Lightning strikes onboard

by John Payne

Lightning has long been a problem for mariners. As far back as the early 1800's boat builders were installing lightning protection systems to minimize the catastrophic effects of strikes. These methods were essentially the grounding of spars and rigging. More than one vessel lost mizzens and masts along with compass problems as a result. Bonding systems were also evolved as a response to dissipation of strike energy. In the late 20th century, nearly 200 years on, the same measures are still valid. It is a fact that virtually all classification societies and national marine authorities lay down recommendations for protection of vessels from lightning strikes, but very few cruisers bother to adhere to the them. From my own experience the figure is around 5%. Of more importance is the startling statistic uncovered during research that nearly 10% of fatalities on cruising yachts are the result of lightning strikes, out of the 100 killed in the US through lightning strikes yearly. Lightning causes along with death and injury an enormous amount of damage in shore installations, in particular in the telecommunications and electrical power distribution industries. For these simple economic cost considerations many measures are taken to design systems that minimize the effects of strikes. The main effects are high energy, high voltage transients that result in flashover and damage. They can be either resulting from direct strikes or induction into power or signal cables, or induced, either through capacitive or inductive coupling.

Lightning Physics

What causes lightning? Within the cloud formation, strong updrafts and downdrafts generate high electrical charges. When the voltage reaches a sufficiently high level both cloud to cloud and ground discharges occur. Strikes occur when the ground is at positive polarity and the cloud negative region attempts to equalize with ground. Alternatively strikes can occur when the positively charged cloud top equalizes with the negative ground, or when the positive charged ground equalizes with the negative charge cloud or the negatively charged ground equalizes with the positive charged cloud top.

Lightning consists of a number of components, which form a multidirectional flow of charges. Peak currents can exceed 200,000 amperes (200kA) at over 30,000°C for a matter of milliseconds (25-100 ms). The positively charged ions rise to the cloud top, and the negative ions migrate to the cloud base. Regions of positive charged ions also form at the cloud base. Eventually the cloud charge levels have sufficient

potential difference between ground and another cloud to discharge. The processes are as follows:

*** Leader. The leader consists is a negative stream of electrons consisting of many small forks or fingers that follow and break down the air paths offering the least resistance. The charge follows the fork finding the easiest path as each successive layer is broken down and charged to the same polarity as the cloud charge.**

*** Upward Positive Leader. This is a positive charge that rises some 50 meters above the ground. (Sometimes from your mast head)**

*** Channel. When the two meet a channel is formed.**

*** Return Stroke. This path is generally much brighter and more powerful than the leader and travels upwards to the cloud partially equalizing the potential difference between ground and cloud. (Often directly through your vessel)**

*** Dart Leader. In a matter of milliseconds after the return stroke, another downwards charge takes place following the same path as the stepped leader and return stroke, sometimes followed by multiple return strokes (multi-pulse surges).**

· Multi-pulse Surges. These occur in over 70% of strikes. This phenomenon is where up to 20 re-strikes follow the initial strike at intervals of around 10-200 milliseconds apart. In addition continuing currents of 200-500 amps with durations of up to 1-2 seconds may also occur. The movements happen so fast that it appears to be a single event. This sequence can continue until the differential between cloud and ground has been equalized.

Protection Systems

Protection can never be achieved using a single method, and a number of measures should be used to minimize the risks. The main objectives of any systems are:

· Capture of the strike at a nominated point, ie mast head

· Conduction of the strike current to ground safely using a well installed down conductor that reduces side flashes

· Dissipation of the strike energy to ground, through a low impedance ground system so that rises in ground potential are minimized

· Equipotential ground bonding of all relevant systems and components

· Protection of power supplies from high voltage transients and surges that may damage equipment

· Protection of conductors both power and signal from induced surges that may damage equipment

As a reference to official guidelines the measures are in accordance with NFPA 302 Fire Protection Standard for Pleasure and Commercial Motor Craft

Lightning Protection Zone. The most reliable protection system is one that grounds any strike directly and the principles are as follows:

*** Grounding. The primary purpose of a grounding system is to divert the lightning strike discharge directly to ground through a low resistance circuit suitably rated to carry the momentary current values. This has the effect of reducing the strike period to a minimum, and reducing or eliminating the problem of side strikes as the charge attempts to go to ground. As electricity follows the path of least resistance to ground, little goes down the stays.**

*** Cone of Protection. The tip of the mast, or more correctly a turned spike clear of all masthead equipment gives a cone of protection below it. The cone base is the same as the mast height. This protective cone prevents strikes to adjacent areas and metalwork, which in a yacht can mean stays, rails or other items lower than the masthead.**

Lightning Protection Systems. Most classification societies, American Boat and Yacht Council and other advisory bodies generally recommend lightning protection in the form of a directly grounded mast and spike. Other devices have come onto the market, and effectiveness of most has yet to be conclusively confirmed.

The Great Myth. Lightning rods and grounding actually attract lightning strikes! The presence of a properly installed lightning protection system will give a number of advantages:

*** It will safely ground the strike energy**

*** It will in most cases limit the damaging effects of heat and reduce the current levels flowing, as well possibly the length of time the strike takes (this is in milliseconds). This reduces damage to equipment and crew**

*** In GRP vessels, in particular multihulls, under certain weather conditions, a static charge builds up on the deck. It is my contention that ungrounded vessels actually promote strikes to the vessel due to this condition. Additionally grounding the mast dissipates this charge, and in the process removes a common cause of radio (RFI) noise that occurs as small arc occurs as the static charge goes to ground.**

Mast. Lightning will generally strike the highest point, and take the path offering the lowest resistance to ground. The mast is usually the strike point. Note that a stainless steel VHF whip does not constitute any protection.

Mast Spike. The mast spike ideally should be a copper rod with pointed end. To avoid metal interaction, stainless rods are commonly used but should be of a thicker section than the more conductive and lower resistance copper. The spike should be at least six inches higher than any other masthead equipment, including VHF aerials. Many commercial units (Dynarod and Seaground) have an offset in the rod, which although not being the required straight section would be satisfactory. The purpose of the point being sharp is that it facilitates what is called point discharge. Ions dissipate from the ground and effectively cause a reduction in potential between the cloud and the sea. In many cases the strike may be of lower intensity or not occur at all.

Dissipation Systems

Lightning Protection Device (LPD). This was an Italian development of some 10 years ago, and consists of a high performance varistor. The device is designed to interact with the electrical charges of the initial stepped leader where current values are relatively low and avoid the return strokes. Charges accumulate on the atmospheric electrode and varistor poles. The varistor conducts and the charge condition on the electrode alters. These charges leave when some streamers form to meet the leader.

No Strike Charge Dissipater. This is based somewhat on the pinted spike only that there are many points in a brush arrangement. This is to stop development of a stepped leader forming and minimize the strength of any that do occur,

Mast Cable. Much of the damage in a strike results from heat, as the large current flow into a resistive cable acts as a heater. It is essential that cable cross sectional area is sufficient, typically 35mm^2 or greater. Under no circumstances use soldered joints alone, as they will melt during a strike causing further havoc. Always crimp connections and ensure that all bonded connections are clean and tight. All connections must be bolted.

Grounding. A good ground requires direct and permanent immersion in seawater. It must also have sufficient area to adequately dissipate the strike energy. Through hull fittings must never be used as a primary ground point unless you want to sink the vessel. The bonding cable from the mast base to the ground plate should be as straight as practicable without sharp corners as side discharges occur and this is called corona discharge. Similar side discharges can occur from boat to boat in crowded marinas. Normally I enclose the cable in high quality electrical conduit to reduce the possibility of side strikes on the cable, as electrical insulation will frequently break down under high voltage conditions.

Steel/Alloy Vessels. Connection of the mast base with a large, low resistance bonding strap to the hull or as more practical the mast step is sufficient.

GRP Vessels. A keel acts as a good ground and is sufficient. Bridge out with a stainless link at least two keel bolts to spread the contact area. On multihulls you have to install a large separate ground plate, such as a radio ground (Dynaplate, Wonderbar or Seaground). This will ensure that there is a large and efficient ground area. Do not use the radio RF ground plate as the lightning ground. Never bond the lightning system to the corrosion system bonding, machinery or electrical system negatives or grounds. Never bond the lightning system to bronze through hull fittings (unless you want to sink the vessel!).

Wooden Vessels. Wooden vessels normally have a metal mast track. The track should be properly grounded. If possible a copper strap can also be run, although this is not always practical. Direct bonding to a ground plate or the keel should use the same grounding method as GRP.

Emergency Ground. A heavy gauge copper cable can be clamped to a stay over a half-meter section. The other end should be clamped to a ground plate, and hung over the side. Do not use chains and anchors (another great myth), as they are ineffective as a ground.

Electromagnetic Pulse. A vessel can have damaged equipment from a strike within a few hundred meters. Insurance companies don't like to accept claims on damage unless you can show total damage to masthead systems. A strike sends out a very large electromagnetic pulse, which is a strong magnetic field. This field is induced into wiring and systems as a high voltage spike, doing just as much damage. If you suspect damage from an induced electromagnetic pulse from a localized lightning strike, check with all vessels adjacent to yours, and get statements to support the contention. Generally all the electronics will be out if this is the case as the mast and any wiring acts as a large aerial.

Sidestrikes. It is common in very closely moored vessels and crowded marinas to have lightning strikes literally jump from vessel to vessel as it attempts to find ground on ungrounded vessels. Usually the strike exits from stays, chainplates and spreaders. In many cases the strike will go to water from the chainplates causing serious damage to hull and fittings. In many cases the rig may topple.

St.Elmo's Fire (Brush Discharge). This phenomenon is more common on steel vessels and when it occurs usually precedes a strike, although the effect does not occur all the time. The vessel in effect becomes a large ground mass. Ionized clouds and balls of white or green flashing light that polarizes at vessel extremities characterize the discharge. The discharge of negative ions reduces the potential intensity of a strike. Damage to electrical systems is usually induced into mast wiring, as the steel hull itself acts as a large Faraday cage.

Corrosion Factors. Considerable care must be taken when bonding various items of equipment into a lightning protection bonding system. On steel and alloy vessels the hulls are the one ground plane for all equipment and all grounds are held at the same potential. In GRP and timber vessels it can be more complicated, but problems may arise where indiscriminate bonding of through hull fittings and other items is carried out. It is easy to create differences of potential between various items creating a corrosion nightmare. After connecting up a lightning system, it is prudent to monitor the corrosion rate of anodes, and observe any underwater bonded items.

Bonding. Most authorities recommend that all stanchions, chainplates, and large metallic equipment such as stainless water tanks should be bonded to the lightning ground. Failure to bond can result in side flashes as these can offer an alternative path. The bonding should be made at the point closest to the main conductor. I prefer not to bond the stays and chainplates as often recommended. My reasoning behind this is that if a good low resistance path is made from mast to keel or groundplate the strike energy will be directed that way. Grounding stays offers alternative high resistance paths, encouraging side strike activity. Current flows can also cause crystallization and permanent damage to stainless stays and fittings in a severe strike (try and get that past the insurance company!). Bonding must be undertaken with care. Dissimilar metals such as the aluminum mast copper strap, and steel must be interconnected to ensure no galvanic corrosion can occur. More importantly interconnection of various grounding systems must be undertaken with great care. It is only necessary to bond internal metallic equipment within six feet of the mast. In practice this is rarely water tanks under bunks etc, but should include tankage under the cabin sole.

Lightning Safety. In an electrical storm, the following precautions should be taken to avoid any shock or something more serious.

* Stay below decks at all times.

* Stay well away from mast, boom shrouds, chainplates and the mast compression post or mast if below deck.

* Take a position and plot it prior to shutting down, or in case of all electronics equipment being blown.

* Turn off all electronic gear and isolate circuit breakers if at all practical. Disconnect aerials also if practicable.

* Do not operate radios until after the storm unless in an extreme emergency.

* After a lightning strike, be aware that the compass may be incorrect.

* Check all running rigging and fittings after a strike as damage can occur that may seriously affect vessel capacity to sail.

*** Check all through hull fittings for damage, if you have decided to risk bonding them. Usually if they are damaged or gone, you will see water ov**

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