LIGHTNING PROTECTION AND LIGHTHOUSES

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Introduction

Three General Lighthouse Authorities have responsibility for lighthouses in the British Isles. Trinity House is responsible for England, Wales, the Isles of Scilly and the Channel Islands. The Northern Lighthouse Board is responsible for Scotland and the Isle of Man. The Commissioners of Irish Lights are responsible for Eire and Northern Ireland.

Of the fixed and floating aids around the British Isles, Trinity House has 67 lighthouses (7 manned) and 12 automated major floating aids. The Commissioners of Irish lights have 80 lighthouses (5 manned) and 4 automated major floating aids. The Northern Lighthouse Board have 196 lighthouses (11 manned).

Historical developments

Early lighthouses used coal braziers or candles followed by oil wick lamps, paraffin vapour burners and acetylene gas. Finally, the coming of electricity resulted in its widespread use from the 1930s.

Michael Faraday was a scientific advisor to Trinity House from 1836 to 1866. During his time Faraday performed trials on electric lamps including Professor F H Holmes' arc lamp. His work was not restricted to electrical matters. He was involved in many varied projects such as light sources, fuel oils, wicks, optics and even fresh water supplies for the lighthouse keepers.

Lightning protection

Most lighthouses visited by the author have, at least, the basic form of structural lightning protection. Indeed, most of the systems examined were well executed with good bonding to metal window frames, hand rails etc. These systems, despite the general adoption of a single down conductor, were perfectly adequate for lighthouses until the introduction of PVC insulated cables, semiconductor control systems and remote (telephonic) monitoring systems. The strike to Nash point lighthouse, described later in this paper, is an example of this.

Introduction of radiobeacons for radio direction finding

In the 1930's radiobeacons were introduced to enable mariners to navigate by taking bearings from two or more of these radiobeacons.

Before the introduction of radiobeacons lightning damage to lighthouses was not considered an important issue and there was no apparent need to provide other than the basic level of structural protection.

Because of the low radio frequency (283.5-315 kHz in the UK) used by the radiobeacon service, the aerial systems were relatively large affairs. These were often a long wire 'T' pattern with one end anchored to the lighthouse and the other end supported by a pole or lattice tower. The centre vertical radiator leads down to an aerial matching and tuning unit that connects to the radiobeacon in the lighthouse by an underground feeder cable.

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The radiobeacon aerial installation considerably increases the lightning collection area of the lighthouse. The exposed nature of the aerial with its associated 'earth mat' and support structures provide a good lightning air terminal and earth.

Radiobeacon transmitters used by Trinity House containing early semiconductors had a high failure rate. Although there is little recorded evidence, some of these failures were probably due to low energy lightning strikes. High energy strikes would be noticed by the keepers and reported as such.

One incident where the cause of the damage was not in doubt was at Round Island in the mid 1980s. Such was the force of the strike that the radiobeacon power unit (requiring two men to lift) was blown 6 inches out of its rack mounting.

The effect of modern materials on lightning protection

The development of lighthouses was a very slow process in the early years. Lighthouses were built to last and so was the electrical installation. Early wiring was run in iron or steel conduit followed by the use of steel wire armoured and then mineral insulated copper covered cables. Control systems were simple and employed contactors and manual switches. These installations were able to withstand considerable transient overvoltages and carry their share of lightning currents with little or no damage.

It has been normal practice, since the first electrification, to provide reserve power supplies from batteries. Early battery chargers were simple, robust devices comprising a transformer, resistance and rectifier. Some batteries were charged directly from a dynamo via a series resistance. The method of regulating the charge would have been by simple, robust, electromechanical devices or manual intervention. Modern chargers have sophisticated control circuits, designed to maintain the batteries in peak condition. While the output circuitry of modern chargers may be robust, the control circuits require connection to the load. This provides a path for transient overvoltages direct to the sensitive heart of the charger.

Many sensors are used to control and monitor plant and machinery in the modern lighthouse. Radio and radar beacons using semiconductors and integrated circuits have been introduced. Stepper motors with their associated circuitry are now used to rotate the optic.

Automation

The coming of acetylene gas made automation possible. Ingenious gas valves permitted lights to be flashed at coded intervals. On some stations the lens was made to rotate using the high pressure of the acetylene gas before burning it in the lamp. The first automated station was Grey Rocks, Scotland in 1890. The general automation of lighthouses started to be seriously considered in the late 1950s and early 1960s.

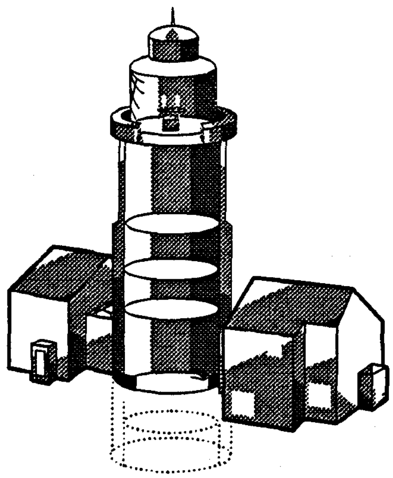
The remote monitoring of lighthouses requires some form of communications medium; radio communications and the humble telephone being the most common of these.

Radio and telephone equipment has to have a connection with the monitoring equipment to function and the monitoring equipment is connected to the lighthouse operating system. Thus a path has been created by which direct lightning currents and induced or common mode transient overvoltages can be introduced into the monitor and from there into the lighthouse operating equipment.

Previous studies conducted into lightning protection, before automation, had been mainly concerned with structural protection. Lightning damage had, in the past, not been a significant problem and the need for special protection of the automated station was not identified when the major automation programme was started.

The unpredictable nature of lightning resulted in a major part of the automation programme being completed before the first of the really damaging strikes occurred. This study was initiated because of the strike to Start Point Lighthouse with remedial work being undertaken as the investigation progressed. With limited resources and finance available it was inevitable that other damaging strikes would occur before preventive work could be completed.

START POINT LIGHTHOUSE



Start Point is one of the most exposed peninsulas on the English coast, running almost a mile into the sea on the south side of Start Bay near Dartmouth in South Devon. The lighthouse was designed and built in 1836 by James Walker. Battlemented parapets around the gallery are typical of his designs. The 28 metre high tower is constructed from granite blocks. The focal plane of the main light is 62 metres above sea level. In 1871 some intermediate floors inside the tower were removed. Two attached and one detached keepers' dwellings were constructed.

Work on automating the station started in August 1992 under a turnkey contract. The lighthouse was de-manned in early 1993 following completion.

The lighthouse and dwellings are now unoccupied. At the time of the strike, Start Point was monitored from St. Catherine's lighthouse on the Isle of Wight.

The lantern or main light room, including floor and roof, is a cast iron structure with cast iron glazing bars (astragals). The present light is a 1 KW metal halide lamp. Two groups of three beams are projected by means of a rotating catadioptric Fresnel lens assembly.

Initially, the lens for the main light was rotated by a clockwork mechanism powered by a weight housed in an eleven-inch diameter cast iron tube. The tube ran centrally from the base of the lantern down into the lower basement. A section of the tube was removed between the sector light room floor and the engine room ceiling during later alterations.

Also housed in the lantern are the main and secondary light ballast, optic drive control and monitor panels and an emergency light with its associated batteries, charger and controls.

The floor immediately below the lantern contains a sector light that projects a red light over the Skerries bank. Also housed in this room are the sector light batteries and charger (50V), a main light control cubicle, and sector light control panel.

The main entrance room, which is just above ground level, houses the station 24V batteries, charger and controls, the mini telephone exchange and the telemetry monitoring cabinet. A ground-level passage to the south houses mains distribution panels and the electric fog signal cabinets and controls. The entrance lobby, to the north, contains security, fire and station condition monitoring panels. Cabling is distributed around this floor on high-level cable trays. Cabling to the upper floors and lantern is on a vertical cable tray fixed to the west wall. A granite spiral staircase with iron handrails connects to the upper and lower floors.

The upper basement floor (which is at ground level to the rear of the tower) houses the mains power incoming fuses, primary sub-main distribution boards, the standby generator with its associated control and changeover panels and a service fuel tank. The main power cable enters the tower in the unused lower basement.

The original lightning protection system consisted of a single, external, half round copper conductor of approximately $100mm^2$ csa. down the north eastern wall of the tower. The conductor runs under the yard, appearing again on the seaward side of a high retaining wall where it continues down into the thin soil covering the rocky cliff.

A compressed air fog signal, standby generator and reserve batteries were housed in a detached building to the south of the tower. When this building collapsed into the sea in December 1989, the fog signal was replaced by an electric emitter on the headland which was later moved to its present position. The generator and batteries were moved to the tower.

3 phase mains electricity was first installed in 1959 by means of a long overhead route. This was later changed to a single phase pole mounted transformer.

The telephone cable is an armoured underground cable terminated on the detached dwelling then running underground (not armoured), entering the tower just below the entrance room.

Two additional down conductors had recently been installed by a lightning contractor. One conductor is on the south eastern wall. Earthing is by means of an underground conductor under the yard, terminating some distance from the tower. The second down conductor, on the south west wall, is more interesting as it takes a 90-degree turn to run over the south passage roof then turning up(!) and continuing horizontally part way down the south dwelling pitched roof, finally going to earth under a concrete yard to the south of the dwelling. A coronal band had been installed a short distance below the gallery parapet.

Radiobeacon

Start Point was one of a number of lighthouses which provided a radiobeacon service. The radiobeacon was removed in 1992 following rationalization of the service. The extensive earth mat for the radiobeacon aerial and the connection to the lighthouse are still in place. The conductor tape enters the building at ground level immediately below the new south west conductor and ends in the south passage at ground level.

Lightning Strike

On the 18 January 1995, the monitoring station at St. Catherine's lighthouse reported loss of telemetry and the Attendant was dispatched from his home in Kingsbridge, 7 miles away, to investigate. On arrival he noted that the main light was extinguished and the emergency light operating. The standby generator was running providing lighting in the tower. Some domestic electricity supplies were operational but all circuit breakers in the tower were tripped. There was a strong smell of burning in the tower. Telephone wires were burnt out and junction boxes blown apart. The mini exchange was destroyed. The telemetry unit had an adjacent telephone line surge arrestor, this was 6m from the point at which the cables entered the tower. The internal modem was damaged as was the digital interface board. The fire and intruder detection systems were inoperative.

Damage Assessment

The author first visited the lighthouse in March 1995 in the company of a lightning consultant. The visit was part of a development project to produce lightning protection guidelines for the three General Lighthouse Authorities. Discussions with the Attendant, maintenance engineers and a physical inspection revealed the following:

External Damage

The generator main fuel storage tank is located on the base of the old (removed) three phase mains transformer about 6m from the north dwelling. Plastic conduit containing the fuel level sensor conductors was blown apart at the fuel tank end. A large chunk of concrete was blown from the transformer base, exposing the old transformer cables. Tarmac was displaced on a footpath where the S.E. lightning earth conductor crossed the path of a disused underground power feed to the old fog signal and generator building.

Aluminium flashing around the tower at south passageway roof level was damaged. Structural damage occurred to the eaves wall at roof level of the south dwelling where the down conductor turned upwards(!) and over the pitched roof.

A wooden hut, about half a mile along the access road from the tower, containing water storage tanks and pumping equipment, supplies water to the lighthouse from a deep borehole. The water level transducers and control box were all destroyed. Electricity to the water pumps is supplied from the lighthouse.

Internal structural damage

While there was no evidence of actual structural damage to the tower, there were signs of side flashing from the sector light pedestal mountings to a suspended ceiling below and from the suspended ceiling to the vertical cable tray. Arcing had also occurred between the cable tray and telephone cables and to equipment housings.

Damage to electrical and electronic equipment

Little actual damage had been caused to the mains distribution system, most MCBs were resettable.

The greater part of the damage was to the electronic equipment in the lighthouse:

- Damage to the standby generator control circuits caused the generator to start (not the failure of the mains).
- Battery charger control circuit boards were faulty;
- The mini telephone exchange had a hole burnt in the cover (and, presumably, in the printed circuit inside);
- Considerable damage was evident on the printed circuit cards in the navigation light control cubicle;
- There was evidence of arcing from a cable tray to the metalwork of the navigation control cubicle;
- The fog detector on the gallery parapet had failed.

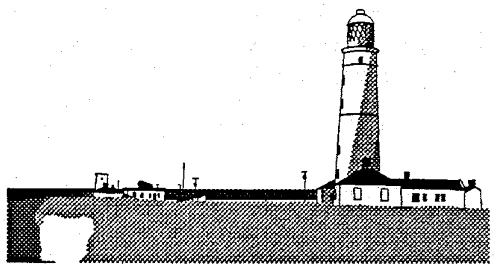
Observation on the lightning protection system

A visual inspection of the lightning protection revealed shortcomings, some serious, in the installation:

- The down conductors were not bonded together at the base of the tower, nor was there a cross bond to the bottom of the weight tube which is bolted to the foundations of the tower;
- The connection to the radiobeacon earth mat is in place but was isolated from the building;
- The incoming and outgoing mains were not directly bonded to the lightning protection system;
- Only one telephone line surge arrestor had been fitted, located a long way from any suitable earth point. The incoming and outgoing telephone lines of the mini exchange were unprotected;
- Various isolated sections of cable tray were bonded with short 4mm earth wires, one gap did not appear to be bridged at all;
- The cable tray is connected to the metal lantern floor at the top but was not connected to the lightning protection at the bottom;
- When the middle section of weight tube was removed, bonds to the staircase handrails were inadvertently isolated;
- Many metal equipment cabinets were not correctly bonded to the cable tray;
- The telemetry and navigation light control cubicles are of plastic construction and therefore do not offer any screening. The metal backplanes of these were not properly bonded to the cable tray;
- The fog detector was not bonded to the lightning protection system.

These findings were communicated to the maintenance department and remedial action put in hand. Since the work was completed there have been two instances of surge arrestor failure on the telemetry telephone line, possibly suggesting further strikes to, or near the lighthouse. One of these failures coincided with a damaging strike at Nash Point lighthouses in South Wales.

NASH POINT LIGHTHOUSE



Nash Point lighthouse is located at the entrance to the Bristol Channel. The nearest village is Marcross, Nr. Bridgend. The lighthouse was designed by James Walker, the then Engineer-in-Chief of Trinity House, in 1832 and was the last to be built by Joseph Nelson. Two circular towers, constructed of granite, were built 300m apart. The eastern (37m) tower is still in use today while the west (22m) tower was abandoned early this century. Keepers' accommodation was provided adjoining the base of each tower. The two towers formed 'leading lights'. A mariner wishing to enter the Bristol Channel, avoiding a sand bank, would position his vessel so that the two lights were one above the other. By maintaining this orientation the mariner would remain in the navigation channel only changing course when indicated by the alignment of other aids to navigation. A fog signal and engine house was built between the two towers at a later date. The remaining (high) light was electrified as late as 1971. The present optic is a catadioptric drum lens illuminated by a 240V 1500W tungsten filament lamp. The character of the light (flash code) is produced by an electric motor driven cam timing unit which produces two unequal flashes every 10 seconds. A red filter was fitted to the drum lens producing a red beam over the sand bank. The lighthouse is still manned, the keepers being responsible for the monitoring of Eddystone, Hartland Point, Flatholm and Breaksea.

Roof: GPS satellite receiving aerials.

Lantern: (focal centre 56m above sea level)
920mm catadioptric fixed drum lens;
A 3-way lamp changer fitted with:
Two 240V 1500W tungsten filament lamps, main & standby;
A 50V 500W tungsten filament emergency lamp.

Gallery: Aerials for VHF, Cellphone and telemetry.

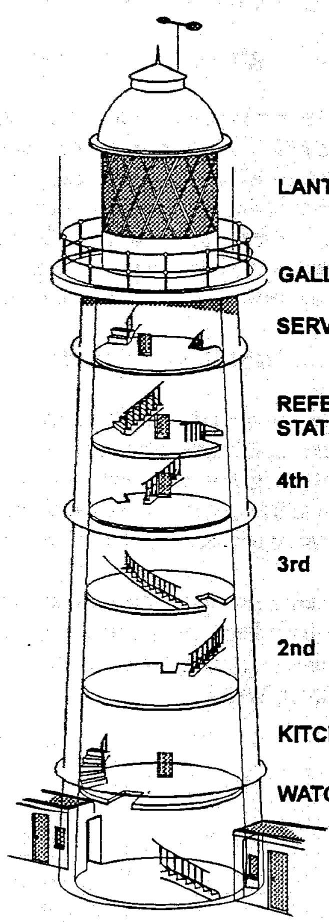
Service Room: Navigation light control panel;
VHF telemetry receiver and processor.

5th Floor: DGPS reference station.

The 4th, 3rd and 2nd Floors are empty

The base of the tower forms the keepers' watchroom and houses the following:

Mains distribution panels;
Standby generator and compressor indicator panels;
Navigation light indicator panel;
Station battery distribution panels;
Radiobeacon transmitter and battery charger;
Mini telephone exchange; VHF radio;
Telemetry monitoring processor;
Telemetry monitoring PC; Administration PC;
Cellular radiotelephone and modem;
Facsimile machine;



Part of the base of the tower is partitioned off to provide space for the station 50V batteries and the radiobeacon 24V batteries. The main telephone entry point is in this room (underground to a dwelling attached to the tower then at facia board level).

Mains electricity is fed to the site by a 3 phase overhead HV supply to 3 pole mounted transformers, located near to each tower and the engine house. Distribution (including the 50Vdc) within the lighthouse is mainly using steel wire armoured or MICC cables. It is important to note that the navigation light with its long vertical run of armoured cable was unaffected by the strike. However, some recent additions, notably the reference station, use PVC.

The original lightning protection system consisted of a single, internal, half round copper conductor of approximately $100mm^2$ csa. Three additional external down conductors had been installed.

Nash Point has a radiobeacon, the aerial for which is a vertical top loaded whip located between the engine house and the east tower. An extensive copper earth mat is buried under the grassed area between the lighthouse and the engine house. In addition to providing the normal service, the radiobeacon at this lighthouse is used to transmit trial correction data for GPS.

In July1995, the U.S. Global Positioning System (GPS) was declared fully operational. This satellite navigation system provides positioning accuracy of 100 metres (95% of the time). While this is perfectly adequate for ocean navigation, greater accuracy is required for navigating in restricted waters and the approach to harbours. A trial differential GPS reference station was installed at Nash Point. The reference station measures the errors of the GPS, calculates corrections and transmits them to shipping by modulating a second carrier on the radiobeacon transmission. Differential corrections increase the accuracy of the GPS signals to about 10 metres. Should this service be offered to the mariner by Trinity House then the availability and reliability will be of paramount importance.

Lightning strike

The GPS aerials on the roof of the lighthouse were struck by lightning on the 10 July 1995. Scaffolding around the disused low light tower and a pole near to a dwelling were also struck.

There are no reports of structural damage. An aerial tuning unit located at the radiobeacon aerial and a pole mounted telephone junction box were the only external items of equipment to be damaged. A mains detection relay was the only equipment damaged in the engine house.

The following is a list of equipment damaged within the lighthouse:

Service room:	VHF telemetry receiver and modem;
Fifth floor:	GPS satellite receivers, monitor PC, modem and radiobeacon RF modulators;
Watch room:	Equipment connected to telephone lines: Remote telemetry monitoring processor and communications cards; Telemetry PC; Facsimile machine; Mini telephone exchange; One extension telephone. Equipment not connected to telephone lines: Cellphone and power supply; Marine VHF transceiver; Radiobeacon transmitter; Radiobeacon battery charger;

Observations on the lightning protection system

A visual inspection of the lightning protection revealed shortcomings, some serious, in the installation:

- A section of the old, internal down conductor has been removed in the service room isolating it from the cast iron lantern;
- The internal and external down conductors are not joined at the bottom;
- Surge protection is not provided for the incoming and outgoing electricity or telephone cables;
- The radiobeacon earth mat is not bonded to the lightning protection earth;
- Radio aerial feeder cables were not bonded to the station earth;
- Surge protection was not provided on the long signal cables between the GPS reference equipment (fifth floor) and the radiobeacon transmitter in the watchroom;
- Surge protection and screening of the control cables between the radiobeacon and the aerial tuning unit is needed.

SUMMARY

The construction and history of the lighthouse are both important factors in assessing the lightning protection requirements. The majority of lighthouses date from the middle of the 19th century and are largely constructed of stone. It was common practice to construct the lantern of cast iron. Other than discontinuous handrails and a few lighthouses which posses a full height weight tube, there is little or no structural metalwork to share the lightning currents.

The installation of electricity for the light and, in some cases for rotating the optic, provided additional earth paths for lightning currents. Most lighthouses are hollow structures without central support therefore cables and cable trays are affixed to the outer wall, reducing the current sharing effect of the external down conductors. Also, external conductors have to negotiate architectural details such as parapets etc. thus increasing their length compared with some internal cable routes.

A significant proportion of lighthouses are built on rock with perhaps only a thin covering of soil making earthing inadequate and costly. Many lighthouses are built on remote headlands leading to long electricity and telephone cables, considerably increasing the lightning collection area. Being located in remote, exposed positions, lighthouses have always suffered the ravages of storms. It is not surprising, therefore, that lightning strikes have not previously given cause for concern. Over the years, parts of lighthouses have crumbled into the sea. This has left a legacy of disused, buried cables pipes etc. to trap the unwary lightning engineer.

To improve the timing of optic rotation and reduce power consumption on solar powered stations stepper motors are replacing the traditional electric motor and gearbox. Similarly, solid state timers are being used to control flashed lights. In an attempt to standardize installations, much of the control and monitoring equipment is being housed in a single control cubicle leading to many, sometimes long, vertically disposed electrical interconnections. These factors combine to considerably increase the potential for transient overvoltage damage to vital circuitry and the consequent need for improved lightning and surge protection.

From these studies, and consultants' reports, the author has produced a set of draft guidelines for the protection of aids to navigation from the effects of lightning. Trinity House is currently preparing a procedural document on lightning protection for future automation and for updating existing installations.