned the fiberglass belt and sometime the insulator failed structurally allowing that panel corner to fall to the ground and the remaining insulator and hardware to hit the tower resulting in significant damage to the tower.

Failure 4: The fourth insulator was damaged during a lightning storm in late July of 2004. This insulator had also been modified with the larger end cap. The porcelain covering around the fiberglass belt was completely shattered. The fiberglass belt was heavily tracked so the insulator failed electrically but not structurally. The evidence indicates that the lightning flashed over near or on the surface of the porcelain and the intense thermal and possibly acoustic shock shattered the porcelain [4]. Later analysis by Vaisala, the Tucson company that operates the National Lightning Detection Network, indicated the strike that damaged the insulator was unusually large, having a peak current of 100 Kamps.

Oil leaks: During the time when the new end caps were being installed two insulators were discovered that had oil leaks. One oil leak was discovered when the insulator was removed for modification. That oil leak was due to a flaw in the O-ring (failure at the vulcanized junction of the ring) with possible contribution from a scored bell casting near the leak. The other oil leak was due to a flaw in the lower (smaller) end cap casting, which was discovered prior to installation. Both of these insulators were shipped to the factory for repair. In both cases, the amount of oil lost was so small as to be un-measurable.

In July of 2005, another insulator with a small oil leak from the vicinity of the o-ring seal on the end was discovered. The amount of oil lost was not measurable.

10. Fort Collins, CO. (WWVB) There are two antennas each consisting of a single panel of a Tri-Deco type antenna with the single insulators at each of the corners of the panel. Prior to installation, one of the insulators shipped to the site was observed to have a small amount of oil that had leaked past the O-ring. It was sent back to the factory and repaired. The amount of oil lost was not measurable.

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This report describes reliability analysis of safety core insulators. Known incidents (Navy and non-Navy installations) of safety core insulator failure since 1970 were identified and categorized, and mean time between failure estimated. In general, safety core insulators were determined to be extremely reliable. However, it was found that reliability at one Navy installation (Cutler, ME) was poor due to the different configuration of the Cutler antenna and insulator, combined with the occurrence of large lightning strikes in that area. The report analyzes the failures at Cutler and provides recommendations to mitigate these failures.

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