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DIESEL FUEL IN THE ROYAL NAVY

J. Ritchie, B.Sc., R.N.S.S.

Admiralty Oil Laboratory

Introduction

Diesel Fuel — Dieso — is now used by ships of the Royal Navy in diesel engines, gas turbine engines in marine applications, in certain helicopters operating from ships in temperate and warmer waters, and under boilers in the Guided Missile Destroyers and most Frigates. Hodgson⁽¹⁾ has discussed the service and commercial fuels suitable for use in H.M. Ships.

New warships (other than the nuclear propelled) will have diesel or gas turbine propulsion machinery and it is intended that the standard fuel shall be diesel fuel to Defence Standard 91-4(NATO F-76). Experience to date indicates that a fuel of this quality is required to obtain acceptable standards of performance and life between overhauls for the aircraft gas turbine engines used in helicopters and the Olympus, Proteus and Tyne engines that are to be used for ship propulsion. Considerable benefits follow from adopting it also under boilers, including

- (i) reductions in maintenance and repair costs, because of the low ash content and therefore absence of deposits on fireside boiler tubes resulting in greater ship availability and improved morale of the ships' companies.
- (ii) logistic advantages in that only one fuel is carried in the supply system.

Allied Navies with somewhat different requirements have different fuel policies.

The U.S. Navy is now in the process of introducing Navy Distillate Fuel (ND) to specification MIL.F.24397 (SHIPS) of 2nd July 1969 (NATO F-85) in place of its boiler fuel Navy Special Fuel Oil (NSFO) for use under boilers and as a potential diesel engine and gas turbine engine fuel. ND is a cheaper, heavier, more viscous fuel than Dieso and may be expected to have inferior properties.

The French Navy appears to be following a policy very similar to that of the Americans. Specification STM 7130 "Combustible Marine, á Usages Multiples" (NATO Symbol F.85), is for a heavy distillate fuel like the U.S. Navy Distillate.

The Canadian Armed Forces (Sea) use a Low-Ash Fuel to Specification 3-GP-11 under boilers in certain ships. This is a distillate fuel purchased in a few areas only, it was introduced to reduce the degree of fouling of superheater tubes and the resulting unacceptable maintenance load. When low-ash fuel is not available Canadian Forces ships are instructed to burn standard Navy Diesel fuel or FFO in that order of preference. Experience with the type of fuel that has been supplied against the specification has suggested the possibility of using this fluid in shipboard diesel engines. The Canadian Armed Forces are building gas turbine powered destroyers and recognise that there would be considerable advantages to be gained from being able to operate on a single fuel. The present-low-ash fuel is believed to be unsuitable for gas turbine operation but it would appear possible that the specification will be progressively upgraded until a fully multi-purpose fuel is achieved. The U.S. 'Navy Distillate', French Navy 'Combustible Marine, á Usages Multiples' and Canadian Armed Forces 'Low Ash Fuel' are all suitable for use under boilers but cannot be recommended for use in gas turbines or diesel engines. At present the RN has in Dieso a fuel suitable for use in all types of propulsion engines in use in the Fleet. The other Navies are not yet in this position but are moving towards it. It may be that they will eventually standardise on distillate fuels with characteristics similar although possibly somewhat inferior to those of the RN's Dieso.

Properties of Dieso

Dieso consists of 100% petroleum distillates and is required to be stable in storage, clear and bright, free from visible water and suspended matter with low water retention characteristics. The specification is designed to ensure that the fuel is suitable for use in high speed diesel engines and includes requirements covering distillation range, carbon residue and cetane number.

Distillation range is a measure of the volatility characteristics and is important if good atomisation and complete burning in the combustion chamber is to be obtained. Carbon residue is a measure of the amount of carbonaceous matter that might remain after combustion and cetane number is a measure of ignition quality. Cetane number gives an indication of the ignition delays, fuels with high numbers have desirable short delays, those with low numbers have long delays, it is a function of the type of hydrocarbon molecules present; normal paraffins have high cetane numbers and aromatics and to a lesser extent naphthenes have low numbers. Insistence on a high cetane number limits availability.

The specification requirements are listed in Table I together with the characteristics of the allied Navies distillate boiler fuels. Viscosity is of particular importance to the Navy because of the need to ensure not only that the fuel is suitable for diesel engine operation at all temperatures likely to be encountered but also to permit starting gas turbine engines even at arctic sea temperatures *i.e.* 28° F. To ensure this a maximum viscosity at 100°F of 3.9 cSt is specified.

The other services do not have this requirement, their diesel fuel specifications permit higher viscosity at 100°F, the limitation for their applications relating to flow characteristics in the European petroleum products pipeline. The present common U.K. Defence Standard for diesel fuels purchased for Army and Navy use is to be replaced shortly by two separate Defence Standards reflecting the different requirements of the two Services.

Gas Turbine Engines Fuel Requirements

Gas turbine engines require fuels free from corrosive materials and dirt. Blade materials in use at this time are susceptible to corrosion by vanadium, and by sulphur in the presence of sodium, the so called sulphidation corro-

sion. Vanadium is present in crude oils as porphorin complexes, these large organic molecules become concentrated in the residuum after refinery distillations and FFO and NSFO's commonly contain between 100 and 300 parts per million of the metal. Very much smaller concentrations than this cause corrosion of the hot parts of gas turbines and for this reason the US Navy Distillate specification requires that the vanadium metal content shall be less than 0.5 parts per million (ppm). The dieso specification does not specify vanadium levels but because it is 100% distillate fuel these would be expected to be very low indeed. Of more than 40 samples obtained from refineries throughout the free world that have been analysed none contained more than 0.01 ppm. Fuel containing vanadium must be avoided if satisfactory life of gas turbines is to be obtained, and this means that fuels containing distillation residue, such as the commercial Marine Diesel Fuels, cannot be used.

Sulphidation corrosion occurs when sulphur and sodium are present together in contact with high temperature turbine blades. It is much more of a problem in marine applications than in aircraft since contamination of both intake air and fuel with sodium salts from sea water is more frequent. Use of fuels that do not contain sulphur would avoid the problem, but all reasonable priced fuels contain far higher concentrations of sulphur than are required for corrosion to occur. Since removal of sulphur is uneconomic, contamination by sodium must be reduced to the minimum.

In aviation practice it has been found necessary to ensure that the dirt content in fuel should not exceed 1 mg/litre of fuel if satisfactory operation is to be obtained. Diesel fuels supplied to helicopters have normally contained less than this level of dirt but it would be unrealistic to think that diesel fuels in general will be as clean as aviation fuels.

The need to ensure freedom from dirt, vanadium and sodium makes the aviation type gas turbines the most critical of fuel quality, of the power plants in use in the Fleet. Diesel fuels and commercial fuels of the same generic type, often called gas oils, are the cheapest suitable fuels in widespread service and commercial use; although the specifications demand compliance with test requirements, such as cetane number, of no importance for gas turbine applications.

Fuel Supply for Gas Turbine Engines.

(c) History of Aircraft Fuel Supply Systems

Aircraft fuelling methods and systems have developed over many years to reduce water and dirt contamination to the minimum. Water has to be removed since at high altitudes it freezes and can block fuel filters causing blockage and fuel starvation. Particulate matter first needed to be removed from fuel used in direct injection piston engines since the injector system incorporated high pressure fuel pumps with extremely fine clearances and carefully calibrated injection nozzles, which were very susceptible to wear or blockage by particulate matter. When jet aircraft came into service it was soon realised that they also needed fuel of very high cleanliness, control mechanisms being particularly demanding; moreover the kerosene type fuels needed much greater care in handling than had been necessary with gasoline if fuel problems were to be avoided.

With gasoline fuels, routine settling and drainage of water from fuel had proved adequate. The kerosene fuel used in gas turbines tended, due to its higher viscosity and density, to retain in suspension fine dispersions of water. Improved fuel handling procedures enabled the free water delivered to aircraft to be reduced to a minimum but could not affect the level of dissolved water. This could be precipitated at low temperatures. Special arrangements had to be made to prevent the build-up of ice on the aircraft filters, by heating the engine filters or adding an Anti-Icing additive into the fuel, to depress the freezing point of any water. Just as kerosene tended to hold up dispersed water to a greater extent than did gasoline so it also retained in suspension very fine particles of dirt. Longer settling periods in storage tanks and greatly improved filtration equipment were required. The US Specification MIL-F-8901 of 1961 laid down in detail the performance requirements of "filter/separator" units in terms of water and dirt handling ability, pressure loss limits etc. Such filter/separators have been fitted as standard equipment on fuelling vehicles, on the delivery lines from airfield storage tanks and sometimes on fuel receipt lines also.

However, filter/separator elements were often changed before the end of their dirt collection life because their water separating performance was found to deteriorate. Sometimes the elements were found to be failed by slimey organic materials. Surface active mater-

ials (surfactants) in the fuel either carried over from refinery treatments or picked up from petroleum products handled through common systems were responsible⁽²⁾. In the USA clay filters have been fitted on pipeline distribution systems to absorb these surfactants from the fuel and so prevent the "disarming" of the filter separators.

Today aircraft kerosene type fuels are distributed from refineries to the aircraft with regular checks for water with detecting kits and with frequent "Millipore testing" for particulate matter. Storage tanks are frequently lined with epoxy resin based paints and aluminium, stainless steel or internally coated pipework is used to minimise dirt generation in the system. As a result, fuel delivered to aircraft rarely contains more than about 3 ppm of free water or 0.1 mg/litre of dirt.⁽²⁾

(b) Fuel Supply to Marineized gas turbine engines on ships

Aircraft gas turbine engines such as the Rolls Royce Olympus, Proteus and Tyne are being adopted for marine use in warships. The compact sizes, and ease of replacement are amongst the advantages. Nevertheless, some redesign of engines for the naval application is necessary and some problems with fuel handling can be anticipated. Differences from aircraft practice include the use of diesel fuel in place of kerosene and the increased risk of sulphidation corrosion due to operation in a salty atmosphere. Full scale engine trials to determine the effect of sodium contamination in engines have led to the opinion that sulphidation corrosion could be a major factor limiting engine life. As explained above corrosion can be prevented or reduced by keeping down the extent of sodium contamination. The most probable sources of sodium are—

- (1) Airborne salt, present in the combustion air, and
- (2) Sea water contamination of the fuel.

It is not easy to determine the extremely small salt content of a marine atmosphere but as a result of work undertaken jointly by the Naval Marine Wing of the National Gas Turbine Establishment and the United States Navy's Philadelphia Test Laboratory (NAV-SECPHILADIV) on H.M.S. "Tartar" and the Royal Danish Navy's "Pedar Skram" it has been concluded that gas turbines at sea are subjected to an average contamination level of 0.01 ppm of sodium chloride in the air.

Rolls Royce have suggested that the maximum tolerable level of sodium is equivalent to 0.6 ppm of the fuel. In the naval application it appears that the equivalent of 0.3 ppm of sodium in the fuel will be admitted *via* the combustion air so it is hoped to limit the sodium content of the fuel to 0.3 ppm.

The most likely source of sodium in diesel fuel is the presence of sea water as a contaminant. Fortunately the sodium is held in the suspended or free water, and not in the dissolved water, and can be removed with this free water by conventional physical methods such as gravity settling, centrifuging or the use of filter/separators. Thus, just as in aircraft practice, it is necessary to keep the dirt and water levels in fuel to extremely low levels, although in the marine application it is not the water itself that cannot be tolerated, but rather sodium present in the sea salt.

The sodium content of sea water is very approximately 1% so even if there is no other source of sodium in the fuel, the water content has to be reduced to 30 ppm to achieve sodium contents of 0.3 ppm or less.

Similar levels of fuel cleanliness to those achieved in aircraft practice are needed but with the following adverse factors—

- (1) the use of a heavier and more viscous fuel, both factors slowing down water separation.
- (2) the absence of scrupulously careful fuel handling procedures all the way from the refinery to the user.
- (3) the probable presence in the fuel of more contaminants including surfactants due both to the higher boiling range and less carefully controlled production and handling.
- (4) the possible presence of sea water in the ships fuel tank.
- (5) the ships motion and vibration inevitably reducing the efficiency of the filter/separator unit.

(c) Water and Sodium Contents of Fuels

In the marine application our concern is basically about the sodium carried into the engine in the fuel rather than the water. Sodium can be expected to be present in some or all of the following modes:

- (i) dissolved in any sea water present.
- (ii) dissolved in the fuel itself.
- (iii) as a constituent or attached to suspended particulate matter.

Filter/separators should remove some at least of any sodium present in forms (i) and (iii) but cannot materially affect the level dissolved in the fuel.

Investigations⁽³⁾ of the sodium levels in diesel fuels supplied by refineries all over the world has shown that these are very low indeed. It appears that diesel fuel will leave most refineries with a very low sodium content but that the handling operations between the refinery and the engine tend to introduce salt as a contaminant. Determinations of sodium content of dieso from warships' fuel tanks^(3, 4) suggested that the sodium content was related to the sea water present. The results of careful sodium determinations on large numbers of fuels suggest that dissolved sodium levels are normally very low. Needless to say there may be a fuel or fuels of unusual type or hackbround that contain sodium in solution but examples of such fuels have not been encountered. Oil suppliers do not use sodium containing additives in this type of product nor do the commonly encountered contaminants contain oil soluble sodium.

It has been suggested that when dieso and sea water are mixed the sodium salts present in the water are partitioned between the two liquid phases. Fortunately the sodium level of the fuel that results appears to be very small and no significant sodium contents due to this mechanism are known to the author. Where distillate fuels have stood over sea water bottoms the salt content of the water tends to increase as water, but not the salts, dissolves in the fuel. It is reported that in a power station tank the salts concentrations of the brine has even reached 11%.

The solubility of water in fuels varies with the temperature and the chemical nature of hydrocarbons making up the fuel^(5, 6). Fig. 1 illustrates the wide range for different fuels. Fuels always contain some dissolved water and tend to absorb water from the atmosphere during the heat of the day, precipitating some of this perhaps as a fine haze of water droplets, as the temperature falls at night.

When fuel contacts sea water, in a tanker or a ship's tank, it already contains some dissolved water; in general therefore sodium is associated with the suspended or free water and not with dissolved water.

Water contents of fuels tend to be quoted as either free or total *i.e.* free plus dissolved water. Confusion can arise over which is meant. Field instruments frequently indicate

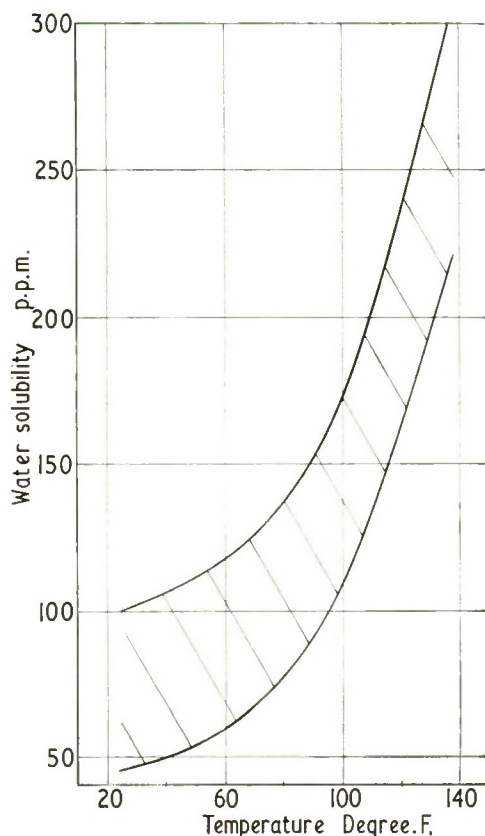


FIG. 1. Solubility of Water in Diesel.

free water but they have to be calibrated from a total water figure most often obtained by the Karl Fischer Method, by subtracting the estimated dissolved water. In general, total water figures contain fewer errors than those for free water.

(d) *Factors Affecting the Separation of Water from Fuels*

The higher viscosity and density of diesel against aircraft fuels have deleterious effects on the rate of separation of free water from the fuel. Idealised systems would obey Stokes' law

$$v = 2g r^2 (d_d - d_m) / 9\eta$$

where v is the velocity of fall of a drop of radius r and density d_d falling through liquid of viscosity η and density d_m . The motion of droplets towards the bottom of a tank or pipeline etc. will deviate from this equation because of convection currents, fluid currents caused by ships' motion, agglomeration, etc.

White⁽⁷⁾ has calculated, assuming the validity of Stokes' law, that terminal velocities

of sea water droplets falling through a fuel having a 10 centipoise viscosity would be

24.1 ft/day for a 100 micrometer diameter droplet.

0.24 ft/day for a 10 micrometer diameter droplet.

0.0024 ft/day for a 1 micrometer diameter droplet.

0.000024 ft/day for a 0.1 micrometer diameter droplet.

The order of magnitude of these figures are probably correct and the fuel viscosity taken is not untypical of those to be expected for diesel in ships tanks in cold waters. Small drops will therefore take a very long time to settle. White calculates it would take 2750 years for a 0.1 micrometer drop to move from the top layer of quiescent fuel to the bottom of a 24 ft high tank. In practice fortunately larger drops when present travel faster and overtake smaller droplets and coalesce with them creating larger masses, thus tending to sweep the fuel clean.

Filter/separators also called filter/coalescers or coalescer/filters assist the gravity separation of water droplets. They involve filtration of the fuel through a fibre bed. Small droplets are retained until growth occurs by coalescence. The larger drops are then swept from the fibre bed by dynamic forces ideally being of such a size that they then rapidly separate under the influence of gravity.

Hazlett^(8, 9) has studied the mechanism of coalescence in this type of filter bed with aviation fuels. Water is collected chiefly by fibre interception and bed depth studies in a laboratory coalescer indicated that complete collection is normally accomplished in depths much less than those used in the coalescer portions of commercial filter elements.

Water is not released immediately by a fibrous bed. An equilibrium concentration for the particular condition is established after which, with most of the water on the front part of the bed, water moves into flow channels and passes through the remainder of the bed. In the ideal case such a water stream feeds a water drop attached to the downstream face of the bed. The balloon shaped drop formed continues to grow until rupture occurs at the neck. The size of the drop released is a function of flow velocity, interfacial tension and neck cross-section. Surfactants in the fuel affect these processes and can markedly reduce drop size and settling rate resulting in increases of water carry over from the filter.

A cotton sock is commonly used as an outer wrapping round glass fibre coalescer elements, these affect the size of water drops released. Lindenhofen⁽¹⁰⁾ also working with aviation fuels, has shown that the presence of a sock greatly improves coalescence. He also showed that new coalescer elements fitted with socks that had been removed from used elements passed from 10 to 20 ppm of free water above normal baseline performance. Socks could be made to malfunction by pretreatment with water and surfactant. He suggested that when a sock is wet with water it tends to absorb surfactant from the fuel causing a large concentration of surfactant active contamination at the point of detachment. Water drops coalesced by the fibre bed are then redispersed by the surfactant at the point of release. Lindenhofen suggests that a fluoro-carbon coating on the sock should reduce the sorption of water and surfactant and therefore protect against "poisoning" in service.

In practice a wide variety of materials which can contaminate fuels result in impairment of water separation characterisation, these include additives put into fuels to improve other characteristics, soaps, other petroleum products, etc. Aviation fuel specifications contain test methods intended to ensure good water separation characteristics and freedom from fuel acids; the very careful handling of such fuels keeps to a minimum the likelihood of contamination before use. The same checks do not apply to diesel fuel, the content of fuel borne acids is not controlled to the same extent and a much greater variation in both type and quantity of surface active agent content must be expected. Even the smallest quantities of FFO or other residue containing product has a very deleterious effect on the water separation properties.

From the above it would seem that filtration and water separation problems might be expected with diesel fuels. This in fact appears to be the case, where the dirt and surfactant level of diesel fuels are low then satisfactory water separation can be obtained at suitably low flow rates, other fuels do not behave so well however.

(e) *Laboratory Trials*

Trials at the Naval Marine Wing, National Gas Turbine Establishment involving additions of sea water to diesel fuel being recirculated through a rig incorporating a filter separator were very successful when a commer-

cial diesel fuel was used. The limited quantities of dirt and surfactant present were removed in the first few passes through the filter/separator, subsequently salt water was effectively removed to yield a clean, dry, sodium free fuel. A second fuel supplied from the Navy system, actually a 1% sulphur content diesel engine reference fuel, was not so easily handled and even after repeated recirculation considerable quantities of water and salt were still being carried through the filter/separator. Subsequently a filter/separator manufacturer found during development testing, that a diesel fuel which was readily cleaned up when contaminated with distilled water was much less amenable when sea water was used. This again involved recirculation of a limited quantity of fuel through the filter elements. Single pass operation, as in service, must of course provide a much more severe test of a filter/separator since the quantity of dirt and surfactant available to "poison" the elements build up continuously throughout the testing period.

AOL has conducted a very limited trial of filter/separator elements using single pass fuel operation⁽¹¹⁾. Diesel fuel was pumped from one bulk storage tank to another in the Oil Fuel Depot, Devonport through a small filter/separator fitted with facilities for salt water addition to the input fuel through the eye of the pump. Conditions used were:

- (a) fuel straight from the tanks; this fuel always contained dissolved water and on occasions some suspended "free" water.
- (b) fuel to which salt water at a concentration of approximately 100 ppm was continually added at the eye of the pump.
- (c) fuel to which slugs of salt water were added prior to the pump to simulate pick-up of water from tank bottoms in rough weather.

The results obtained indicated (1) there were differences between performance on the different fuels, (2) the dirt content of some of the diesel fuel caused filter blockage and (3) fall off in efficiency was noted after passage of large quantities of reasonably dry fuel.

Service Experience in H.M.S. Exmouth

H.M.S. *Exmouth*, a frigate of 1500 tons displacement was converted to gas turbine propulsion to act as a floating test bed for new ships designs⁽¹²⁾. She put to sea in June

1968 as the first major British warship to be all gas turbine propelled. The propulsion machinery fitted consisted of one Olympus TMI and two Proteus 10 M/533 engines driving a single controllable pitch propeller *via* individual clutches and a combined reduction gearbox of conventional design. The Olympus has its rating limited to 15,000 h.p. because of transmission limitations on this particular ship; the Proteus engines can develop 3560 h.p. The control system permits the ship to be driven by the Olympus engine alone, the two Proteus together or either one of them.

The air intakes for the gas turbines embodied knitted-mesh filter arrangements for salt exclusion. The fuel supply system was fitted with fine filters for the removal of particles and with coalescer filters for the removal of water. The fuel system was constructed of mild steel except for the section down stream of the coalescer which was completed with copper-nickel-iron tubing. The main fuel tanks, which had been used previously for furnace fuel oil were cleaned as thoroughly as possible to remove traces of fuel oil. These tanks are constructed of mild steel, removal of FFO residues therefore left rust surfaces. Consideration was given to applying a tank lining but the presence of strengthening webs inside the tanks made the adequate preparation of the surfaces impracticable. No surface coating has therefore been applied.

An early trial involved operation in arctic waters to investigate cold weather behaviour. During extremely rough sea conditions the

filter/separator was frequently blocked by dirt, particularly after refuelling at sea in these conditions. Probably the tank cleaning had been inadequate, it is extremely difficult to clean these tanks. Finer particulate filtration upstream of the filter/separator was provided on one fuel line. Fig. 2 is a diagrammatic representation of the fuel system. Subsequent experience has indicated that even with the additional pre filter, the filter/separator is being frequently blocked particularly in rough seas. The storage space for elements presents a problem on a warship, as does the maintenance load needed to change them.

Exmouth does not have sea water ballasted tanks so it would be expected that dirt rather than water would be the cause of the filter blockage. First thoughts were that rust from the tanks must be the cause of the trouble but when the rate of blocking did not decrease with the passage of time it seemed likely that some other agent must be responsible for, or at least contributing to the blockage. Several sets of filter elements, after they had had to be changed because the limiting pressure differentials had been reached, were received at the Admiralty Oil Laboratory so that the nature of the blocking dirt could be ascertained.

Elements received at the Laboratory consisted of coalescers, separators and single elements from the duplex prefilter housings. Suspicions had been voiced that microbiological growths in the fuel were the plugging agents and it was known that a U.S. Coast-guard ship had been in severe trouble from

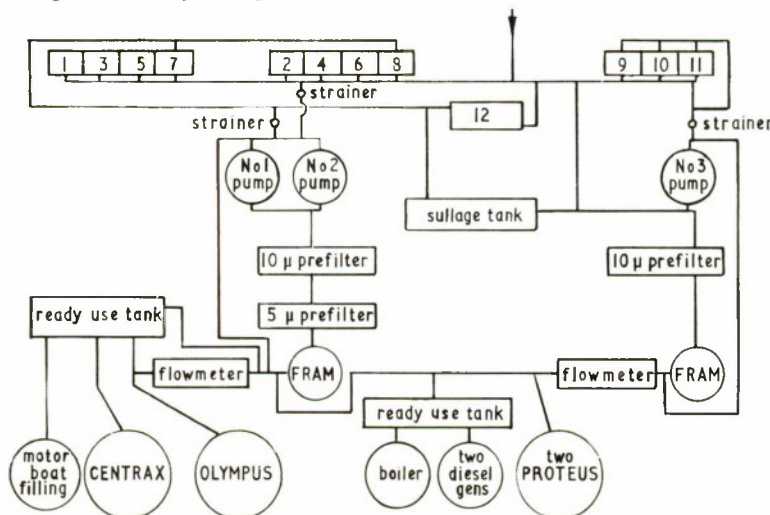


FIG. 2. H.M.S. *Exmouth*
Fuel System Schematic.

TABLE 1.
Summary of Fuel Specifications

<i>Nation</i>	<i>Britain</i>	<i>U.S.</i>	<i>France</i>	<i>Canada</i>
<i>Fuel</i>	Diesel 47/20	Navy Distillate	Combustible Multiples	Low Ash
<i>Specification</i>	Def. Stan. 91 - 4	MIL-F- 24397	STM 7130	3-GP-11
<i>NATO Code</i>	F 76	F 85	F 85	—
<i>Colour ASTM max</i>	3½	—	—	—
<i>Specific Gravity 60/60 min</i>	0.82	—	—	—
<i>Specific Gravity 60/60 max</i>	0.86	—	0.89	—
<i>Distillation 90% °F</i>	675 (357°C)	740	(743) 395°C	—
<i>Flash Point min °F</i>	150	150	(150) 66°C	140
<i>Pour Point max °F</i>	+20	+25	(+25) —4°C	+15
<i>Cloud Point max °F</i>	+24	—	—	—
<i>Viscosity @ 100°F cSt Min</i>	1.8	—	2	1.8
<i>Viscosity @ 100°F cSt Max</i>	3.9	10	10	10
<i>Sulphur %</i>	1.0	1.3	1.0	1.5
<i>Copper Corrosion</i>	1	2	2b	—
<i>Carbon Residue 10% bottom max</i>	0.2	0.4	0.4	—
<i>Ash %</i>	0.01	0.01	0.01	0.01
<i>Acidity, mg KOH/g</i>	0.5	Neutral	0.5	—
<i>Cetane No. min</i>	47	39	—	—
<i>Storage Stability mg 100 ml</i>	1.0	—	—	—
<i>Vanadium Content ppm max</i>	—	0.5	0.5	5

such growths. Sections of the media from the various types of elements were cut out and sent to the Admiralty Materials Laboratories Microbiology group who checked for fungal growths. They concluded that although isolated fungi could be identified there was no fungal infection and that these materials were not the reason for the filters blocking.

Further analysis of the dirt on the filter elements showed that the major portion was of fuel origin, and of very fine particle size. Rust was also present as a major constituent, but most was collected on the prefilters and the first filter medium of the coalescer elements. The fuel borne dirt was so finely dispersed that it tended to pass through the different filter media eventually contaminating them all.

H.M.S. *Exmouth's* fuel system is unusual in that fuel is recirculated through pumps, filter separators and prefilters. This probably results in more efficient removal of dirt from the fuel, together with more rapid filter blockage than would occur with once through operation.

The filters received from H.M.S. *Exmouth* had a filthy appearance, the different filter media all being coated with a black sticky deposit but although the weights of this material present on the filter amounts to the order of a kilogram, this actually represents only approximately 1-2 milligrams of sediment per litre of fuel passed.

In aviation practice, fuel is passed through separator filters whenever it is transferred so that when it reaches the engine it has probably been filtered four or five times. Diesel fuel, which is heavier and probably somewhat dirtier than aviation fuel, is not handled in this way so it is to be expected that relatively large amounts of dirt will be collected by the only fine filters in the fuel system. It would appear that filter separators with higher dirt carrying capacity or perhaps incorporating larger pore size filtration media so that the fine dirt can be passed through, are required unless additional fine filtration of the fuel supplied to the ship can be provided.

Summary and Recommendations

The R.N. has adopted dieso as the standard propulsion fuel for use in diesel engines, under boilers and the most critical usage in the aircraft type gas turbines being fitted into new ships.

Allied Navies have made some steps towards the idea of using multipurpose fuels. The U.S. Navy, French Navy and Canadian Armed Forces (Sea) have introduced distillate fuels for use under boilers but these may not be fully suitable for diesel engine and gas turbine applications. It is anticipated that there will be tendencies towards up-grading these fuels to the minimum qualities needed for these engines so some approach to the R.N.'s present position of having a multipurpose distillate fuel is expected.

The requirements of interchangeability of products within the NATO alliance suggests that there will be pressure in the future to standardise amongst the Navies on a cheaper, heavier product than dieso. Fuel supply systems being designed for future R.N. ships should have the capability of dealing with such heavier fuels.

Dieso is a suitable fuel for gas turbines but the removal of dirt and water from it is anticipated to be somewhat more difficult than with aviation fuels. The greater viscosity, specific gravity, particulate dirt and surfactant content are all deleterious to the separation of fuel and water by settling or with filter/separators. The heavier fuels used by the Allied Navies would be expected to be more difficult again to purify.

The work being put in hand now at several Establishments and filter/separator manufacturers to develop improved units specifically for the removal of dirt and water from diesel fuel on board ships should be vigorously pursued with particular attention to

- (1) the variations in dirt and surfactant content between different diesel fuels
- (2) the need for the systems finally adopted to be able to deal with heavier, dirtier fuels supplied by Allied Navies
- (3) long life of elements between changes.

Our present sketchy knowledge of which trace materials in fuels block or inactivate coalescer filters makes it difficult to select for test those fuels likely to cause problems in service and even more difficult and dangerous to select a suitable "dope" for addition to clean fuel in recirculating test.

It would therefore seem that the development testing should utilise large quantities of several different fuels passed once only through coalescer elements. Handling these large volumes of fuel will present problems to the testing establishments but the cost of

the fuel is not really involved since the tests will not include combustion and should in fact improve fuel quality. In many ways it would seem most convenient to take the systems being tested, including prefilters and coalescer filters, to fuel depots since they will be very much more easily transported than the required quantities of fuel.

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ICING AT SEA

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Following an Engineering Apprenticeship at the Royal Aircraft Establishment, Farnborough (1940-45) **Theo V. Small** joined Vickers-Armstrongs Ltd.—now the Commercial Aircraft Division of British Aircraft Corporation—1946, to work in the then newly formed Research and Development Department under Sir Barnes Wallis on the early 'swing-wing' projects and the design of a large environmental test facility.

First became involved in trawler icing in 1955 during a programme of icing experiments on ship models in the test chamber.

In January 1969 went to Iceland on a normal fishing trip to experience icing at sea, first-hand.

August 1970 transferred to the Staff of the Chairman's Office, British Aircraft Corporation Limited.

Introduction

In Northern Waters in winter, icing is an ever present hazard.

Icing can occur whenever the air temperature and the surface temperature of the target fall below the freezing point of water. The temperature at which sea-water begins to freeze depends on the salinity, being very nearly 0°C in the Baltic and -1.8°C in the Arctic Basin of the North Atlantic.

The Effects of Icing on a Ship

The primary hazard to a small vessel such as a side-fishing trawler, tug or minesweeper, exposed in an icing environment, is the loss of stability due to ice accretion on the hull and upperworks. Stability is always the problem for the smaller vessel.

The first effect of icing is an increase of displacement and therefore, a reduction in freeboard. This means that as the vessel sinks lower in the water, her deck-edge will go under at a smaller angle of roll. The minimum angle of roll to deck-edge immersion recommended by I.M.C.O. for fishing vessels is $12\frac{1}{2}^{\circ}$.

The second effect is to raise the ship's vertical centre of gravity (VCG) which in its turn, reduces the metacentric radius (GM), the righting lever (GZ) and the stability range.

Fig. 1 is the textbook diagram for a floating body and holds for small disturbances only. Here GM is a measure of the ship's initial stability, W is the weight of the body which is taken to be equal to the displacement (Δ). The righting moment is then $\Delta \text{ GZ}$.

At large angles of roll—beyond, say, 7° - 10° , we need to examine the ship's statical stability curve and Fig. 2 shows such a curve for a typical trawler. The shape of the full-line curve is peculiar to the vessel under one set of loading conditions and is derived from the cross-curves of stability produced by the builder from knowledge of the hull shape.



THE PHOTOGRAPHS ABOVE AND TO THE RIGHT SHOW THE ICED TRAWLER *WOTTS COUNTY* AFTER SHE HAD BEEN DRIVEN ASHORE ON THE EASTERN SIDE OF ISAFJARDHARJUP, N.W. ICELAND IN FEBRUARY 1968.



Here GZ , the righting lever, is plotted against the angle of inclination and we see that when the vertical centre of gravity of the ship is raised by the accretion of ice, GZ is reduced as also is the 'range' and the angle at which the maximum value of GZ occurs.

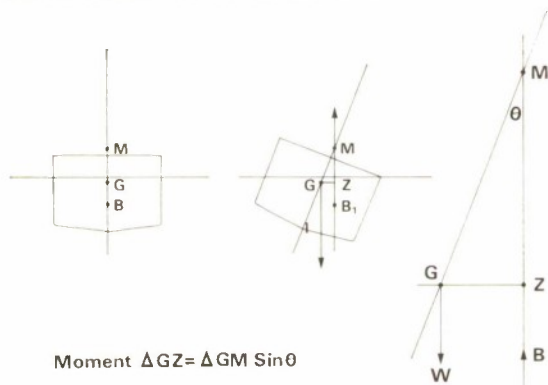


FIG. 1. Statistical Stability at small angles (not to scale).

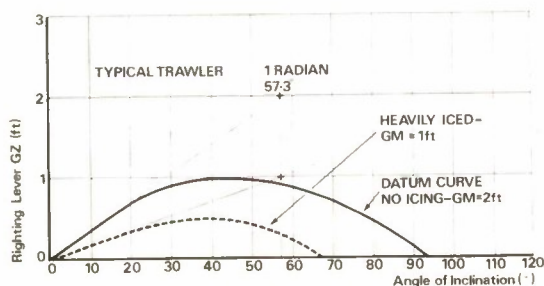


FIG. 2. Stability at large angles.

Figs. 1 and 2 both depict ideal still water conditions but are useful for assessing, roughly, the built-in stability of the vessel. In a sea-way with random waves passing under and over the ship, calculations become a great deal more difficult—if not impossible.

The rise in the vertical centre of gravity of the ship for varying weights of ice adhering at a number of centroid heights is shown in Figure 3. The datum vessel for these and other calculations which follow is a conventional side-fishing trawler, 142 ft. in length, 29 ft. beam and a gross tonnage of 431 tons.

Fifty tons of ice at a centroid height of 28 ft. above the keel, raises this ship's vertical centre of gravity by approximately one foot, thereby effectively halving the initial GM .

Theoretically, 106 tons of ice with its centroid at this height would result in neutral i.e. $GM=0$.

Raising the vertical centre of gravity reduces the metacentric radius by approximately the same amount. As GM is reduced, the rolling period of the vessel is increased. Fig. 4 is a typical plot of rolling period versus GM and is drawn for the datum ship. It will be seen that the period of roll ('out and back') for the clean ship is 8.60 seconds taking $GM=2$ ft. When the value of GM is halved by the addition of ice to the ship, the period of roll lengthens to 12.14 seconds. The ship is now sluggish in roll and under open sea conditions with normal wave periods, she will ship water over the lee rail.

A third effect of heavy icing is the increase in sail-area forward due to curtains of ice on the foremast and rigging. Without more power, and therefore, more spraying, it becomes increasingly difficult to hold the ship into the wind.

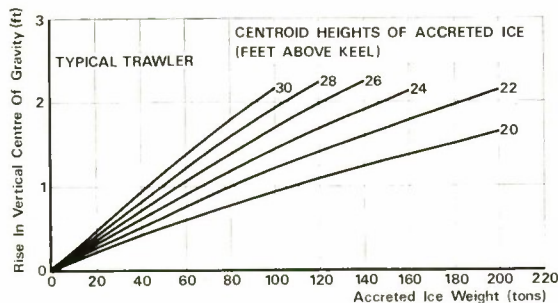


FIG. 3. Rise in Vertical Centre of Gravity with accreted ice.

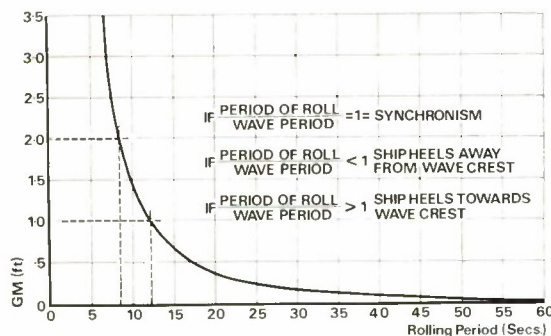


FIG. 4. Typical Trawler—Period of Roll.

Further, the weight of the ice forward causes the stem to trim down and to plough into the sea giving rise to still more spray at each wave encounter.

Finally, there is the fourth serious effect of icing at sea, namely the loss of operational efficiency. For the larger vessel and particularly for warships of frigate size and above, which may escape the problems of stability, this is the most serious consequence of icing. In this age of radar, electronics and missiles the effect can, quite literally, be disarming. Tests at sea and in a large climatic chamber have shown that relatively insignificant quantities of a particular freshwater/salt spray slush at temperatures a little below 0°C readily absorb electromagnetic radiation and incapacitate radars. A typical navigation radar

with less than half an inch thickness of this mix adhering to its window became totally blind during a storm experienced by the author off Iceland.

Communications failures in icing weather are more common than is generally realised because a trawler 'on fish' and a warship on patrol both maintain radio silence for long periods. Apart from the obvious fact that long spans of wire—the M.F. aerials—ice quickly and are often carried away, the insulators and leads from the radio-room become shorted out with sea-ice early in any icing encounter. The present designs of whip aerial suffer badly from icing due to the run-down of freezing spray. Thus power may never leave or enter the very expensive equipment installed.

The use of a notch-type aerial, as for aircraft, has been suggested and a VHF notch aerial was in fact installed in a trials trawler by British Aircraft Corporation.

Unfortunately, no money is available to develop the aerial most needed by the merchant and fishing fleets—an M.F. unit—although the Holland-Martin Report on trawler safety specifically mentions that a new design of M.F. aerial is most desirable.

To the trawler skipper the navigation radar is a vital piece of equipment and is usually duplicated. Often the standby scanner is of a superseded pattern which, when mounted alongside the slotted waveguide primary unit, ices more quickly and fails first. Without his radar, the skipper dares not approach a coastline too closely and must stand off in the teeth of the gale.

Clearly, fishing is not possible in severe icing conditions and the fact that the fishing gear is bonded to the deck by ice is not of immediate concern to the crew. What is important is that safety equipment such as stowed life-rafts and boats, will require much strenuous manual effort on a violently heaving deck to extricate and launch. Recent regulations allow the substitution of an inflatable life-raft for the rigid work-boat on the aft deck of a British trawler.

In the absence of heated bridge windows, visibility from the wheelhouse will be nil and an urgent requirement exists for a cheaper version of the electrically heated transparencies used by H.M. ships. For this application, a certificate of battleworthiness from H.M.S. *Excellent* would not be necessary!

A further worthwhile refinement would be the use of rugged, low-voltage, multi-filament lamps for the mandatory navigation, steaming and fishing lights. Lamp replacement could then be carried out at base and the large amount of ice-catching 'clutter' provided for access to the units at sea—but rarely used—could then be removed.

Origins of Icing

The icing of ships at sea may result from precipitation (*i.e.* rain, fog, snow), ship-generated spray or spin-drift. In the worst icing conditions all three forms will be present.

Precipitation

Icing from rain, snow or fog, rarely results in hazardous conditions. 'Black Frost' is encountered when a cold ship penetrates a fog of supercooled water droplets which freeze on impact on to all exposed parts of the ship to give a uniform coating of ice. There are varying degrees of severity depending on the air temperature, the windspeed and the extent of the layer. The texture and appearance of the coating likewise varies from a 'fairylane' hoar frost, to dense grey ice. The term 'black frost' is generally applied to a fog layer extending from the water-line to a height above the eyelevel of an observer on the bridge. 'White Frost' is similar but below bridge level so that an observer there looks down on to the fog rather than through it. In practice, it is often possible to avoid these banks of freezing fog which occur near the Ice Edge where cold air drains off over a warmer sea.

These fog banks occur when the ambient air temperature is 8-9°C colder than the sea surface temperature and are generally associated with relatively calm conditions.

'Arctic sea-smoke', a third variant, is found at higher windspeeds when cold air is driven across the sea and rapid heat exchange takes place at the air-water interface. The sea is carpeted with a hazy vapour and plumes of white 'smoke' stream from breaking wave caps.

In each of the foregoing cases, the ice forming on the target will be fresh water ice.

Ship-generated Spray

The cause of this form of icing is evident from its name, but there are some interesting points to consider. Firstly, it is well known to any sailor that some ships are 'dirty' in any seaway while others are comparatively 'dry'.

This is truly the realm of the naval architect as it is concerned with ship lines.

Modern vessels, in particular naval ships and the newer stern trawlers, have a fine entry, often with hollow waterlines forward. This results in reduced buoyancy at the stem when compared with the older tug or collier lines. The pitch axis is further aft; especially if the vessel has a transom stern. These ships tend to dig deeper into the sea under severe conditions, throwing green water high over the superstructure. A case could be argued for the adoption of a modest bulbous bow to reduce pitching, especially on trawlers where accelerometer readings taken in the fo'c'sle of a conventional trawler showed that zero gravity conditions could exist at the sharp end!

Stern trawlers of recent construction have experienced icing from self-generated spray under 13 kt. cruising conditions in a Force 4-5 sea state. With fine bow lines the spray-foot—to use a planing term—is moved further aft and the bridge superstructure just happens to be situated so that it intercepts the spray trajectory at its highest point. In relatively calm water at cruising speed, the water rises from the spray foot and curves in a gentle arc to deposit spray over the entire bridge and the working deck aft, where in the dead area abaft the funnel the vortices from the bridge wings die out. At sub-zero temperatures the result is continuous icing on the vertical surfaces and snowing on the working deck!

When severe icing conditions are experienced, it is highly desirable to be able to reduce engine power to the minimum necessary to hold the vessel up into the wind. Excess power results in more spray at each wave encounter. Ship lines aft and the trim decide the grip the vessel has in the water. A standard ship has practically no weathercock stability and mizzen sails are demodé. In the age of steam, it was possible to reduce the propeller revolutions and therefore the thrust, smoothly down to zero. With modern motorships there is a minimum speed at which the diesel will run reliably so it is just not possible to hold the ship fixed over the ground, unless she has a V.P. propeller.

Spin-drift or Drift

In sea-states beyond Force 5-6 windblown spray from breaking waves begins to aggravate the icing problem. Since the energy is provided by the wind, one is tempted to relate spray quantities to the wind velocity squared.

However the sea-state changes with rising wind and the higher waves have steeper wave-fronts so that beyond Force 8 the quantities of water arriving at the ship increase at an alarming rate. This is particularly the case in a short, steep sea such as is encountered over the Continental Shelf, *i.e.* where the fish are to be found.

The vertical distribution of spin-drift is not known with any certainty but salt spray icing on windscreens is known to R.N. 'Buccaneer' pilots flying at 200 ft. above the sea, as also is icing of helicopters and their airborne stores. In terms of ship icing, taking a small trawler as an example, icing from windblown spray is not a significant item in terms of added weight at heights above 25 ft. from the weather deck, but the problem of effectively protecting radars and antennae remains. A large radar on a frigate, for an example, may be expected to acquire about two tons of ice in 24 hours when trained athwartships into a gale force wind at sub-zero temperatures!

Rate of Icing

The important parameters to be considered are:—

1. Ambient Air Temperature.
2. Wind Speed.
3. Sea Temperature
4. Ship Course and Heading
5. Ice-worthiness of the Ship.

Taking each in turn.

1. *Ambient Air Temperature*—which as ΔT in any heat transfer equation affects directly the rate of freezing.

2. *Wind Speed*—which is important for three reasons: (a) Convective heat transfer, (b) Sea-state —affecting ship movement and wave period and (c) Rate of arrival of airborne water.

3. *Sea Temperature*—which influences the de-icing performance of excess water, *i.e.* if the seawater is just at its initial freezing temperature, no amount of free water striking the ship will melt and carry away accreted ice.

4. *Ship Course and Heading*. These affect the period of wave encounter and if the ship is heading other than directly upwind, assymetrical icing occurs to complicate the problem.

5. *Ice-worthiness of the Ship*. This comprises (a) Initial stability and trim, (b) Statical and dynamic stability, (c) Degree of design refinement and (d) Type of propulsion.

From the foregoing it will be obvious that with so many unknowns and variables to contend with, any calculations of icing rates, even under textbook conditions, would be practically impossible. Clearly the refined methods used for aircraft icing studies are not applicable. We have to assume that there are limitless quantities of cold air and water—measured in cubic miles, at least—which may arrive at the ship.

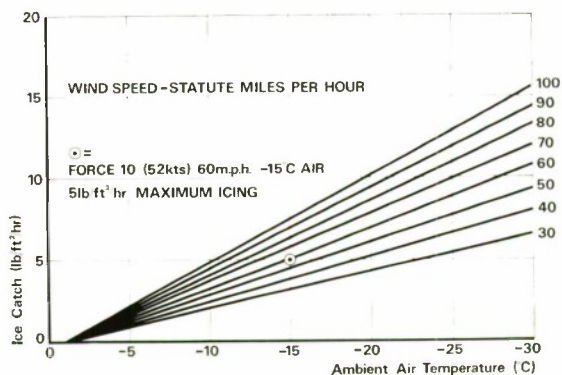


FIG. 5. Maximum rate of icing (Seawater).

There was however, one approach to the problem hitherto untried. We would consider the vessel as a complete entity in a vast wind-tunnel and assume a heat transfer coefficient for the whole ship thereby hoping to calculate the Total Rate of Heat Loss for the vessel. Since it requires a known amount of heat to be removed in unit time in order to freeze a unit quantity of seawater, it should then be possible to determine the maximum possible weight of ice which could form on the ship in a given time at any combination of air temperature and wind speed, assuming the ship to be bathed in water continuously. See Fig. 5.

The method employed and the results of this study are more properly the subject matter for an appendix, suffice it to say here that the answers given by this simple exercise are in broad agreement with 'at sea' experience.

The next problem to be tackled was that of the actual icing pattern to be expected *i.e.* the distribution of the accreted ice over the ship. From the icing pattern a centroid height for the ice might be calculated. Probably the first work done on this aspect was the 1955 trials programme using a one-twelfth

scale model trawler afloat in the B.A.C. (then Vickers-Armstrongs Ltd.) climatic chamber at Weybridge.

The experiments showed that the distribution of ice on a ship was not greatly influenced by the icing rate or indeed, the temperature of formation. Some allowance must of course, be made for the de-icing effect of 'warm' seawater washing over the lower parts of the ship in less than extreme conditions.

For confirmation of the expected pattern, photographs and data from British, Japanese, Russian and Canadian experience were studied and plotted. The most interesting information came from an unknown Nova Scotia trawler which docked at sub-zero temperatures so that her ice was intact and the distribution was measured, photographed, and most important, weighed. From this the total weight and the ice centroid position had been established for this ship.

In order to compare our experience and calculations a rough and ready means of scaling was devised for geometrically similar trawlers between 100 ft. and 200 ft. in length. A very detailed 'paper study' of a larger British trawler had given us an ice-centroid height 26 ft. above the keel when carrying 45 tons of ice.

Factored scaling from the Canadian evidence gave 46 tons at 25.5 ft. and was a much simpler exercise.

Types of Icing For ice to form on any object the latent heat of fusion must be abstracted from the water.

If the cooling rate is high (i.e. low temperature, high wind speeds, small droplets) the ice formed will be 'rime' ice which is white, opaque and of lower density because each particle freezes on impact without run-off. At lower convective cooling rates, the droplet strikes the surface, gives up its heat of fusion which locally melts the existing ice coating very slightly before convective cooling gels the drop. Under these conditions the ice surface is characteristically wet and at a temperature very near to that of the initial freezing point of the water (approximately -2°C for seawater icing). The resulting formation is of dense, hard 'glaze' ice.

Saltwater ice is of greyish colour and fibrous structure due to occluded pockets of brine and has no sharp edges. The ice weathers with time as the brine leeches out, with consequent decrease in density.

When the droplet does not freeze instantly on impact, run-down takes place due to gravity.

Under any icing conditions, different types of ice will form at different points on the ship. Those parts where the convective heat transfer is highest will obviously be the first to gather ice. At relatively warm temperatures (-3°C) these may be the only parts with any significant icing. Heat transfer is highest where the characteristic dimension (the 'diameter') is smallest and thus, ice begins to form first on rods, rails, wires, lights, aerials and fittings. At lower temperatures and/or higher wind speeds, white rime ice will form on these parts with dense glaze ice on the deck and superstructure.

If the sea is relatively warm ($+3^{\circ}\text{C}$) the lower parts of the vessel and the outside plating will be de-iced by water wash.

With very low sea temperatures, as near the Ice Edge, de-icing by the sea will be minimal so that a great amount of ice will form on the deck, choking the scuppers and the freeing ports and thereby further hazarding the ship.

Time to Critical Conditions

The amount of ice which can be safely borne by any vessel can only be determined by a professional naval architect having full knowledge of the hull design and sea-keeping behaviour. As engineers we have taken, quite arbitrarily, a reduction in the metacentric radius to half its original value as representing the danger point. The loop is now closed and it becomes possible to estimate the 'minimum time to critical conditions.' A typical curve of survival time plotted against air temperature is shown in Fig. 6 for the datum ship in Force 10 storm conditions.

Whether or not we accept the time scale, a significant feature of the graph is the steep slope of the curve between -5°C and -10°C —the normal range of icing temperatures.

For the datum trawler, an ice-weight of 50 tons with its centroid 28 ft. above the keel would bring the ship to critical conditions. In a Force 10 storm, this weight of ice would have collected on the ship in 13 hours at -5°C , five hours at -10°C or three hours at -15°C .

From knowledge of actual icing rates at sea and information on the 1955 and 1968 tragedies we would suggest that in practice the times might be extended by a factor of two.

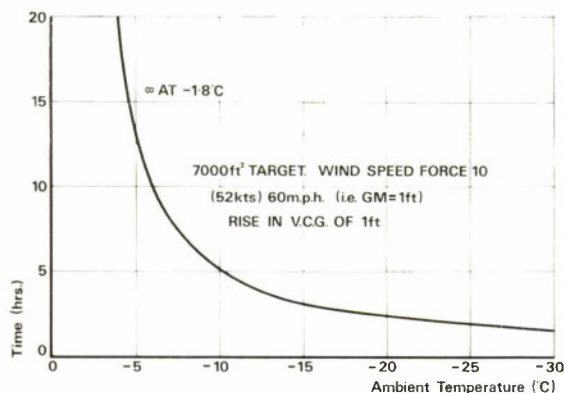


FIG. 6. Time to Critical Conditions.

(The *Roderigo* in 1955 foundered in about 25 hours at an air temperature of -5°C and storm force winds. Her smaller companion, *Lorella* capsized some three hours earlier).

Disaster

Environment

The severe icing storms which sink small ships in the darkness of the Northern Seas are brought about by the unheralded release of millions of tons of air which have been cooling over the Arctic wastes possibly for several weeks. A not very well defined trigger action allows this very cold air (-30°C) to sweep southwards over the sea at hurricane force. This cold air, because of its great density, forms a wedge under the existing, warmer air and holds close to the sea surface. The sea being much warmer than the intruding air, heat transfer by forced convection takes place at the air-water interface. The intruding air is raised in temperature but is held down at the surface by the mass of cold air above it until the buoyancy forces are great enough for the heated and expanded bubbles of air to force themselves upwards. In breaking free, the air cell raises water from the waves which is then in turn torn away and thrown at the ship by more cold air rushing in to replace the bubble. Characteristically these bubbles or cells are estimated to be about 200 yards long.

An observer on the bridge sees all this as a never-ending curtain of freezing spray beating into the ship from a boiling sea. Almost certainly it will be dark and the only illumination a puny finger of light from the ship's searchlight.

Conditions such as these would account for the almost incredibly high icing rates reported in disaster areas.

Clearly as the ship moves northwards into the wind, the conditions deteriorate rapidly and north of Iceland ('around the corner' in the trawler skipper's language) there is nowhere to hide.

These very severe conditions are not always associated with an established sea-state corresponding to the windspeed and direction. More often they are severe squalls which superimpose short, steep seas on a long swell from another direction. Icing off Iceland and in the Norwegian Sea is invariably associated with a N.E. or N.N.E. wind. A change in the wind from N.W. to N.E. brings icing almost at once in winter.

Protection for Survival

The primary requirement is for more complete meteorological information so that severe icing storms may be forecast with greater accuracy. This implies three positive measures. Firstly, more 'on the spot' data from ships in the area. This is now partly provided by the trawler mothership but the installation of very simple and robust meteorological instruments in every ship is a real necessity. At present, a typical trawler does not carry even an air temperature thermometer. A simplified weather code is also needed; the present official reporting code is too complicated for trawler use.

The second measure to be taken is the in-depth study of synoptic charts for those days when severe icing has occurred so that a clue might be found as to the origin of the trigger-action referred to earlier.

Finally, an exercise in physics; namely the study of the air-water interface and the buoyancy forces generated by large temperature differences.

The complete answer to the icing problem is, of course, not to be there when it happens. On the very real assumption that this is a counsel of perfection, what can be done to minimise the icing hazard?

First and foremost, ships below a certain size should be barred from these waters in winter.

Secondly, a qualified engineer should be allowed to 'vet' all designs for known and probably avoidable troublespots. Large uncluttered areas are not the problem; it is the wires, struts and details which cause the headaches.

Thirdly, heated bridge windows and protected antennae are 'musts', as also is a reliable method of life-raft ejection.

Of the many methods of ice removal tried, only two have shown any promise of replacing the axe. They are the inflatable rubber overshoe and the seawater lance driven from a gas-turbine powered fire-pump. High pressure seawater from a $\frac{1}{2}$ in. to 1 in. diameter nozzle may be used to cut a hole in an ice formation and having done so, the jet is projected behind the ice to cut it free from its hold on the ship. Very large quantities of seawater can aggravate the situation by running down and freezing elsewhere but, properly applied, a relatively small lance can be a useful tool.

Paints, greases, pneumatic hammers and steam jets have all been tried without a great deal of success. Electrical de-icing is very expensive and can be dangerous. Very low voltage electrolytic de-icing is a possibility for some applications.

The 'Achilles heel' of ice is that it will not bend easily and advantage is taken of this property in the B.T.R. de-icer boot, the I.C.I. 'Parafil' cable and the use of disposable polythene sheets for covering equipment such as the business end of a torpedo tube, a windlass or a D.F. loop.

Returning to the fishing scene, of the total weight of ice caught by a typical trawler, one third is trapped by the clutter of rigging and details, usually high up on the ship. The remaining two-thirds is attached to the hull but at a lower level so that stability is affected to

a lesser degree. Five tons of ice on the top of the wheelhouse is the equivalent of 31 tons on the main deck.

Conclusions For the crew of a small vessel sailing alone in the hostile environment of the Arctic Sea in winter, hazards will always remain. Of these, the onset of severe icing is probably the most dangerous and certainly the most terrifying to experience.

The purpose of this article has been to stimulate an awareness of the many factors which contribute to the problem of icing at sea.

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THERMAL IMAGING WITH A PYROELECTRIC VIDICON

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Brian R. Holeman joined the R.N.S.S. at SERL in 1958 after taking a degree in Physics at Oxford University. He has since then been concerned with optical properties of semiconductors, including photoemission. In 1968 he transferred to a study of thermal imaging using pyroelectric layers.

Introduction All objects at normal ambient temperatures emit thermal radiation. In fact, the total radiation is typically 400 to 500 watts/m² and it is only because in equilibrium an object can receive as much radiation as it emits that under normal conditions it does not rapidly cool down. Several systems have been constructed to detect this radiation, and to produce acceptable images of objects at and around normal ambient temperatures. These are discussed in detail in a previous article in this *Journal*⁽¹⁾ which also discusses the role of radiation wavelength, and atmospheric transmission.

A new technique, now at the early development stage, for producing thermal images is to use a pyroelectric sensing layer with electron beam readout. This device is called a pyroelectric vidicon, by analogy with a conventional (photoconductive) vidicon used in nearly all TV cameras, and was described originally by Le Carvenec⁽²⁾.

However, before considering this in detail, it will be useful to restate some of the properties of thermal radiation.

Thermal Radiation

Acceptable thermal imaging systems must detect temperature differences of 0.1 to 1°C in the objects being viewed. As a 1°C difference corresponds to only 6 watts/m² the contrast available is very low, just over 1% per °C. Even with the highly sensitive detectors available in the visible region of the spectrum such low contrast images would be difficult to detect. At wavelengths around 10 μm, corresponding to the maximum in the thermal radiation, detectors are not as sensitive as in the visible region and it is surprisingly difficult to produce acceptable thermal images. Atmospheric absorption limits operation to the region between 8 and 14 μm wavelength.

The best way of detecting low contrast images is to use some form of difference technique. If the low contrast image alternates with a uniform radiation pattern and only the difference in signal is detected, then the contrast available is greatly increased. As all objects at normal temperatures radiate, a simple chopper and a lens (Fig. 1) can produce alternately a scene image and a blank pattern at chopper temperature. If the sensing layer detects only changes in radiation level, it will have no output if scene and chopper are at the same temperature. Further the output if scene and chopper are at different temperatures is proportional to the temperature difference, and the signal will alternate in phase with the chopper. Such a system is in effect AC coupled unlike most other photodetectors which are DC coupled, i.e. they have an output proportional to total input at any time.

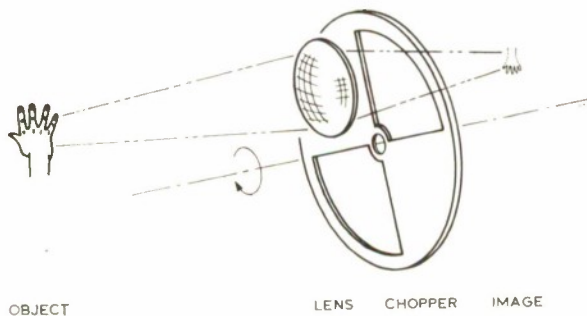


FIG. 1. Schematic view of lens and chopper system.

Outline Description of System Used

A photodetector with an output proportional to changes in radiation level does in fact exist. It makes use of the pyroelectric effect, which is discussed in detail in a previous article in this *Journal*⁽³⁾. The property of interest here is the generation of charge by a change in temperature, the pyroelectric effect. The defining equation is

Signal current per unit area, $i = p \dot{T}$ where

p is the pyroelectric coefficient

$\dot{T}$ is the rate of change of temperature.

The signal current produced can be detected in a variety of ways. Single element detectors are available which use a suitable low noise electronic amplifier. However, for imaging applications it is desirable to use a thin disc of pyroelectric material. The radiation pattern then produces an equivalent charge pattern on the disc. This pattern can readily be detected using an electron beam, effectively as a commutating switch, in a new type of TV camera tube similar to a vidicon.

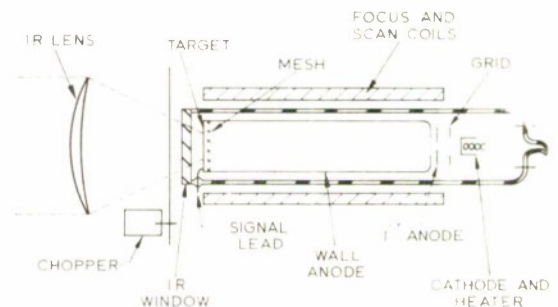


FIG. 2. Schematic drawing of pyroelectric vidicon.

The resulting system is shown in Fig. 2. The pyroelectric target must be in the same vacuum envelope as the electron gun and therefore an infra red transmitting window is required. The role of the lens and chopper have already been discussed. The electron beam is scanned over the surface of the pyroelectric layer by the combined action of the scan and focus coils. A video signal is generated corresponding to the charge pattern on the layer and conventional TV techniques can be used to produce a picture on a monitor. The component parts will now be described in more detail.

Theoretical Assessment

Pyroelectric Signal

Variation with time

If the radiation level at a point on the pyroelectric target is suddenly increased, say by ΔW , then the target temperature will begin to rise. The rate of rise is determined by the thermal capacity of the layer, and the initial rate of rise of temperature is

$$\dot{T} = \frac{\Delta W}{\rho s d}$$

where ΔW is the input in watts/m²

ρ is the density in g/m³

s is the specific heat in
joules/°Cg

d is the layer thickness in m

The temperature will continue to rise until a new thermal equilibrium is reached, and the change of temperature with time is governed by a thermal time constant, τ_{th} . After several times τ_{th} a new equilibrium is reached. In fact, for materials of interest, the thermal time constant is about $\frac{1}{4}$ sec. for every micrometre of target thickness. Typical targets, of 20 to 40 μ m thickness therefore have thermal time constants of five to 10 seconds. As typical chopper frequencies are one to 10 Hz, the thermal time constant is very long compared to the chopper period.

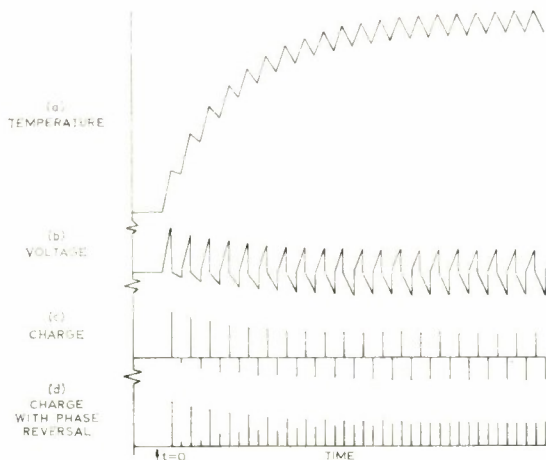


FIG. 3. Signal levels on a pyroelectric target as a function of time with an increase in heat flux through a chopper at $t = 0$.

Fig. 3(a) shows a plot of layer temperature against time. At $t = 0$ the radiation level has been increased. The action of the chopper modulates the temperature as shown and a new equilibrium is reached after several thermal time constants. With an electrical layer output proportional to temperature, the output would increase slowly with the thermal time constant. This is the situation in several previous thermal imaging devices. In this case the layer must be very thin (about 1 μ m) to obtain sufficient speed of response.

However, in use a pyroelectric target is periodically discharged by the reading electron beam, and the resulting voltage variations are shown in Fig. 3(b), and the signal charges read out in Fig. 3(c).

There is now little change with time, and the system would detect the radiation change in only one cycle of the chopper.

The signal produced now alternates with the chopper. If alternate phases are inverted, the resulting signal is shown in Fig. 3(d). The mean signal level is now constant and suitable smoothing of the picture presentation, for example by using a medium persistence phosphor on the picture monitor, will present an observer with an essentially flicker free picture.

The system described here is essentially an imaging phase sensitive detector. If the chopper produces no radiation change, then the system has zero output. The output produced by any chopped radiation will depend on its phase and the system can be arranged to display hot objects as white and cold objects as black.

Magnitude of Signal

If the equations defining pyroelectric effect and temperature rise are combined, the signal current can be calculated,

$$i_s = \frac{p \cdot \Delta W}{\rho s d}$$

For the best pyroelectric material so far obtainable, Triglycine Sulphate, TGS,

$$p = 2.8 \cdot 10^{-4} \text{ coulombs/m}^2 \cdot ^\circ\text{C}$$

$$\rho s = 2.55 \cdot 10^6 \text{ joules/m}^3 \cdot ^\circ\text{C}$$

$$\frac{i_s}{\Delta W} = 5.5 \text{ } \mu\text{A/watt for } d = 20 \mu\text{m}$$

Unfortunately the full 6W/m² for 1°C scene change are not obtainable in an optical image. Infra red lenses have a limited aperture, and for this work the best possible F/No is

required. Even for $F/1.0$ only a quarter of the scene radiation density reaches the target layer. In addition infra red materials have high refractive indices and hence high reflection coefficients. Typical materials used are germanium, arsenic trisulphide and Irtran II. These materials can be bloomed, but even then very high transmissions are not obtainable. The overall signal levels at the target are then typically 0.3 to 0.6 W/m^2 for 1°C scene temperature changes. A typical radiation level of 0.5 W/m^2 would give a signal of approximately 0.3 nA on 10^{-4} m^2 (1 cm^2). This should be compared with typical peak signals of 500 nA and noise levels of 2 nA in conventional TV practice. The pyroelectric signal current can only be increased by either making the target thinner or by increasing the area. The pyroelectric layer also has an electrical capacity. This is given by the conventional formula.

$$C_A = \frac{\epsilon \epsilon_0}{d}$$

ϵ relative dielectric constant

ϵ_0 dielectric constant of free space

C_A capacity per unit area

For TGS, $\epsilon=42$ and the capacity is 1860 pF for 10^{-4} m^2 , with the target, as before, $20 \mu\text{m}$ thick. This is a rather larger capacity than is used in normal TV tubes, and can result in slow operation of the tube, termed lag. This effect will be discussed in more detail later.

The signal current will produce voltage changes across the pyroelectric layer. The voltage produced is given simply by

$$\dot{V} = \frac{i_s}{C_A}$$

$\dot{V}$ = rate of change of voltage, V/sec .

$$\text{Therefore } \dot{V} = \frac{p \Delta W}{\rho S \epsilon \epsilon_0}.$$

For a given material and radiation density, the rate of change of voltage is independent of both layer thickness and area.

The operation of TV tubes with electron beam readout becomes difficult (because of lag effects mentioned previously) when the voltage change during a single TV frame is less than 100 mV . For TGS at 0.5 W/m^2 ,

$$\dot{V} = 150 \text{ mV/sec}.$$

This corresponds to only 6 mV in a single TV frame ($1/25 \text{ sec}$.) and the signal levels on a pyroelectric target are, again, found to be significantly less than those obtained in normal TV practice.

Resolution

For normal TV operation it is apparent from the above calculations that the signal levels from a pyroelectric target are much less than is normal for studio quality TV. However, thermal images are unlikely to match those obtained using visible light unless considerable increases in size and weight can be tolerated. A pyroelectric camera tube can be expected to have a spatial resolution no better than about $100 \mu\text{m}$ at the target.

There are a number of reasons for this and it is worth considering them in a little detail.

Lens performance

Resolution obtainable will be limited to the wavelength of the radiation used. This is 8 to $14 \mu\text{m}$. In addition large lens or mirror apertures, typically $F/1.0$, are desirable and high resolution over a suitable field of view with a flat image plane is incompatible with such large apertures. It is anticipated that $F/1.0$ optics of 70 to 100 mm focal length with resolutions of about $100 \mu\text{m}$ are feasible.

Thermal spread

If fine detail is present on the target, this will spread laterally during the time the chopper is either open or is closed. The thermal pattern on a layer decays with a time constant γ^2/κ where γ is the typical lateral dimension of the thermal pattern, and κ is the material thermal diffusivity ($= \frac{K}{\rho S}$), where K is the thermal conductivity. If real time imaging is desired, the chopper frequency must be high. On the other hand, as will be seen later, the detection of small temperature differences requires low chopper frequencies. The lower the frequency, the more objectionable will be the effects of thermal spread. If the time constant for the decay of the thermal pattern is put equal to $\frac{1}{2}f$ where f is the chopper frequency, then

$$\gamma = \left(\frac{\kappa}{2f} \right)^{\frac{1}{2}}$$

For TGS $\kappa = 3 \cdot 10^{-3}$, and with $f = 5 \text{ Hz}$, $\gamma = 170 \mu\text{m}$.

This limit on obtainable resolution can be improved by either selecting a better material, or by increasing the chopper frequency. TGS is already a good thermal insulator and increasing the chopper frequency

quency introduces signal readout problems.

If this limit of about $100\text{ }\mu\text{m}$ is accepted, then pyroelectric vidicons can either have a lower electrical bandwidth, and therefore lower noise operation, than conventional vidicons, or else they can have larger area targets, and hence generate higher signal levels. Conventional vidicon resolution is typically 10 to $20\text{ }\mu\text{m}$ so considerable increases in sensitivity are possible.

Electron Beam Readout

The mechanism of signal generation in vidicons will be outlined, and then the details of electron beam readout for pyroelectric targets will be discussed.

Signal Generation

Each portion of the target in any vidicon tube, photoconductive or pyroelectric, is essentially a small electric capacitor. One terminal is addressed by the electron beam as it scans over the target. The action of the beam is that of a commutating switch (Fig. 4). The other terminal of the capacitor is connected to a conducting film on the opposite side to the electron beam addressed side. This film is in turn connected to a terminal on the side of the tube and then to the input of a video amplifier.

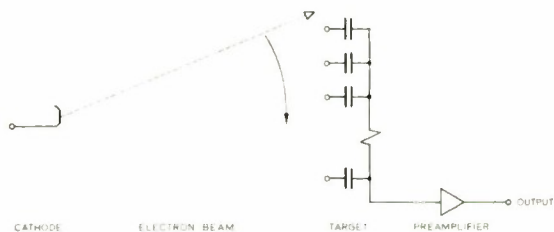


FIG. 4. Principle of vidicon readout.

In operation the video amplifier input is a virtual earth, and any current flow from the target to the amplifier constitutes video signal.

The scanning electron beam drives each element of the target capacity to a constant potential as it lands at that point. During the frame time (1/25 sec.) signal generation in the target will change the potential of that point, and the electron beam must supply an equivalent electrical charge to restore the constant potential when it next lands there. This charge results in a displacement current in the target element capacity and therefore also in the signal lead to the video amplifier.

In use therefore, any pattern of charge generation over the target layer will be read out sequentially by the electron beam to generate the conventional line by line video signal. Normal TV practice is to use 625 lines scanned in 1/25 second.

If the electron beam were to scan the target continuously, and if the target was generating a uniform signal i_s amps/ m^2 , then the total signal current must equal the total video current. That is

$$i_s \cdot A = i_{\text{video}}$$

where A is the total area scanned.

This simple equation enables the transfer of calculations of target performance based on the steady signal current generation in the layer to video performance at the amplifier input.

Over any one area of the target, the video signal will not depend on the video signal from other points on the target, and the condition of uniform signal stated above is in fact unnecessary. At any point the video current is equal to the local signal current density multiplied by the total area scanned.

Beam impedance

Unfortunately the electron beam is not a perfect switch, and it has a finite conductance. If this is too low, then several scans of the beam may be required to establish equilibrium after a change in radiation input. The system will not then respond to rapid changes in the image. This effect is called "capacitive lag."

The beam conductance is the slope of the beam voltage-current characteristic at the operating point, and will depend on a variety of parameters. In readout this conductance is effectively in parallel with the target capacity giving an RC time constant of

$$\tau_B = \frac{A \cdot C_A}{g_B}$$

where g_B is the beam conductance

i.e. $1/g_B$ = beam impedance

Typical beam conductances range from 10^{-6} to 10^{-9} mhos, giving values of τ_B of 1 m sec. to 1 second on 1000 pF targets. Ideally τ_B should be less than a frame time 1/25 sec.

Operating modes

The electron beam must maintain the scanned surface of the pyroelectric target at a constant potential. The operating points are therefore determined by the zero current points on a beam voltage-current plot.

Fig. 5a shows a typical voltage current plot for an electron beam. This was obtained by operating a vidicon normally, with a metal target in place of the normal target. The plot is the voltage-current characteristic of the metal target with the electron gun cathode at 0 volts, intermediate electrodes at 200 to 300 volts (apart from the grid of the electron gun which is normally at -20 to -30 volts) and the final mesh electrode (see Fig. 2) at 246 volts.

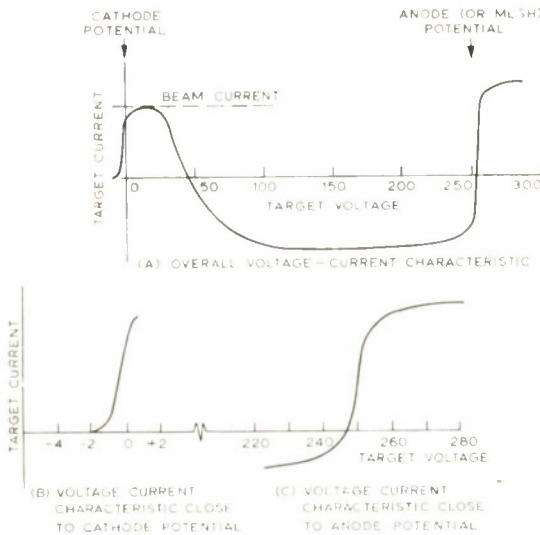


FIG. 5. Voltage current characteristics for a vidicon target scanned by an electron beam.

If the target voltage is negative, then electrons cannot reach the target and no current flows. As the target voltage is increased, the electrons begin to reach the target and the current increases rapidly for small positive voltages until all the electrons reach the target and a saturation is reached. Further increases in target voltage then serve to increase the impact energy of the electron beam and secondary electrons are produced. These are collected by the mesh, and represent electrons flowing from the target. An increase of secondary electron current therefore gives a decrease in nett current to the target, and the nett current decreases as the voltage is increased.

When the two currents are equal, the nett current is zero. This point is 'first cross-overs potential' and is typically between 30 and 80 volts. Further increase of target voltage now results in nett electron current away from the target.

This condition is maintained until the target approaches mesh potential. Then the secondary electrons are no longer collected by the mesh, but are returned to the target, i.e. secondary emission is suppressed. Further increase in target voltage maintains the electron beam current, aided by secondary electrons produced by the mesh.

The only stable operating points are close to $V=0$, termed Cathode Potential Stabilization, or CPS, and close to mesh, or final anode, potential, termed Anode Potential Stabilization or APS.

Cathode Potential Stabilization

This is the mode of operation normally used in modern TV camera tubes. The voltage-current characteristic close to $V=0$ is shown in Fig. 5b. Only positive going signals on the target can be read by the electron beam due to the rectifying action of the characteristic. At small signal levels, the characteristic is exponential,

$$I = I_0 \exp V/V_0 \quad I_0, V_0 \text{ constants}$$

and in this region

$$g_n = \frac{\partial I}{\partial V} = \frac{I}{V_0}$$

A high beam conductance therefore requires a high signal current, and a small value of V_0 . In fact V_0 is related to the energy spread in the electrons of the electron beam, and therefore is a function of the cathode temperature. Typical values of V_0 lie between 150 and 250 mV.

In the case of a pyroelectric target, both positive and negative signals must be detected, unlike a conventional photoconductive vidicon where the signal is always positive. CPS operation is then only possible with a pyroelectric target if an additional constant current is superimposed on the signal, so that true negative going signals do not occur.

Further, as the beam conductance is dependent on I , increased conductance can be obtained by the use of this additional current, which is termed a pedestal current.

The total signals will be

$$I_p + I_s \text{ and } I_p - I_s$$

I_p = pedestal current

I_s = signal current

and the mean conductance will be

$$g_n = \frac{I_p}{V_0}$$

Anode Potential Stabilization

This mode of operation was used in some early TV camera tubes, and has been further investigated by Dresner⁽⁴⁾. The voltage current characteristic for this mode of operation is shown in Fig. 5c. Both positive and negative signals can be read by the electron beam. It is found experimentally that, for a given target at the stabilization point

$$g_B = \frac{I_B}{\eta}$$

where I_B is the electron beam current
 η is a constant

The beam conductance is therefore limited by the total beam current usable, instead of only the signal current as in CPS operation. Practical values of η on metal targets are about 10 volts.

At first sight this is an ideal readout mechanism. It will read both positive and negative signals, and does not require a pedestal for efficient operation. However, there are two disadvantages.

Redistribution

The secondary electrons returned to the target by the mesh do not always return to their point of origin. They can travel significant distances over the surface of the target and can partially discharge the target ahead of the reading beam. The main effect is a loss of contrast in the video signal, coupled with spurious signals near the image edges. It is controlled, but not eliminated, by making the mesh to target spacing as small as possible, typically $\frac{1}{4}$ to $\frac{1}{2}$ mm.

Beam Shot Noise

The target equilibrium is a dynamic one, a balance between primary electron beam current and secondary currents. These currents are statistically uncorrelated, and will generate shot noise. Each component will be of the same order of magnitude as the primary electron beam current giving a total noise

$$\overline{i_{BN}^2} = 2e I_B \beta.B$$

where e is the electronic charge

B is the bandwidth (Hz)

β is of order unity

i_{BN} is the RMS value of noise current

In practice β takes values between 1 and 3.

Noise

To operate adequately, any system must have a sufficiently high signal to noise ratio. So far, only signal levels have been discussed in detail, apart from APS beam shot noise. There are other noise sources in the system.

Amplifier Noise

All TV cameras require low noise amplifiers and therefore these are well developed. There are several papers on their operation (e.g. ⁽⁵⁾) and there is no point in going into great detail about amplifier design here.

A simplified schematic circuit is shown in Fig. 6. R_s and C_s are the shunt resistance and stray capacity at the amplifier input. The sensitivity is determined by R_f provided, of course, that the amplifier gain is high enough.

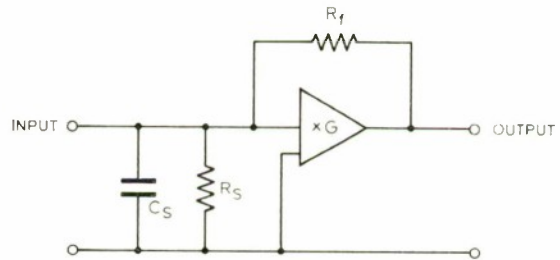


FIG. 6. Amplifier equivalent circuit.

Then

$$\text{Volts out} = \text{Current in} \times R_f$$

The input impedance is R_f/G , and if the amplifier gain is large enough, the bandwidth is not limited by the stray capacity at the input.

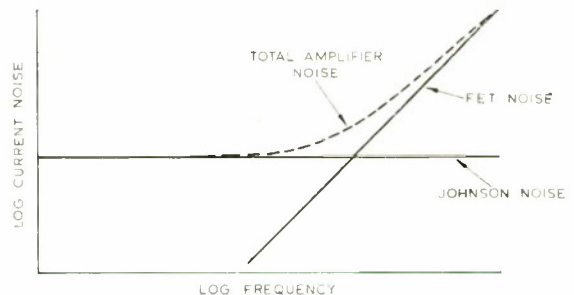


FIG. 7. Amplifier noise as a function of frequency.

There are two main noise sources. The first is Johnson noise in the shunt resistor R_s and feedback resistor R_f , effectively in parallel. This gives a current noise independent of

frequency (Fig. 7). The other is the noise due to the input device (FET or Nuistor) and this is affected by the feedback loop. The nett effect is to give a current noise that increases with frequency (Fig. 7). The overall effect, therefore, is a noise spectrum with Johnson noise at low frequencies and device noise at high frequencies.

The total noise is a minimum if R_s and R_i are made sufficiently large for Johnson noise to be neglected, when

$$\overline{i_{AMP}^2} = \frac{4}{3} \pi^2 V_N^2 B^3 C_s^2$$

V_N = RMS value of input device voltage noise $V/\sqrt{\text{Hz}}$

Typical values of V_N for FET's are 1 to 2 $\text{nV}/\sqrt{\text{Hz}}$ corresponding to equivalent noise resistance of about 100 ohms. It is interesting to note that the overall noise current increases as (amplifier bandwidth)^{3/2}.

Spatial Noise

The properties of the target vary from point to point. If these properties, such as resistivity, dielectric constant or secondary emission coefficient, affect the signal generation or readout processes, the video signal will contain constant unwanted signals as well as the desired signals. These unwanted signals constitute spatial noise. It is impossible to deduce theoretically the magnitudes of spatial noise expected, and their effect can only be studied by constructing the camera tube. However, in conventional TV camera tubes, spatial noise is typically 1% of signal, and is difficult to reduce below this level.

CPS operation demands the presence of a pedestal current in addition to signal currents. Any variation in this current will introduce spatial noise.

Normal 625 line British TV standards are closely defined, and it is an advantage if the pyroelectric thermal imaging camera is compatible with these standards. The 625 lines are divided into two fields of 312½ lines arranged so that the first field comprises the odd lines, *i.e.* 1, 3, 5 etc. and the second field comprises the even lines, 2, 4, 6 etc. This arrangement reduces the effects of flicker which would otherwise be objectionable at 25 frames/second. The relevant data is

Frame rate	25 Hz
No. lines	625 (2 × 312½)

No. active lines	585 (2 × 292½)
Field fly back	40 lines (2 × 20)
Line period	64 μsec
Active period	53 μsec
Line fly back	11 μsec
Bandwidth	5.5 MHz
Picture aspect ratio	4 : 3

The electron beam is switched off (blanked) during line and field fly back and the video signal during this time is therefore zero. Part of this time is used to provide synchronising pulses to drive TV monitors in synchronism with the scan in the camera tube. This system enables one signal lead to carry all necessary picture information. In addition if the zero video output during beam blanking can be detected in a picture monitor, and the drive signal to the monitor electron gun is clamped at this time (black level clamp), then any mean picture level in the camera will be presented correctly on the monitor, even though AC coupled amplifiers are used. In fact, the amplifier low frequency cutoff can be several hundreds of cycles, and can be several times the field frequency of 50 Hz.

Expected Performance

As explained in the section on resolution, a pyroelectric vidicon will use either a lower bandwidth, or a larger target than a conventional vidicon. If the electron beam scan is increased to the maximum area compatible with a resolution of 100 μm at standard TV rates, an area of approximately 60 × 80 mm is covered. The largest target diagonal in either a conventional 1 in. OD vidicon or in the experimental system at SERL is only 17 mm, and if the full scan is used, then the target will appear as a disc in the centre of the displayed area. If larger pyroelectric vidicons were to be made then the displayed image size would increase on the monitor. The calculations will therefore be based on a 625 line system, with sufficient overscan to just resolve 100 μm at the target if full system bandwidth (7.4 MHz for studio work) is used.

Based on TGS, 20 μm thick and with the material properties previously quoted, the relevant parameters are:

Displayed area	58.5 mm × 78 mm
Amplifier noise	2.2 nA RMS
Beam noise in APS	3.6 nA RMS
Pedestal current in CPS	550 nA
Video signal at 1W/m²	32 nA

Such a device would detect radiation levels at the pyroelectric target in APS readout of just over 0.1W/m^2 corresponding to rather less than 1°C . The pedestal current required in CPS operation is uncomfortably high, and any reduction will decrease the signal levels detected. If the full pedestal can be tolerated without increasing the spatial noise, the minimum signal becomes 0.07W/m^2 , rather less than for APS.

The realisation of these performance levels depends on the production of sufficiently uniform TGS targets, coupled with an optimum optical and electrical system with no severe effects due to CPS pedestal non-uniformity or APS redistribution.

Figure of merit

The signal to noise levels actually produced will, in the ideal case, be a function of the pyroelectric material properties. It is worth describing these in more detail.

APS readout

The signal is proportional to the pyroelectric current,

$$\text{i.e. Sig} \propto \frac{p}{\rho s d}$$

The noise is normally beam noise, not amplifier noise. In the calculations above beam noise is only marginally greater than amplifier noise, but the effects of beam noise compared to amplifier noise increase further as the bandwidth is reduced.

The electron beam current required is proportional to target capacity, and beam noise is proportional to the square root of electron beam current giving

$$\text{Noise} \propto C^{\frac{1}{2}} \propto \left(\frac{\epsilon}{d} \right)^{\frac{1}{2}}$$

Therefore the S/N ratio is proportional to

$$\frac{p}{\rho s \epsilon^{\frac{1}{2}}} \cdot \frac{1}{d^{\frac{1}{2}}}$$

CPS readout

- (a) If the full pedestal current can be used, the signal is proportional to pyroelectric current

$$\text{i.e. Sig} \propto \frac{p}{\rho s d}$$

The dominant noise will be amplifier noise, which is independent of target properties and

$$\text{S/N is proportional to } \frac{p}{\rho s} \cdot \frac{1}{d}$$

- (b) If the full pedestal cannot be used, spatial noise on the pedestal will limit the S/N ratio. If different materials have the same ratio of pedestal noise to pedestal, then the spatial noise will be proportional to the pedestal current. This is, in turn, proportional to target capacity giving

$$\text{Noise} \propto C \propto \frac{\epsilon}{d}$$

In this case therefore, S/N is proportional to

$$\frac{p}{\rho s \epsilon}$$

Thus three figures of merit can apply depending on the particular readout problems. If it is assumed that all materials are available at the same thickness, the most suitable figure of merit to take is that for APS operation and is also the mean of the two figures of merit for CPS operation. This gives

$$\text{Material figure of merit} = \frac{p}{\rho s \epsilon^{\frac{1}{2}}}$$

It is interesting to note that $\left(\frac{p}{\rho s \epsilon^{\frac{1}{2}}} \right)^2$

is proportional to the electrical signal power available from the pyroelectric target.

Experimental System

In order to test the previous calculations, an experimental pyroelectric vidicon system was constructed at SERL. It consisted of a continuously pumped vacuum system containing a vidicon electron gun with focus and scan coils and a suitable target chamber with infrared transmitting window. External optics comprised an Infrared lens and a chopper. Suitable voltages were available for driving the vidicon and normal TV signal processing was employed.

Target mounting

The targets were thin discs of TGS 17.5 mm in diameter ranging from 20 to $60\text{ }\mu\text{m}$ thick. They were prepared as described in Ref. (3). A target holder that maintained a constant spacing between mesh and target was used to assemble these two components as a unit before inserting them into the vacuum system.

Before mounting, the TGS discs were carefully cleaned and then coated on the target connection side with a thin layer of conducting graphite (Dag 580—colloidal graphite in alcohol). As TGS is highly soluble in water, water based cleaning liquids cannot be used. TGS itself, although transparent to the eye, absorbs strongly in the infrared and the coating of Dag is merely to produce a conducting film, and is not necessary to absorb the thermal radiation. Slices of TGS only 20 μm thick are fragile until mounted, and handling them requires a steady hand.

Once mounted on its support ring the slice is easily inserted into the mesh and target holder. Fig. 8(a) shows the design of this and Fig. 8(b) shows the complete assembly. The total capacity of the target to earth or mesh is kept as small as possible. The target is insulated from the mesh by the three small glass spheres and the spacing between the two is adjusted using shims. In practice target to mesh spacings of 0.3 to 0.7 mm were used, and redistribution effects in APS were apparent at 0.7 mm and above.

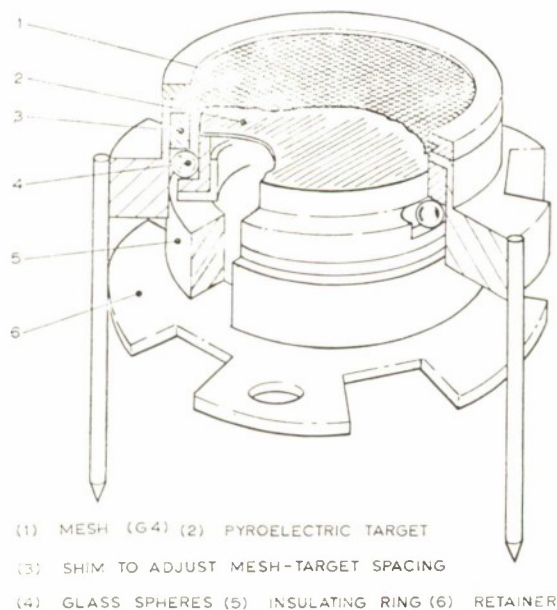


FIG. 8. (a) Sectional view of target and mesh assembly

Demountable vidicon

A typical vidicon electron gun is shown in Fig. 9. For normal TV operation a photoconductive target would be deposited on a face-

plate and this would be sealed to the end of the tube. For the demountable pyroelectric vidicon a special target chamber was constructed. The electron gun is sealed to the target chamber with an 'O' ring, and a similar seal is used for the infrared transmitting window. A side port provides a connection to the pumping system, and the electron gun could be pumped separately from the cathode end through the glass stem.



FIG. 8. (b) Target and mesh assembly.



FIG. 9. Components used in demountable vidicon.

In use the target and mesh assembly was clipped into place on to the end of the support rods shown. In addition one rod provided the target connection to the video amplifier. The

mesh enters the glass tube of the electron gun and this locates it relative to the gun assembly and provides electrical insulation.

Vacuum System

This used an ion pump for normal running, with a rotary pump and an oil vapour trap for rough pumping. In addition, as the electron gun had an oxide cathode when changing the sample it was let down to dry nitrogen and not air. While the tube was open to the atmosphere dry nitrogen flowed gently past the electron gun and prevented contamination by water vapour.

It was found that the rotary pump gave a sufficiently low pressure (about 10^{-2} torr) for the ion pump to take over without the need for other forms of pumping.

Occasionally a new electron gun was required. A new oxide cathode requires activation and this released significant gas loads in the vacuum system (on activation barium carbonate is reduced to barium oxide and carbon dioxide). A large mercury diffusion pump was incorporated for this stage. This was also used during initial bakeout of the vacuum system to provide an initial outgassing.

During normal operation the system pressure was 10^{-7} torr, and this could be reached

within an hour of inserting a new target. The vacuum system is shown in Fig. 10. Most of the controls are automatic with manual overrides, and the system could be safely left operating unattended overnight or during weekends.

Electronics

Fig. 11 shows a block diagram of the power supplies and signal processing. The system can conveniently be divided into three parts; power supplies for tube, pulse generation and scan supplies, and signal processing.

Power Supplies

The electron gun requires power for the cathode heater, together with the following drive voltages.

Cathode	OV
Grid	-60 to -20V
1st anode	+200 to +300 V
2nd anode	+200 to 500 V
Mesh	+200 to 400 V
Target	OV to +400 V

Of these only the 1st anode requires any significant power, and this only draws a milliamper or so. The wide range of drive voltages were required to allow tube operation over a very wide range of conditions; APS, CPS, high and low beam currents and so on. In particular the target voltage was within a few volts of OV for CPS, and within a few volts of mesh voltage for APS.

Pulse Generation

A commercial synchronising pulse generator (SPG) was used to provide standard 625 line TV waveforms. These were fed into a Link Electronics type 101 TV camera. In normal use this camera would then drive its own conventional vidicon with the necessary voltages to tube electrodes and drive currents to the scan and focus coils, and would provide a normal video output for driving a picture monitor. The camera was in fact modified to provide drive for external scan and focus coils, these being mounted on the demountable vidicon. An additional modification made available the pulses for blanking the electron gun so that the demountable vidicon was suitably controlled. The operation of the external electron gun then matched the operation of the internal electron gun.

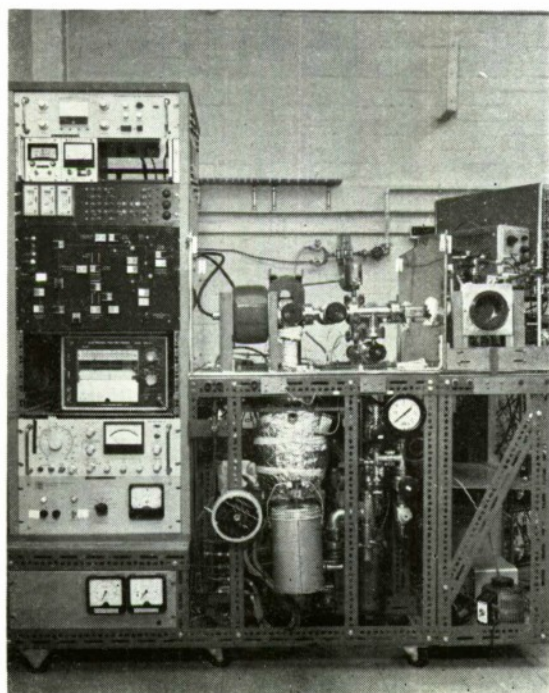


FIG. 10. Vacuum system.

Signal Processing

This starts with the head amplifier. After initial experiments with a normal 5 MHz head amplifier, a low bandwidth amplifier was constructed in order to match the particular pyroelectric targets available. This amplifier had a bandwidth of 0.22 MHz and an input noise of 50 pA RMS. This noise level is rather more than would be expected from theoretical calculations and no doubt some improvement is possible.

Thermal Imaging

Still pictures taken from a TV screen seldom do justice to the results obtained, and this is as true as ever in the pyroelectric vidicon work. However, the results presented here should give an impression of the present state of the art.

Tube operation

Satisfactory operation in CPS conditions could not be obtained at SERL. TGS targets

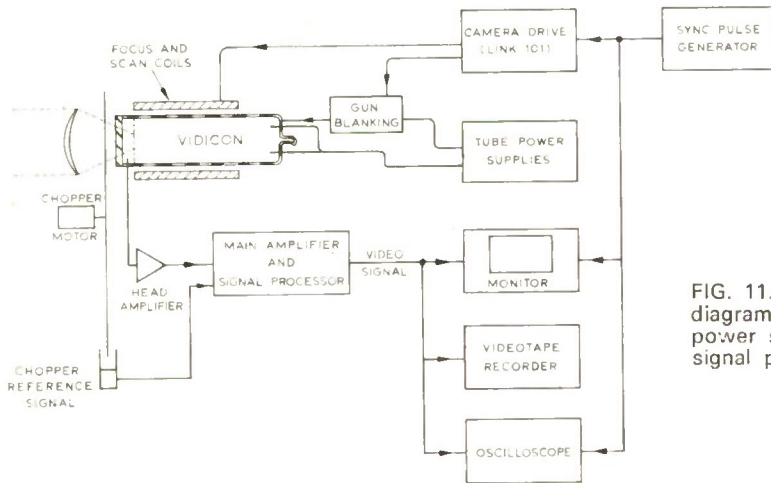


FIG. 11. Simplified block diagram of vidicon power supplies and signal processing.

The video signal was then fed into a video processor, in effect a special effects generator. The signal was split into a normal channel and an inverted channel, and each had separate control of overall brightness and contrast. If required, a reference signal from the optical chopper provided automatic switching between the normal and the inverted channels in synchronism with the chopper.

This processed video signal was then fed to

- (a) an oscilloscope for measurement
- (b) a display monitor for viewing
- and (c) a videotape recorder for permanent recording.

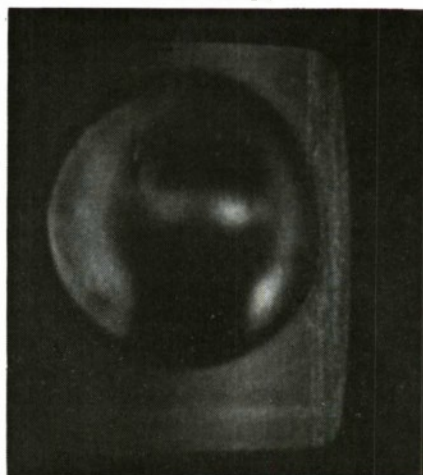
Earlier work at SERL had used simply a typical closed circuit TV camera and monitor. The introduction of the system controlled by the synchronising pulse generator using full TV standards made possible much better control of the video signal, and the use of normal commercial equipment.

have a very high resistivity (at least $10^{14} \Omega\text{-cm}$) when measured after several hours in a vacuum system. The vacua obtained and the exact configuration of electron gun electrodes precluded the use of positive ions to provide the required positive going bias pedestal current.

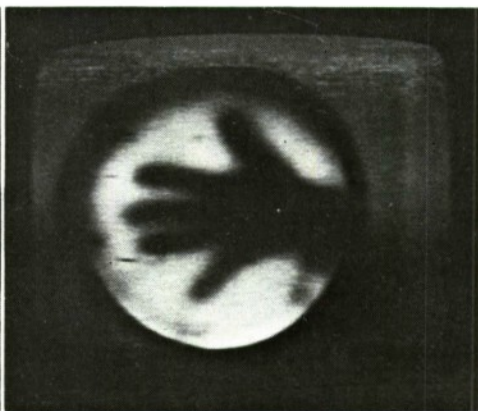
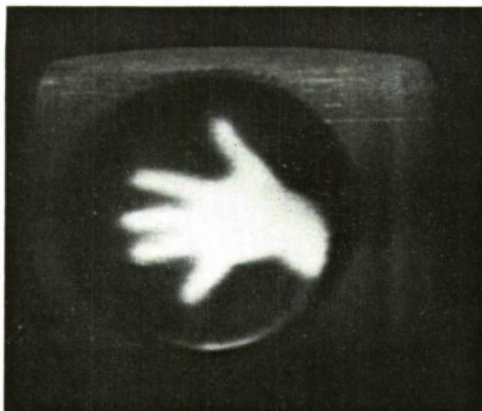
APS operation was used without difficulty on almost all targets. Some spatial noise was generally visible, and the effects of both beam noise and redistribution could be seen. TGS pyroelectric targets require poling, as described in Ref. 3, and this is readily accomplished in APS operation by applying the desired voltage between target and mesh. Either polarity of poling could be used.

The system sensitivities at present obtained are shown in Fig. 12. Hands, faces, etc. are easily visible against a normal laboratory ambient of 20 to 24°C. The overall impression is of real time imaging, that is, objects moving reasonably fast can be easily seen.

THERMAL IMAGE OBTAINED ON DEMOUNTABLE VIDEOCON OF A FACE. THE WHITE IMAGE IS SEEN ON OPENING THE CHOPPER, AND THE BLACK IMAGE ON CLOSING THE CHOPPER.



AS ABOVE WITH A HAND AS THE TEST OBJECT.



AS ABOVE WITH AN EMISSIVITY TEST OBJECT. THIS WAS A WARM POLISHED METAL SURFACE OF LOW EMISSIVITY WITH 'LETRASET' LETTERS OF HIGH EMISSIVITY.

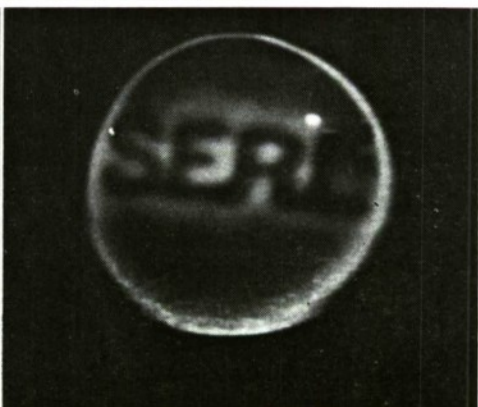
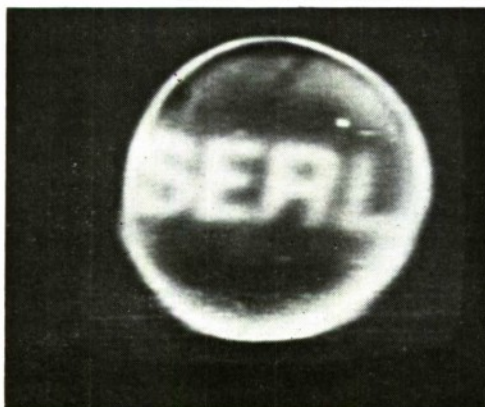


FIG. 12. Thermal images obtained with a pyroelectric vidicon.

In fact, the pyroelectric tube detects moving objects better than static objects. If an object is moving, it is producing temperature changes in the pyroelectric layer, and therefore signal. Under these conditions an optical chopper is not required.

Temperature resolutions of a couple of degrees centigrade are realised with this experimental system, whose performance is close to that expected from its operating parameters. This is coupled with a limited spatial resolution due to limitations in the performance of the optics used.

Sealed off tubes

An associated CVD contract at English Electric Valve Co. Ltd. has produced sealed off versions of this tube with a very similar performance. Surprisingly, TGS is compatible with the vacuum requirements of an oxide cathode.

Conclusions

The performance obtained on the present demountable pyroelectric camera is sufficiently good to warrant serious consideration for

some thermal imaging applications. It is feasible to make a sealed off device, and the resulting system need not be much larger than a typical conventional closed circuit TV camera. Compared to previous thermal systems, it does not require refrigeration, it is fast and it is a relatively simple system.

Acknowledgements

The assistance of Dr. R. G. F. Taylor and Mr. K. E. Trezise, both of SERL is gratefully acknowledged.

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ELECTRICITY, MAGNETISM AND CLOCKS

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Charles Kenneth Aked was educated at Pudsey Grammar School, Leeds; and Leigh and Southall Technical Colleges; joining the R.N.S.S. in 1947 at the A.S.E. Extension at Risley to work in the Radar and W.T. sections, and later the Quartz Crystal section. He moved to the Admiralty Engineering Laboratory in 1955, transferred from the Technical Class in 1958 to become E.O., promoted to S.E.O. in 1962 and took up the post of Works Manager (L) in the Electrical Department. From 1967 - 9 engaged in the development of "Quaver", returning to works management and took over the two posts previously held by the Works Manager (L) and (M). Interested in horology and historical research, and is currently Librarian and Curator to the Antiquarian Horological Society and also Chairman of the Electrical Horology Group.

Introduction Electrical horology has its origins much earlier than is realised and before discussing electric clocks it is desirable first to review the early history of electricity and magnetism. Electrical effects in the form of lightning have been known to man from the earliest times but he was, of course, completely unaware of the natural force involved. The first man-made electricity was discovered by the rubbing of amber, a pale yellow translucent fossil resin of ancient pine trees found in many parts of the world and regarded as a precious stone at one time. Amber has the power to attract light objects to it after it has been rubbed. Thales of Miletus, 640 - 546 B.C., father of Greek philosophy, explained the effect to the presence of a soul in amber.

Thales knew too of the attractive powers of lodestone on small pieces of iron. Lodestone is a magnetic oxide of iron which occurs naturally in certain parts of the world. Thales also ascribed a soul to lodestone to explain its curious power. Long before the Greeks, the Chinese were aware of the power of the lodestone and it was called by them the love-stone or thsu-chy, and the stone which snatches iron, or ny-thy-chy. There is a legend, now discounted⁽¹⁾ that the great Emperor Hoang-Ti, in the year 2635 B.C., had a chariot constructed incorporating a lodestone and which indicated the cardinal points. However the Chinese appear to be the first to have made use of the lodestone for indicating the North pole of the earth and finding their way across the featureless tracts of China. From these beginnings the mariners' compass was later evolved although the knowledge of the use of the lodestone for navigational purposes was lost and found many times again. The Greeks and Romans of Thales' time did not know of the direction-indicating property of the lodestone and it was left to Peter Peregrinus to record the knowledge of magnetism, such as it was, in the thirteenth century A.D. under the title of *Epistola da Magnete*.

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Dr. William Gilbert, 1540 - 1603, physician to Queen Elizabeth I, was the first to explain the nature of magnetism in his classical treatise *De Magnete* published in 1600. He turned a globe from lodestone and called it *terrella*, or little earth, and showed that it caused effects similar to those of the earth's magnetic field, thus demonstrating that the earth is a huge magnet. Amongst other things he showed that magnets have two poles and that steel retains magnetism whereas soft iron will not. He further showed that the north-seeking pole of a magnet repels a similar pole but is attracted by a south-seeking pole. In like manner a south-seeking pole repels a similar pole but is attracted by a north-seeking pole.

Dr. Gilbert also performed experiments with amber and found that whilst iron could only be magnetised by a lodestone or other magnet, many substances could be electrified. He called this mysterious force "electrics" from the Greek word signifying amber. He also classified substances into two groups, those which could be electrified and those which could not be persuaded to do so. William Gilbert therefore was the founder of the science of electricity and magnetism.

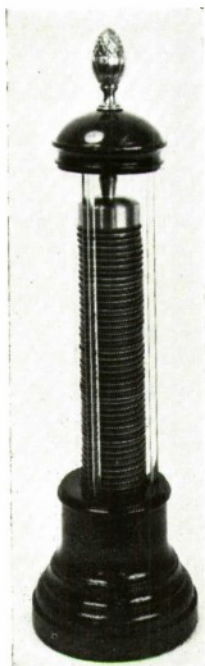
Baron Otto von Guericke, 1602 - 1686, of the famous Magdchurg hemispheres experiment, made the first "frictional machine" for producing electricity. He used a globe of sulphur mounted on a spindle and rotated the globe against the friction of his hands or silk pads. His machine produced electricity in greater quantity than had been previously possible but it was what we now refer to as "static electricity" i.e. high voltage, extremely small currents, and hence very little power although capable of many spectacular effects. Sir Isaac Newton replaced von Guericke's globe of sulphur by a globe of glass and improved the working of the machine but beyond that seems to have made little contribution to the science. The discovery of the Leyden jar by Musschenbroek, 1692 - 1761, and his pupil Cuneus about 1745; and independently by von Kleist, Bishop of Pomerania; which allowed charges of electricity to be stored and enabled even more spectacular effects to be demonstrated, caused great excitement in the scientific circles of Europe and America. Muschenbroek was the first man to experience the effect of the discharge of a Leyden jar through the human body and had

no desire to repeat it, however there were others more foolhardy and it became a common parlour trick to discharge a Leyden jar through many people, sometimes up to a thousand, in order to enjoy the spectacle of seeing so many all jump at once.

Stephen Gray, 1696 - 1736, discovered that the substances which Dr. Gilbert was unable to electrify, nevertheless could conduct charges of electricity. Working with Granvil Wheler he found that charges of electricity could be conveyed several hundred yards along pack thread providing it was supported on silk cords to avoid contact with any object. His work is fully reported in *Philosophical Transactions for 1731*, volume xxxvii, p18. J T. Desaguliers, 1683 - 1738, showed that the charge was conveyed more effectively by moistened pack thread although the supports had to be kept dry to prevent the charge leaking away.

In 1678 Jan Swammerdam, 1637 - 1680, demonstrated to the Duke of Tuscany the contraction of a frog's muscle hanging by a thread of nerve bound by a silver wire and held over a copper support. When the silver wire touched the copper support the muscle twitched as though alive. More than a century later, in 1786, the Italian physician Luigi Galvani, 1737 - 1798, noticed that dissected frogs' legs twitched in the vicinity of electrical machines when in operation and also that when two dissimilar metals were placed in contact with the nerve and muscle of a frog's leg, the muscle twitched when the metals were touched together. He attributed the effect to the production of electricity in the frog's leg. However a fellow Italian, Alessandro Volta, 1745 - 1827, demonstrated that the electricity was generated by the two dissimilar metals when immersed in a salty fluid. Further he produced the first practical source of current electricity by inventing the famous Volta's pile, shown in Fig. 1. Another battery invented by Volta was his famous "Crown of Cups" or "Couronne de Tasses". Volta reported his findings to the Royal Society and they were printed in *Philosophical Transactions*, 1800, volume xc, pp. 403 - 431.

Shortly afterwards, in 1802, Romagnosi of Trente found that a wire carrying an electric current caused a compass needle to move. He did not publish his findings and his discovery dropped into oblivion. Professor Hans Christian Oerstedt, 1770 - 1851, re-discovered the



effect almost by accident in 1819. Further effects due to electric currents in conductors were demonstrated by Andre M. Ampère, 1775 - 1836. His theories of the electric current were formulated into his "Electro-dynamics" to distinguish it from the earlier electrical effects known as "Electrostatics". Ampère also discovered the solenoid, or spiral coil of

FIG.1. Volta's Pile,
the first current
source.

wire, which behaves like a bar magnet when an electric current flows through it. Dominique Arago, 1786 - 1853, another Frenchman, found in 1820 that the solenoid's magnetic field could be considerably increased by inserting a soft iron bar within it, a discovery also made independently by Humphrey Davy, 1778 - 1829. When the current ceased to flow through the solenoid the soft iron lost its magnetism completely. William Sturgeon, 1783 - 1850, used these discoveries to make the first electromagnets in 1825. He improved the effect by bending the soft iron bar into a U-shape and winding many turns of bare copper wire on the limbs. It is said that he used his wife's silk wedding dress to provide the insulation of the bare copper wire from the iron core. If this is so her remarks have not been recorded! When Sturgeon passed an electric current through the copper wire he found the bar to behave exactly like a strong permanent magnet but when the current ceased the iron returned to its original unmagnetised state. These effects could not be displayed for very long for the primitive cells that were then in use could supply current for short periods only. It was not until John F. Daniell, 1790 - 1845, invented his famous two-fluid Daniell cell in 1838 that a reliable steady current source became available.

Electrical Horology

The scene is now set to consider electrical horology. One of the first allusions in writing is made by Alexander Cumming in his account area 1770 of the "Properties of the Magick Alarm: by means of which many pleasing and surprising Tricks may be played, in the manner of Comus, like playing an organ or ringing a bell at a fixed time". Whilst the writer has not discovered the actual account of the apparatus used, it is obviously electrically operated since item six of his account states, after an initial deletion, "If a Stranger attempts to remove it from its place: it will instantly Electrify him". This may be very useful to frighten Thieves or House breakers Or to drive away Rats that have got possession of Granaries". Item one states that "It will Play an Organ, Ring bells etc. at any desired time within Ten days; and begin without fail, within a few moments of the hour of Night or day appointed; without any immediate communication with its owner for several days before its performance". Cumming obviously anticipated electric clock alarms and radios for arousing sleepers by one and a half centuries!

About the same time James Ferguson, in his treatise "An Introduction to Electricity", 2nd Edition published 1775, pages 26 - 30, described a clock and an orrery driven by electrostatic motors. In the preamble on page 25 Ferguson writes, "It must be confessed, they do not properly belong to the class of electrical experiments, because they might properly be put into motion by water, wind or weights. Yet, as it is not displeasing to see them move by electricity . . . All the wheels and trundle-heads are made of card-paper, the axles of common knitting wires, the trundle-staves of wood, the frames (in which the ends of the axles turn round) of thick brass wire, and the supporting foot of wood. The biggest wheel, which resembles the water-wheel of a common breast-mill, is five inches in diameter; and all the rest of the wheels much in the same proportion thereto. as the figures represent them. The whole work is made so free, easy and light, that a force equal to one grain weight, acting on the great wheel, will put all the rest in motion." The clock and orrery described and illustrated by Ferguson were only demonstration models, as he states on page 25, ". . . and, for the amusement of those who attend my lectures, I set these models in motion

by a stream of electric fire". As Ferguson's models were driven by static electricity and since the only source available at that time was the electrostatic machine turned by hand, it was hardly a practical proposition, nor could timekeepers be made using this principle.

Circa 1809 J. A. De Luc invented an electrical device to which he gave the name electric column. It consisted of a very large number of pairs of silver and zinc discs separated by paper, mounted within a glass tube or within three glass rods to keep them in position. Connections were taken to the outer extremities of the column and De Luc found that he could show static electricity effects by means of his column. He devised an electrically driven pendulum working from his column consisting of a gilt-coated pith ball suspended by a silk thread which oscillated between two brass balls or two bells connected to the column. The electrostatic forces of attraction and repulsion of the charges on the bells and gilt ball caused the ball to oscillate rapidly between the bells. De Luc was not interested in an electrical timekeeper but rather in trying to find the relationship between atmospheric electricity and the weather. In fact he called his pendulum and column the "Aerial Electro-scope". However another experimenter, F. Ronalds of Hammersmith, London, succeeded in 1814 in constructing a "Galvanic Clock" which made use of a modified De Luc's pendulum. About the same time workers on the Continent were also engaged towards the same end.

In the summer of 1815 an electrically operated clock was displayed in the window of the store belonging to J. G. Zeller in the Rosengasse, Munich, Germany. It was the work of Professor Ramis and was for sale at 30 Carolin or 600 Gulden, a price evidently regarded as high. The clock was driven by two electric columns containing two thousand elements enclosed in glass tubes. In spite of the high voltage of the columns they were quite safe to touch since the voltage collapsed if the connections were contacted. Professor Ramis's clock appears to have had a compound pendulum fitted with an upper extension carrying a small hammer which was alternately attracted and repelled by the potential of some four thousand volts existing between the two bells mounted on the top of the columns. As the hammer struck the bells in turn it gave

a fine ringing sound according to accounts of the time.

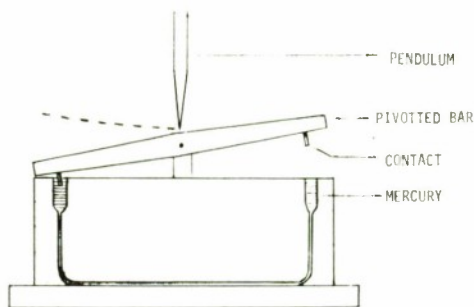
De Luc's electric columns are now known as Zamboni piles and still have applications today e.g. night vision binoculars and telescopes. Zamboni himself demonstrated a similar clock to that of Professor Ramis to the Art Society of Geneva many years later in 1832. He must have been aware of the applications of De Luc's pendulum and Professor Ramis's clock. It is also of interest to note that at the Clarendon Laboratory at Oxford there is a Zamboni pile connected to two bells between which hangs a brass ball suspended on a silk thread. The pendulum has been working continuously and ringing the bells for over 130 years!

Francis Ronalds also made use of static electricity with clocks when he constructed his telegraph in the grounds of his house in Hammersmith. Clocks were used at both transmitting and receiving positions to allow synchronisation and identification of the letters passed over the telegraph. Ronalds also made use of the pendulum of an ordinary spring-driven clock to generate the static electricity required for the operation of his telegraph by means of his ingenious "Pendulum Doubler of Electricity". The *modus operandi* of his device is too complex to describe here⁽¹⁾ This was one of the last attempts to harness static electricity with telegraphs and clocks, and whilst the description used by the writer is dated 1823, it is certain that Ronalds used his device as a modification of the revolving doubler of Nicholson or Bennet invented earlier. Thus we must leave the field of static electricity with the observation that no acceptable practical time-measuring device resulted from its employment as the motive power.

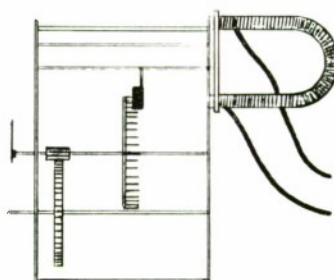
We have already seen that the magnetic effects of a current were known by 1819-20 as a result of the work of Ampere and Arago. To give some idea of the great step forward as a result of these discoveries, the prize question set in *Natural Philosophy* for 1810 reads: "Philosophers have long bestowed great value on seeking to discover the connexion that subsists between electricity and magnetism, which exhibit phaenomena so similar and so different . . . The Royal Society, thinking that this part of experimental philosophy may

be considerably improved, offers a prize to the writer, who, taking experience for his guide and support, shall give the best exposition of the material connexion between electricity and magnetism". Henceforth, with the discovery of the connection between electricity and magnetism, inventors always made use of magnetic fields created by electric currents to provide the motive power for electro-mechanical devices.

In 1826 Georg Simon Ohm, 1787-1854, propounded his now famous law connecting voltage, resistance and current in an electrical circuit. The basis of his law was contained in his paper published in 1827 in Berlin, "Die Galvanische Kette mathematisch bearbeitet". Also in 1826 a young man called Carl August Steinheil, 1801-1870, built an observatory and workshop at Perluch near Munich. He was a member of the Scientific Academy of Bavaria and became a Professor of Munich University in 1835. Steinheil erected a telegraph system about this time which made use of the principle of the two bells first used by De Luc. He had already studied time measurement and realised that just as messages could be sent by telegraph, a good clock could be arranged to report its time to any other place or to any number of other clocks by employing the agency of galvanic currents. He was granted a privilege by the King of Bavaria on the 2nd October 1839 and built a master clock fitted with contacts which he placed in the Educational Institute in Munich. The master clock sent out current pulses to simple clocks fitted with a magnet passing through a solenoid which moved an anchor escapement in reverse thus driving the hands of the clock. Daniell cells from England were used to provide the power for the current pulses. Steinheil used either a rocking contact, developed by Gauss, or a similar type invented by himself but where the contacts dipped into mercury, operated directly by the pendulum as shown in Fig. 2. His improved type of contact was supposed to take only one hundredth part of the impulse given to the pendulum in the master clock. Another method he used was the closing of contacts every half-minute by one of the wheels in the train of the master clock. The half-minute current pulses were used to drive a different type of secondary clock to that for the pendulum contact. How successful the systems used by Steinheil were in practice I have yet to discover.



SECTION THROUGH STEINHEIL'S ROCKING CONTACT



STEINHEIL'S SECONDARY CLOCK

FIG. 2. Steinheils Rocking Contact and Secondary Clock.

Alexander Bain

In the early 1800s great interest was shown in the development of electrical science and applications of electricity to telegraphic communication, particularly in England although there were very few who understood the fundamental laws governing the behaviour of electrical circuits. Even quite brilliant men of science were unable to explain phenomena which could now be elucidated by a 10 year-old schoolboy. Popular lectures and demonstrations on scientific subjects were the order of the day. A young Scotsman named Alexander Bain, a 19 year-old apprentice to Mr. Sellar, watchmaker, of Wick, attended such a lecture on light, heat, and electricity at Thurso in 1830. He may not have known it at the time but it was to be the turning point of his life. Bain was completely fascinated by the lecture and lingered afterwards listening to the remarks of the lecturer to some of the audience who remained behind. He then

returned to his father's farm at Watten 13 miles away, followed by a walk to Wick next morning of eight miles! Many years later Bain wrote in his book "A Treatise on Numerous Applications of Electrical Science to the Useful Arts", published in Edinburgh, circa 1870, "The listening lad was cold too, for it was a bitterly cold night, so he made his way home as fast as he could; but he never forgot the lecture, nor the subsequent conversation". He goes on to say: "He had but little opportunity to learn much until he came to London, early in 1837, when he began to attend lectures at the Adelaide Gallery and Polytechnic Institution; and seeing the beautiful electro-magnetic apparatus in action at these places, his attention was drawn to consider how they could be applied to useful purposes. The application of this mysterious power to the mechanism of his own business (clockwork) was naturally the first to suggest itself; and shortly afterwards he thought on various ways to applying it to telegraphs. It may be well to state here that at that time he was entirely ignorant of what was done by others in this direction. He had seen no books on the subject, nor had he acquired any information previously, except a little in relation to frictional electricity."

Bain in 1837 was working in Clerkenwell as a journeyman clockmaker. Some writers aver that he did not complete his apprenticeship and that his father paid compensation as a result which Bain later repaid. From the dates quoted previously there would appear to have been ample time for him to have served his full apprenticeship. In the spring of 1838 he spoke to a friend, a Mr. M'Dowall, regarding his intended electric clock. By July 1840 Bain had succeeded in producing rough models of both his electric clock and a printing telegraph. He was in need of a patron since he had little money of his own and spoke to Mr. Baddeley, Editor of the *Mechanics Magazine*, who introduced him to Professor Charles Wheatstone on 1st August, 1840. Two weeks later Bain took his models to Wheatstone who gave him £5 with a further promise of larger sums of money for two models of the printing telegraph. Alas for Bain he could not have gone to a worse man for he was advised by Wheatstone to postpone for the time being all proceedings in his work and not to mention it to anyone. Wheatstone exhibited a model of an electric clock, sup-

posedly of his own design, before the Royal Society of London on 26th November 1840. On the 10th October previous, John Barwise, Chronometer Maker, St. Martin's Lane, London; and Alexander Bain, Mechanist, Wigmore Street, London, had applied for the first electric clock patent in this country. The patent was not granted until the 11th June 1841 and sealed 10th July 1841 as Queen Victoria could not sign the letters patent because of one of her confinements. Contrast Bain's treatment with that of Steinheil who made application on 20th September 1839 and received his privilege on 2nd October 1839. Had Alexander Bain received encouragement or if he had had money at his disposal, his application might very well have preceded that of Steinheil's. When one reflects that Alexander Bain was a young man with no formal education or advantages of any kind, it is remarkable that he could compete with university professors on equal terms in the fields of electrical horology and telegraphy.

In January 1841, Barwise, on behalf of Bain, successfully served an injunction on Wheatstone thus preventing him from exhibiting his electric clock model in the Adelaide Gallery as his own invention. Soon afterwards, 18th March 1841, Bain's clock was displayed at the Polytechnic. This clock was an ordinary spring driven pendulum clock fitted with contacts operated by the pendulum which controlled currents to operate secondary clocks. Bain laid claim to the invention of the Electro-Magnetic Clock in the *Inventor's Advocate* of 24th March 1841. These incidents served to stir up a bitter dispute between Bain and Wheatstone which was never reconciled. At this point in time it is clear that Wheatstone did not act as a gentleman in the matter. The dispute went to the length of some unknown person acting on behalf of Wheatstone on 22nd May 1841 offering a sum of money to the proprietors of the *Inventors' Advocate* if Bain's letters were excluded from the journal. A full account of the conflict is given in the book written by John Finlaison, "An Account of Some Remarkable Applications of the Electric Fluid . . . by A. Bain; with a vindication of his claim to be the first inventor of the Electro-Magnetic Clock, etc., etc." published London, 1843.

Bain's Patent No. 8783 of 1841, Barwise being included presumably for providing the money to take out the patent; shows quite

clearly that Bain was a genius. Most of the applications of electricity to horology are anticipated by this single patent. Briefly the points covered in the patent are as follows:

1. The application of a pendulum having operating contacts to provide electric current to move other clocks.
2. The use of electromagnets to drive clocks.
3. The application of a central clock to impulse any number of other clocks.
4. The use of a central clock to wind up any number of other clocks.
5. The use of a central clock to regulate the pendulums of any number of other clocks.
6. The application of a central clock to set the hands of an ordinary clock to time.
7. The use of a central clock to set the hands of other clocks to agree with those of the central clock.
8. The application of conducting wires insulated in any of the usual ways and twisted together with hemp to form a flexible rope.
9. The use of electricity as the motive force in lieu of springs or weights.
10. The use of a balance for making and breaking contacts for transmitting electrical currents to other clocks.
11. The use of an electric current for the striking of a bell of a clock by means of an electromagnet.
12. The transmission of impulses from one clock to another in a series circuit of clocks.

At the end of his patent Bain makes it clear that he envisages uniform time distribution throughout the whole country by means of his system. One item mentioned in his patent but not claimed as an improvement is his ingenious method of providing his batteries with fresh chemicals by means of an automatic dispensing disc. This single patent justifies Alexander Bain being given the title of "Father of Electrical Horology." He continued to carry out further work in connection with electric clocks and telegraphs and took out several other patents. Patent No. 9745, issued 27th May, 1843, covers the electromagnetic pendulum driven by the interaction of a solenoid and a consequent pole permanent magnet and drawing current from the earth battery devised by Bain; consisting of a simple



FIG. 3. Bain Electric Wall Timepiece.
(Courtesy of the Science Museum)

cell formed by a zinc plate and a copper plate or a mass of carbon buried in moist soil. Such an arrangement gives a relatively constant output voltage at low currents and hence a constant driving force to the clock. Bain developed the solenoid arrangement to allow his pendulums to function on the very small power available from his earth battery, the great advantage being that his battery would deliver current for an indefinite period, whereas the commonly available battery arrangements in the middle of the last century required a great deal of attention to maintain them and they were also very expensive to instal and keep running. Since Bain did not discover the principle of the earth battery until 1842 in connection with his telegraph experiments, he must have worked very hard to develop his new type of clock in the time, see Fig. 3. Another notable achievement was Bain's time transmission from Edinburgh to Glasgow in 1846. In the same year, after a legal wrangle, he was paid £7,500 by the Electric Telegraph Company who took over his patents, the company undertook to make

the clocks, provide the working capital, and Bain was to receive half the profits. An old colleague of Bain, Professor Wheatstone, was associated with the company and resigned as a result of the decision. Bain's association did not last long however and he went into independent production of clocks. The events of Bain's later life are not at all well known and his last years were not good. He was given a Civil List Pension by Mr. Gladstone amounting to £80 per annum which he drew for some four years, and died after a short period at the Broomhill Home for Incurables, Kirkintilloch, in 1877. Alexander Bain was before his time and can now be seen to have been an inventive genius with a prophetic vision.

Other Inventions

Another early inventor making use of electricity as a motive force for clocks was Dr. Matthäus Hipp of Neuchâtel. He devised the now-famous Hipp toggle contact system for maintaining a pendulum in motion. Although the first clock using this principle was not made until 1842, he stated that he first thought of the idea in 1834. The arrangement consists of a freely pivoted steel trailer mounted on the pendulum which moves over a notched steel block fixed to a spring blade carrying an electrical contact, see Fig. 4. When the amplitude of the pendulum swing falls below a fixed amount the trailer falls into the notch and as the pendulum swing reverses the trailer is pressed down and the electrical contact on the spring blade touches a fixed contact. Current then passes through an electromagnet mounted beneath the pendulum and attracts an armature fixed to the pendulum. Just before the vertical position the trailer is released from the notched block, the current ceases and the magnetic field from the electromagnet collapses, thus allowing the pendulum to pass freely after receiving a powerful impulse. Not until the amplitude of the pendulum swing falls again to the critical level does the preceding action repeat itself. Hipp's system is most ingenious and reliable and continues in use today for those clocks not requiring the highest performance and it is widely used in "waiting train" systems where the system is used to provide a source of power only to a clock train, the actual timekeeping being provided by an accurate master clock delivering synchronis-

ing signals. The Hipp toggle has been reinvented many times by electrical horologists and is a great favourite with amateur horologists because of the ease of manufacture. Even crudely made clocks built on this principle are capable of a good standard of timekeeping, however if the notched block of the toggle is not correctly designed the pendulum will occasionally stop through the steel trailer fouling the block.

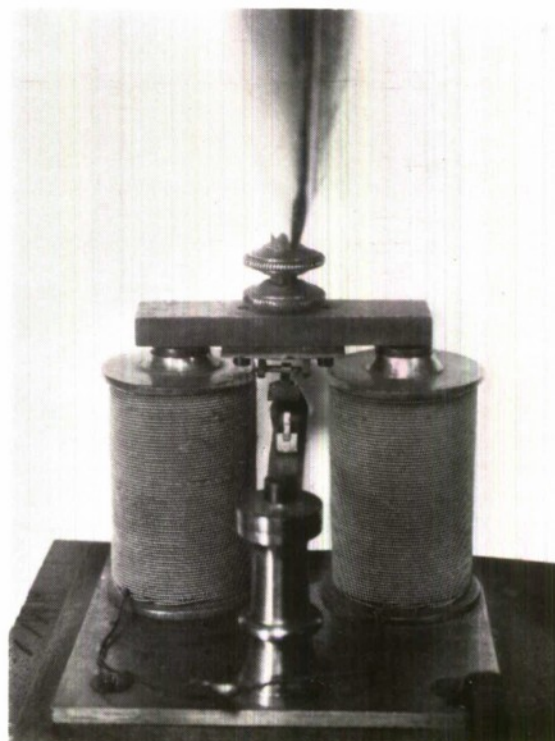


FIG. 4. Hipp Toggle Contact System.
(Courtesy of the Science Museum)

A well known variation of the Hipp toggle was due to Lemoine and consists of a mica vane affixed to the trailer. As the mica vane was usually of a butterfly shape clocks employing Lemoine's variation are called "Electric Butterfly" clocks. There is little advantage gained over the original arrangement which has the basic weakness that the upper limit of pendulum swing is determined by the battery voltage and condition, hence the rate varies with the battery output, although it is precise enough for ordinary clocks. Naturally the pendulum must have temperature compensation to achieve a good performance.

One of the points made by Bain in his early patents was that the amount of impulse given to the pendulum could be made independent of the battery voltage by causing the force from the electromagnetic device to store energy in a spring or weight and then using the constant amount of stored potential energy to impulse the pendulum. Providing the battery voltage was greater than the minimum to achieve operation, no variation of battery voltage could affect the going of the clock. Charles Shepherd in 1849 devised an arrangement whereby an electromagnet raised a weighted arm which was released by the pendulum to give a constant impulse. His system is described in Patent No. 12567 of 1849 and it was selected to be used at the Great Exhibition of 1851. Due to trouble with the contacts it failed ignominiously and the time at the Exhibition was given by a large clock made by Dent to the design of Lord Grimthorpe. Thus Lord Grimthorpe was able to say in his book "Clocks, Watches and Bells", "These clocks never answered in any practical sense; nor would anything but the strongest evidence, independent of the inventor, convince me that any independent pendulum directly maintained by electricity can succeed in keeping good time for any considerable period". It is to be feared that the precarious nature of the contacts used in electric clocks at this period and the condemnation of Lord Grimthorpe served to bring electrical horology into disrepute. The manufacturers of mechanical clocks in England were facing too much competition from abroad to welcome electricians into the fold and were only too pleased to witness the failure of electric clocks.

One of the improvements Shepherd incorporated in his clock was the provision of two contacts and two separate batteries to drive his secondary clocks. By doing so he ensured that the secondary clocks were impelled by reversal of current and not dependent on the indifferent contacts available. He, of course, like many others before him, used the pendulum to operate the contacts directly; hence the contact pressure available was light and uncertain in action. However one of Shepherd's original secondary clocks in a slightly modified form still continues to function at the main entrance to the Royal Observatory at Greenwich. Shepherd's system was tried at Greenwich in 1850 as a result

of Sir George Airy's interest, he then being the Astronomer Royal.

Froment, in France, devised a simpler and improved version of Shepherd's clock in 1854 and it was invented completely independently by Sir David Gill on almost similar lines. A great deal of money was expended by Gill upon his clock but he never achieved success with it during protracted tests at the Cape Observatory. The trouble, as usual, was the uncertainty of the contacts; but I believe that Gill's clock has been tried out since with perfectly satisfactory results. His clock could never have met the requirements laid down by the British Association in 1879 when he was appointed to form a committee to secure improvements in astronomical regulators. Yet he laid down the complete specification for such a clock, his reason for failure resting with his contact system.

The difficulties of devising consistent contact systems were early recognised and the causes of failure were known. Gold and silver contacts were used to avoid failure but it only needed a speck of dust to render them inoperative with the light pressures available from a pendulum. Professor Wheatstone must be given the credit for finding a solution to the problem. Using a very large weight driven mechanical clock with a pendulum carrying a coil passing over two large permanent magnets, he induced a current within the coil which reversed at each swing. The current thus induced was used to drive secondary clocks without the need for contacts of any kind. He outlined his proposal to use the magneto-electric current discovered by Michael Faraday in a paper read to the Royal Society in 1840. Unfortunately for Wheatstone he had got rid of his troublesome contacts at the expense of devising one of the world's worst timekeepers in the whole of the history of horology, see Fig. 5. He might just as well have put his pendulum in a bucket of water as use it to act as a miniature electric generator. His system was given a brief trial at London University and in the Royal Institution about 1873, the scheme failed and was abandoned on the death of the inventor in 1875. Wheatstone's original master clock may be seen in the Science Museum at South Kensington. Had Wheatstone allowed his pendulum to perform the timekeeping unencumbered and used the clock train to let off a separate train to actuate the generating mechanism, he would have succeeded. Martin

of time indicators in the world, the common synchronous electric clock.

Electrical Time Synchronisation

One might be tempted to enquire what motive lay behind this search for electrically driven clocks and electrical time systems. The answer is that no one has yet succeeded in keeping a large group of mechanical clocks in absolute step. E. J. Wood in his book "*Curiosities of Clocks and Watches*" tells the story of the Emperor Charles V of Austria who abdicated about the middle of the 16th century and retired to a monastery with his watches and clocks. He endeavoured to make his clocks "accord" but all in vain, upon which he is supposed to have said, "What an egregious fool must I have been to have squandered so much blood and treasure in an absurd attempt to make all men think alike, when I cannot even make clocks keep time together". The rapid growth of the railways in Britain during the middle of the last century supplied the incentive to find means of ensuring clocks did in fact tell the same time. A pioneer of synchronising clocks was the stationmaster at Chester in 1857, R. L. Jones. He adopted Alexander Bain's system of sympathetic pendulums driven by a master clock providing the current pulses to keep the pendulums in step. A fair degree of success was claimed although it was not generally adopted because a temporary loss of current pulses, whilst not stopping the secondary clocks, could mean the wrong correction being applied when the pulses were restored. Also the secondary clocks had to be rewound by hand and unless fitted with maintaining power, would require a correction by hand after each winding. Essentially there was little advance on Bain's work and the system died a natural death.

Attention was directed from electric clocks as such to the perfection of electrical synchronising systems which would allow the correction of ordinary clocks at suitable intervals. One of the first services for the distribution of time, although not electrical, was due to John Pond, the Astronomer Royal 1811-35, who put forward a scheme for the sending forth of Greenwich time from the Observatory. He appointed his adopted son John Henry in June 1836 to carry a chronometer showing Greenwich time to the principal watch and clockmakers in London. On one day of each week the watch was re-certified as to its

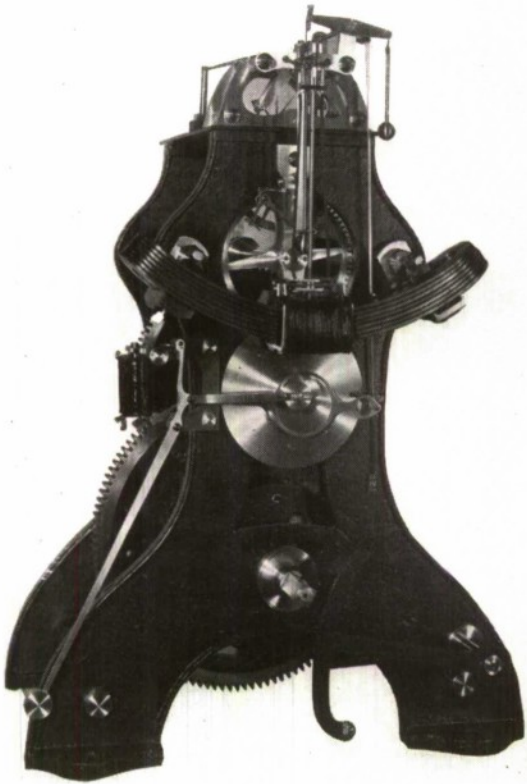


FIG. 5. Wheatstone master clock of about 1870.
(Courtesy of the Science Museum)

Fischer, of Zurich, in 1900 managed to produce Wheatstone's system in a suitable form when he produced the Magneta clock system. His master clock was a very high quality mechanical movement with a dead beat escapement and compensated pendulum functioning in the normal way. Each minute the clock releases a powerful weight driven train which rocks an armature of a generator within the poles of a powerful permanent magnet and the current pulses are used to drive secondary clocks, up to 60 or more in number. Exceedingly robust movements and very heavy weights are used so that Magneta system is hardly recognisable as an electric clock. The outstanding advantage is, of course, the absence of contacts. Another anticipation of Wheatstone's was the use of continuously rotating discs in his secondary clocks driven by his pendulum generated circuits, *i.e.* synchronous electric motors almost 80 years before they were introduced by H. E. Warren of America, and which now form the largest single group

accuracy. Previously clockmakers were compelled to send their own men to Greenwich or to make transit observations of a star. Sir George Airy, Astronomer Royal 1835-81, in his annual report of 1849 stated, "The general utility of the Observatory will be increased by the dissemination throughout the kingdom of accurate time signals by an original clock at Greenwich". E. B. Dennison (Lord Grimthorpe) wrote in a letter dated 5th February, 1862, "The Westminster Clock is at last going to be made to report its time rate to Greenwich, for which I made preparation three years ago (1858 or 1859). The rate has seldom varied more than two seconds a week since last May, and *I do not trust the carrying of watches to report on such small rates*".

By 1864 the Magnetic Telegraph Company initiated the control of public clocks by electric time signals from the Glasgow Observatory, followed by a similar service in 1865 from the Liverpool Observatory. Greenwich Observatory was reported by Sir George Airy to be sending synchronising signals *via* a telegraph line to the Lombard Street Post Office Clock in 1869. The service from Greenwich to the Post Office expanded rapidly in addition to that given by private telegraphic companies, these however were taken over by the Post Office in 1870. The famous firm of Barraud and Lund in 1877 instituted a time signal service by electric currents sent out each hour from their own regulator which was corrected by signals from Greenwich. A limited area in London was served and the service eventually became the Standard Time Company. Lund also took out a patent in 1876 for the forcible correction of the minute hands of clocks, which method was adopted by some firms and railways in 1892. F. J. Ritchie, in a paper read before the Royal Scottish Society of Arts in 1878, reviewed the electrical time services and stated that the annual cost was too great for most watchmakers. He mentioned his system of sympathetic pendulums, *i.e.* electrically driven pendulums driving secondary clocks and controlled by a master clock, similar to R. L. Jones's system except that the secondary clocks did not require winding; and of course anticipated by Bain 40 years earlier. After dealing with Bain's work and his systems for hourly correction of clocks, and paying tribute to the ideas of Bain, Ritchie goes on to describe his system for the hourly correction of clocks by electrical signals from a master clock which had

taken him almost 20 years to develop. His scheme utilised ordinary weight or spring driven movements which were adjusted to have a gaining rate of two to five minutes a day. The minute hand of such clocks would arrive at the hour a few seconds early. An electric current from the master clocks sent out 15 seconds before the hour stopped the escape wheel of the clock until the exact second of the hour, the pendulum swinging idly meanwhile; at the cessation of the current on the exact hour, the clock recommenced its going corrected to the nearest second. Ritchie's system allowed only the correction of clocks with a gaining rate but it was a relatively cheap method and reliable in action, whilst the circuits could be checked at any time except during the synchronisation period. The alternative schemes involving forcible correction of the hour hand, were not really suitable for large turret clocks with massive hands acted on by the wind, etc. A successful system which has withstood the test of time was evolved by the Self-Winding Clock Company of America; in this the secondary clocks are re-wound electrically and also re-set at the hour by signals from a master clock, see Fig. 6. The system is still in use on some underground railways of London. From these early attempts grew the present time distribution services including the Post Office Speaking Clock, or TIM, and the radio time signals from Greenwich.

Examination of horological books published during the last decades of the 19th century will reveal a fine disregard for electric clocks, evidence of the disrepute into which they had fallen as a result of their indifferent performance in practice. J. W. Benson in his "Time and Time Tellers", published in 1875, writes "Electric Clocks are now seldom made". Similarly J. F. Kendall in "A History of Watches and other timekeepers", published in 1892, says of electric clocks, "... but however well they appeared to perform at first, none of them have secured a lasting place". He quotes the experience of C. V. Walker, who after many years' trial of a clock at London Bridge controlled by signals from Greenwich, pronounced the system to be impracticable. Only three years later however the first step was taken which was to lead to the absolute and undisputed supremacy of the electric clock for timekeeping purposes. The collaboration of F. Hope-Jones with G. B. Bowell led to the invention of the so-called

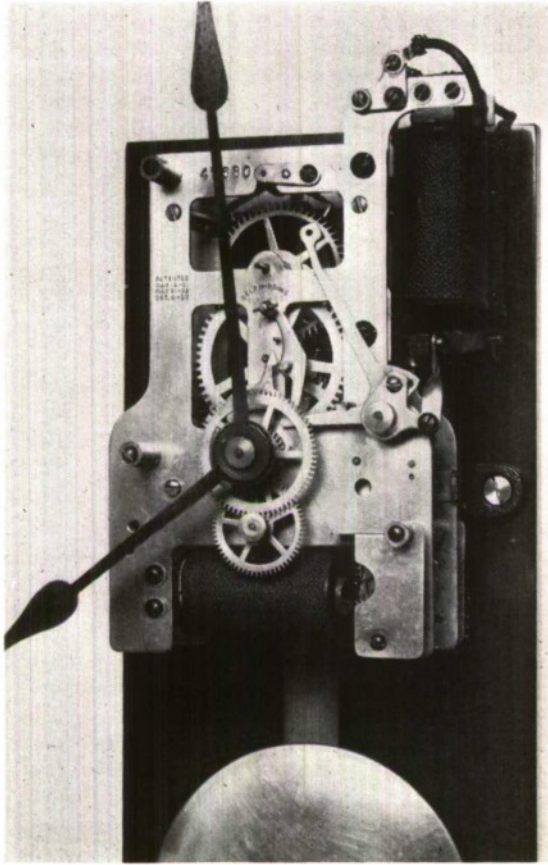


FIG. 6. Hourly re-set, electrically re-wound clock.

(Courtesy of the Science Museum)

Synchronome switch described in a lecture before the British Horological Institute in 1895. Essentially it was an electrically re-set gravity arm driving a pendulum through an anchor escapement. For his first model Hope-Jones used a skeleton clock which he reputedly played with in his nursery days, see Fig. 7. Though somewhat crude it served to show how absolutely reliable half-minute current pulses could be derived for driving secondary clocks. What Hope-Jones and Bowell achieved where others had hitherto failed was the principle of allowing the pendulum to measure the time without having to drive any electrical contacts directly. Their pendulum dictated the time when the contacts would operate but did not take part in the consequent operation. A much more powerful force to close the contacts was ensured by having a massive gravity arm and the force to raise the arm was applied through the electrical contacts.

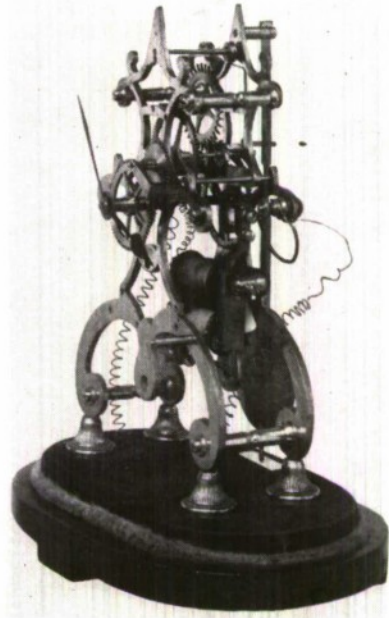


FIG. 7. Self-winding clock with Synchronome Remontoire 1895.

(Courtesy of the Science Museum)

By causing the armature to be arrested by a stop, the inertia of the gravity arm caused the contacts to open decisively and rapidly. Hope-Jones was so proud of his Synchronome switch that he propounded it as a basic law for electric clocks which, of course, it is not. Nevertheless Hope-Jones's electric remontoire of 1895 was quite suitable, when fitted to a Graham dead-beat escapement with a compensated pendulum, to provide an accurate and, what is more important, a completely reliable electric time signal system giving half-minute advancement of secondary clocks.

The next real step was independently taken by several workers, notably Campiche, Lowne, and W. E. Palmer. It consisted of a count wheel driven by the pendulum and arranged to give an impulse to the pendulum at half-minute intervals. Palmer patented his arrangement in 1902 and its only real fault was that the impulse to the pendulum was not in accordance with the requirements for good timekeeping. Hope-Jones saw in the count wheel arrangement the final piece for his electric clock jigsaw puzzle. He married the count wheel to his Synchronome remontoire,

as is described in his Patent No. 60666 of 1905. He tried to avoid the incorrect impulsing of the pendulum by Palmer's arrangement and used a long flexible spring similar to that employed by Campiche. Not until three more years had passed did Hope-Jones place the impulse plane directly on the pendulum and allow the gravity arm to impulse it *via* a small roller. His clock was now able to outperform all but the most accurate astronomical regulators and Hope-Jones began to put his not inconsiderable energies into making it a commercial success and branching out into other fields. To Hope-Jones must go the credit for raising the electric clock from being an object of derision to a universal recognition of its outstanding possibilities.

Little has been said about workers on the Continent and America. Basically they ignored developments in England and lagged behind as a result. Some interesting clocks resulted, for example Professor Charles Fery's clock of 1908. He used a horseshoe magnet attached to a pendulum and used one limb for impulsing and the other to actuate contacts *via* a subsidiary pendulum. By this means he hoped to have a pendulum completely free from contact with any solid body. Since the work to operate the contacts comes from the pendulum *via* the magnetic field, the arrangement has no real advantage. Fery's use of high resistance solenoids was however a step in the right direction.

Another attempt to utilise Bain's principles was made by Bentley of Leicester. Utilising a pendulum carrying a solenoid and using an earth battery, he made improvements to the contact system by using a roller and fitting an amplitude controller. It was intended as an electric clock and not used for impulsing secondary clocks. Considering the late date of its development, about 1910, it is difficult to see why Bentley adopted the system. A similar system was adopted by Favre-Bulle in his well known "Bulle" clock about 1921, *i.e.* a solenoid of many turns carried on the pendulum and passing over a consequent pole magnet, see Fig. 8. Silver was used for the contacts and the clock train driven *via* the physical movement of the contact system. Many thousands of these clocks were made and are still giving reasonable service today.

Bain in his earliest patent mentions the use of a balance but it was not until the early 1900s that they began to appear in any num-

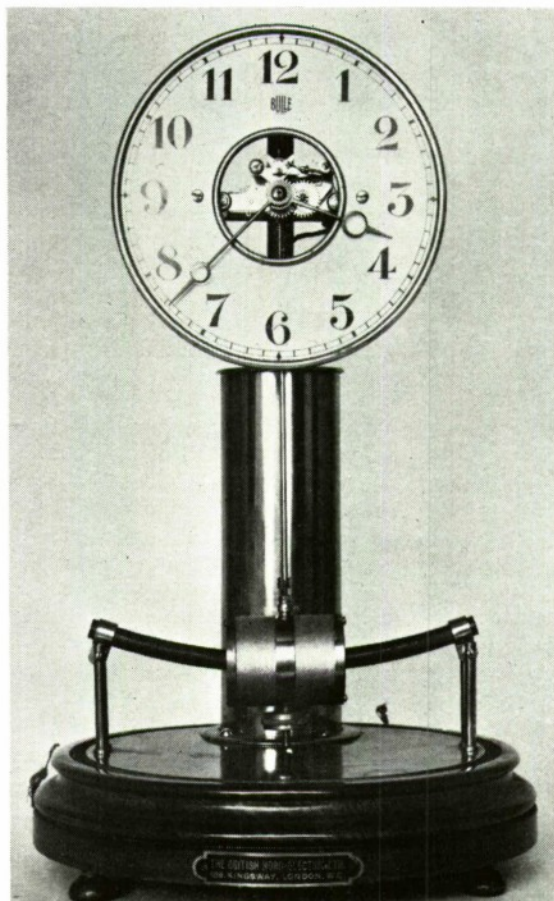


FIG. 8. "Bulle" electric clock.
(Courtesy of the Science Museum)

ber. Some examples are the well known Eureka clock, Murday's Electrically Driven Balance-Wheel Clock; Reid's Electric clock where he used a torsion pendulum, almost an electrically driven 400-day clock; and electric clocks developed for use at sea, *i.e.* marine timekeepers for distributing time to secondary clocks throughout a ship. The early directly operated electric clocks using balances combined all the disadvantages of the early electric clocks together with the normal lower standard of timekeeping when using a balance. They had the doubtful quality of portability as a bonus.

The Free Pendulum

Hope-Jones, in association with William Hamilton Shortt, brought about the final development of the electrically driven pen-

dulum clock with the so-called Free Pendulum first installed in the Edinburgh Observatory at the end of 1921. Basically it consisted of two Synchronome pendulum clocks, one pendulum serving as a slave to perform all the work whilst the other swung freely except for the maintaining impulse at half-minute intervals, see Figs. 9 and 10. The actual free pendulum was built to a much higher quality of workmanship and design than the normal Synchronome clock and the impulsing gravity arm was so light that an auxiliary electrically re-set gravity arm was used to re-set it mechanically, the whole mechanism being enclosed in a cylinder from which the air had been exhausted. The two pendulums were linked electrically as follows. A slight losing rate was given to the slave pendulum and at the end of a nominal half-minute period its gravity arm was released and its contacts closed allowing the current from a battery to operate an electromagnet which released the gravity arm of the free pendulum. A jewelled pin on

the gravity arm then fell on to a small impulse wheel fitted to the pendulum. Should the arm fall too soon the pin rode on top of the wheel until the correct moment for impulse as determined by the free pendulum. After impulse the gravity arm released the electric gravity arm and actuated the secondary clocks *via* its contacts and re-set both gravity arms simultaneously. The current in the secondary clock circuit also actuated a hit and miss synchroniser evolved by Shortt and accelerated the slave clock pendulum as necessary. Shortt's original clock at Edinburgh was not quite as described for the impulse was given below the pendulum bob. Its performance for the first year of operation indicated that a great step forward had resulted and it was not long before astronomical observatories all over the world renounced their mechanical clocks and made use of the Synchronome Shortt Free Pendulum Clock. About 100 of these clocks were made, all by the same man, and as he has now retired at the age of over

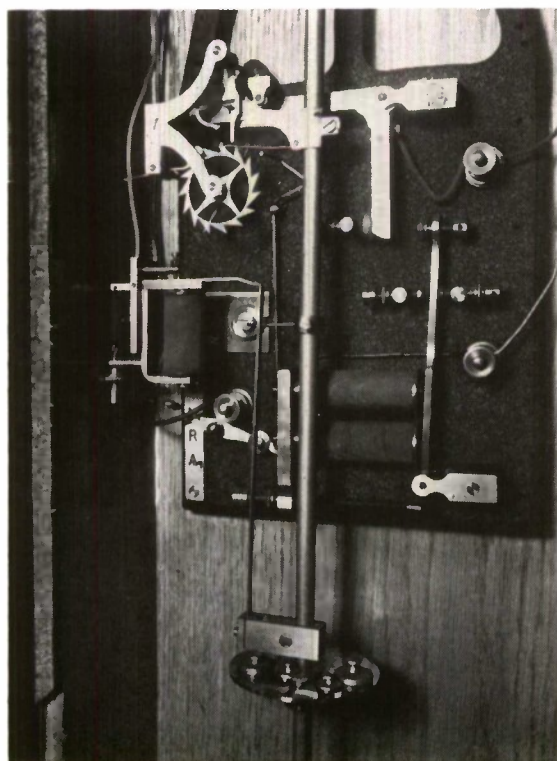


FIG. 9. Slave Pendulum fitted with Shortt's Synchroniser
(Courtesy of the Science Museum)

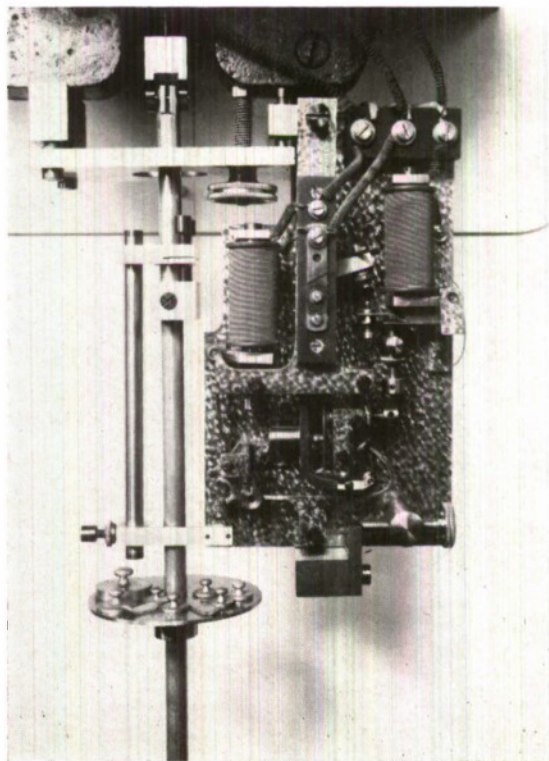


FIG. 10. Impulse Mechanism of Shortt Free Pendulum
(Courtesy of the Science Museum)

70 years, it is hardly likely that any more will be manufactured. They are now quite obsolete for astronomical purposes for much more accurate time measurement instruments are available today.

Present Developments

Of necessity many interesting developments have been omitted and for these the reader is advised to read the material listed later. Interest in electrical horology as an historical subject is growing and there are workers in associated fields examining the origins of the various devices used, for example Dr. Cross of the Clarendon Laboratory is currently investigating the electrostatically maintained pendulum.

The present position of electrical time-keeping is that the pioneer work of H. E. Warren and W. A. Marrison in the United States which led to the invention of the synchronous clock and crystal clock respectively has had far-reaching consequences for us all. There are more electric clocks in use today than Alexander Bain ever envisaged and his dream of universal time distribution has come about through the use of synchronous clocks driven from the public electricity supply system, these clocks forming at present the largest single group of all those in use. However the development of electric clocks proceeds and the trend in America is towards the use of battery driven quartz crystal clocks and watches. It will not be very long before a cheap domestic clock of this type will outperform the very best of the mechanical clocks ever used for navigational purposes and may also bring about the demise of the synchronous clock with its attendant disadvantages.

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A TIME AND LABOUR SAVING DEVELOPMENT IN THE PRODUCTION OF CONTOUR DRAWINGS

B. H. Joyce, R.N.S.S.

Admiralty Engineering Laboratory

Abstract

A method of using a simple pre-calculated "ready reckoner" and a uniform fixed grid system, that has resulted in savings of up to 75% in operator time, is presented for use in the production of contour diagrams.

Introduction

The development of close hull hydrophone survey techniques using a hydrophone necklace has made available a vast amount of data. This data is best presented as sound pressure level contour diagrams of 1/3rd octave data on a plan of the relevant hull.

In a typical survey 30 diagrams are produced, one for each of the mid position frequencies of the 1/3rd octave bands analysed. There are 210 recordings for each sheet making a total of 6,300 readings per survey.

Traditional methods of producing contour diagrams involve either an enormous quantity of arithmetic, involving a large number of staff or a computer, or alternatively the drawing and cross correlation of longitudinal and transverse sections. As there are 37 sections for each survey sheet this method entails the production of 1,110 sections per survey with attendant demands on staff time and availability. It is therefore readily apparent that the reduction or total elimination of either the arithmetic or section drawing processes involved would considerably reduce the man hours required to produce a contour survey.

Method

It was realized that the provision of a "ready reckoner" in an easily consulted form would save a significant amount of time spent in the tedious repetition of proportional arithmetic sums or the interminable drawing of sections. In the absence of a "ready reckoner" of suitable format one was devised in an hour with a desk calculator. This is shown in Table 1. This table presents the results of all the proportional arithmetic sums needed to plot the contour lines on the five division grid system employed and is suitable for use for differences in levels of up to 20 units between adjacent recording points. The table may be recalculated to accommodate any number of divisions used to form a uniform grid system and may also be extended to cover any expected range of difference in levels.

Fig. 1 illustrates an undeveloped scale representation of a typical hull under survey showing the frame and hydrophone positions with the sound pressure level readings entered in their relevant positions. A prime consideration in establishing this format was the need that all the data readings entered and all the divisions on the vertical and horizontal axes

TABLE 1.

Difference in Levels

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	5	2.5	1.7	1.3	1.0	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
2		5	3.3	2.5	2.0	1.7	1.4	1.3	1.1	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5
3			5	3.8	3.0	2.5	2.1	1.9	1.7	1.5	1.4	1.2	1.2	1.1	1.0	0.9	0.9	0.8	0.8	0.8
4				5	4.0	3.3	2.9	2.5	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0
5					5	4.2	3.6	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.3
6						5	4.3	3.8	3.3	3.0	2.7	2.5	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5
7							5	4.4	3.9	3.5	3.2	2.9	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.8
8								5	4.4	4.0	3.7	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0
9									5	4.5	4.1	3.7	3.5	3.2	3.0	2.8	2.6	2.5	2.4	2.3
10										5	4.5	4.2	3.9	3.6	3.3	3.1	2.9	2.8	2.6	2.5
11											5	4.6	4.2	3.9	3.7	3.4	3.2	3.1	2.9	2.8
12												5	4.6	4.3	4.0	3.8	3.5	3.3	3.2	3.0
13													5	4.6	4.3	4.1	3.8	3.6	3.4	3.3
14														5	4.7	4.4	4.1	3.9	3.7	3.5
15															5	4.7	4.4	4.2	3.9	3.8
16																5	4.7	4.4	4.2	4.0
17																	5	4.7	4.5	4.3
18																		5	4.7	4.5
19																			5	4.8
20																				5

should be clearly legible and suitable for reproduction without further processing. It is relevant to note that both the vertical and horizontal axes are divided up into five divisions between recording points thus allowing the use of the table shown in Table 1 to establish where contour lines cut these axes.

The contour lines shown in Fig. 1 are produced by joining up the intersection points of the appropriate contour lines with the grid lines representing the frame and hydrophone

positions. These intersection points are established by finding the difference in level between adjacent recording points, entering the appropriate column under the difference in levels heading in Table 1 and moving down the column the required number of units to adjust the starting level to the required contour level. The number of grid divisions for the number of units required can then be read out of the body of the table and plotted on the relevant grid line.

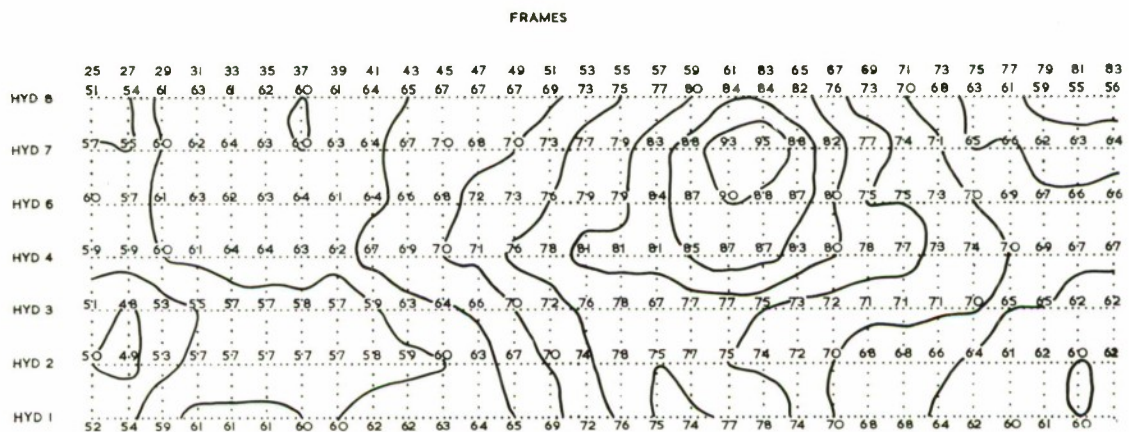


FIG. 1. Undeveloped scale representation of typical hull.

Example To plot the 85 contour intersection point between hydrophones 7 and 8 at Frame 59 in Fig. 1.

Enter the table at 8 under difference
in levels $(88 - 80 = 8)$

Move down the column 3 units
 $(88 - 3 = 85)$

The number of grid divisions, 1.9, is read out of the Table.

Plot the intersection point on the grid line 1.9 divisions from 88 (hydrophone 7) towards 80 (hydrophone 8).

The equivalent arithmetic sum to the above procedure would be:—

$$\frac{5}{138 - 130} \times 3 = 1.87$$

In practice the adoption of this method of producing contour drawings has proved reasonably simple and trouble free. Inexperienced operators have halved the time taken to produce a complete set of close hull survey contour drawings using the section drawing method while experienced operators have achieved time savings of 75%.



BACTERIOLOGICAL EVALUATION OF METHODS FOR DISTILLATE STERILISATION

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Abstract

There is a possibility when distilling in potentially polluted waters, of infection entering the distillate through a leak in a cold condenser. The made water can be contaminated in this way without raising the salinity sufficiently to be detected. To combat this hazard, which in practice is remote, methods of post process sterilisation have been investigated. The present practice of sterilising domestic water in ships with calcium hypochlorite (bleaching powder), is a safe method when properly used, but it is technically difficult to achieve the optimum concentration of available chlorine. Techniques for water sterilisation incorporated in the Electrokatadyn Unit, A Berkefeld Sterasyl candle, and the Patterson Candy Clorocel steriliser were investigated, and were considerably easier to use effectively.

Introduction Recent trials of the Caird and Rayner 4-stage Flash plant carried out at the Admiralty Distilling Experimental Station, Portland, in conjunction with Director General (Ships) showed that a sterile effluent water was regularly obtained when the plant was operating normally (Drake, Elgie and Walters 1971). Deliberate infection of the lower temperature stage with micro-organisms to simulate a leak in the cooling coils, resulted in their being recoverable from the discharge outlet, indicating that high vacuum alone is not sufficient to effect their destruction.

Consideration of the results of this trial led to the conclusion that for maximum safety, especially when distilling in heavily polluted waters, a post process steriliser should be included in the system which would be simple, reliable and require little maintenance. Three currently available systems were considered attractive in these respects and their performance under laboratory conditions is described.

Sterilisation with Ionic Silver **Electrokatadyn Steriliser Unit—Type 4 Marine**

Sterilisation by this equipment is effected by the liberation of silver ions into the water. The unit is installed in a bypass line from the feed water which flows over a special electrode system. This is under a direct current tension of a few volts, and silver ions are added to the water electrolytically in precisely regulated amounts.

An electrode lasts for about 500 hours operation, and may need to be cleaned every 50 hours.

The water to be treated should be clear and free of suspended matter, as this impedes the action of the silver ions and may render them inactive.

Attention was first drawn to the bactericidal properties of silver ions by Krause in 1929, and he introduced an activated form of silver to which he gave the name "Katadyn." He claimed that the metal in this form was highly toxic to bacteria, and suggested its use as a practical means of sterilising water supplies.

Other workers using distilled water artificially contaminated with bacteria, substantially confirmed Krause's claims.

In addition to coliform bacteria, the ordinary water bacteria were readily destroyed. Spore formers were more resistant but were reduced in number. Pathogenic bacteria such as typhoid, food poisoning and dysentery bacteria, proved as susceptible to destruction by silver as *E.coli*, and development of algae was also prevented.

Investigations

The unit was regulated to deliver 0.003-0.005 p.p.m. of silver to distilled water supplied from a Distilling Plant, at a flow rate of 370 gallons per hour, the ionic silver being checked chemically by a sensitive kit supplied by the manufacturers.

In the laboratory, the treated water was heavily infected with intestinal bacteria, (*Escherichia coli*) cultured from one of the Staff, at a dose of 50,000 per ml. At half hourly intervals over a period of four hours, samples of the water were withdrawn and suitably diluted to facilitate the enumeration of colonies of bacteria after culture on plates of selective media. The effective contact time for complete destruction of the infecting organisms, at the silver concentration used, was three and a half hours. (Table 1).

This investigation was repeated using distilled water containing double the concentration of silver ions (0.006-0.01 p.p.m.). As demonstrated in Table 2, the effective contact time under these conditions, was three hours.

Using a lower concentration of silver (0.0025 p.p.m.) it was found that the contact time was prolonged to four hours for complete sterilisation.



TABLE 1.

Infected water containing 0.003 - 0.005 Ag^+ p.p.m.

Contact Time	Count Organisms/ml
0 mins.	50,000
1/2 hr.	14,880
1 hr.	12,000
1 1/2 hr.	3,560
2 hr.	1,420
2 1/2 hr.	380
3 hr.	33
3 1/2 hr.	Nil
4 hr.	Nil

TABLE 2.

Infected water containing 0.006 - 0.01 Ag^+ p.p.m.

Contact Time	Count Organisms/ml
0 mins.	48,500
1/2 hr.	11,750
1 hr.	810
1 1/2 hr.	98
2 hr.	8
2 1/2 hr.	3
3 hr.	Nil
3 1/2 hr.	Nil
4 hr.	Nil

Berkefeld Sterasyl Candle Filter (Household Filter Pattern F)

The filtering medium takes the form of a hollow candle made of Kieselguhr, a siliceous earth, which is an excellent filtering medium. The candle is closed at one end and the other end is fitted into a metal or porcelain mount.

The water passes from the outside to inside and then out through the aperture in the mount, leaving all impurities on the external surface.

It is known that the Kieselguhr candle type of filter gives a high degree of bacteriological purification. Such filter candles operate through having a low porosity and a complex structure which effectively excludes bacteria and other foreign substances from the filtrate. When such candles have not been impregnated with silver however, it is necessary to boil them at intervals to ensure the bacteriological purity of the filtrate, since pollution can occur by the development of bacteria in the intercepted substances retained by the candle. There is a great advantage if the properties of silver are used in conjunction with a Kieselguhr candle, and the Sterasyl is impregnated throughout the structure.

It is claimed that the sterilising property of the candle remains undiminished during its physical life, the emission of silver ions being so controlled that neither excess nor deficiency would be found over lengthy periods. Residual silver in treated water is of the order of 0.01 part per million, similar to that obtainable from the Katadyn apparatus, and although the silver is released in a different manner, the sterilising effect is precisely the same.

Only occasional cleaning with a soft brush and clean water is necessary to remove any dirt or impurities collected on the exterior of the candle, and the sterilising action should remain effective throughout its life of several years.

Investigations

In the laboratory, a large capacity holding tank was filled with tap water, sited at high level, and connected to the filter. The tank water was first infected with *E. coli*, and the filtrate from the candle cultured at intervals throughout 45 minutes. The experiment was repeated using *Staphylococcus aureus* as the infecting organism. In both cases no organisms were recovered from the filtrate.

The bactericidal activity of the silver ions in the filtrate obtained from uninfected mains water was then investigated. The first 100 ml sample was infected with *E. coli* at a concentration of 460,000 per ml, and another sample with *Staphylococcus aureus* at 650,000/ml. The infected samples were allowed to stand at room temperature and 1.0 ml amounts removed for

culture at hourly intervals, to assess the rate of destruction of the organisms. No viable bacteria or cocci were present after three hours contact in the silver impregnated filtrates.

In 1897 Sims Woodhead was responsible for the first practical application of chlorination to public water supplies in England when, as an emergency measure following an outbreak of typhoid fever at Maidstone, the public water supply was treated with bleaching powder.

The efficiency of chlorination in preventing the known water-borne bacterial diseases is well known, but it is essential to obey certain rules in its application otherwise failures occur. The haphazard, uncontrolled addition of chlorine to water samples is dangerous in that it creates a false sense of security, and it may also be responsible for many of the complaints and criticisms of the process. It is necessary that the water to be treated should be clear and free from organic contamination, that the chlorine should be properly applied in respect of method and dosage, that the contact time should be adequate, and the control conscientious and efficient (Thresh, Beale and Suckling).

The required dosage for any water, is that amount of chlorine which, after satisfying the immediate demands of any impurities in the water, leaves a sufficient residuum to destroy the bacteria. Dosage and contact time are closely related, there being a broad inverse correlation between the residual chlorine and the time period in which sterilisation is achieved. Prescott, Winslow and McCrady state that 100% kill of *E. coli* and typhoid bacilli was effected by 0.1 to 0.29 p.p.m. of chlorine within one minute at pH 7.0, but the time was prolonged at the more alkaline pH 8 to 10.

Patterson Candy International Clorocel Steriliser Type SM/T

This is a small compact apparatus incorporating an electrolytic cell, fed with a solution of sodium chloride, which liberates electrolytic sodium hypochlorite at a regulated dose into the distillate stream, to provide available chlorine for sterilisation.

The diagrammatic illustration Fig. 1 shows how the unit is constructed.

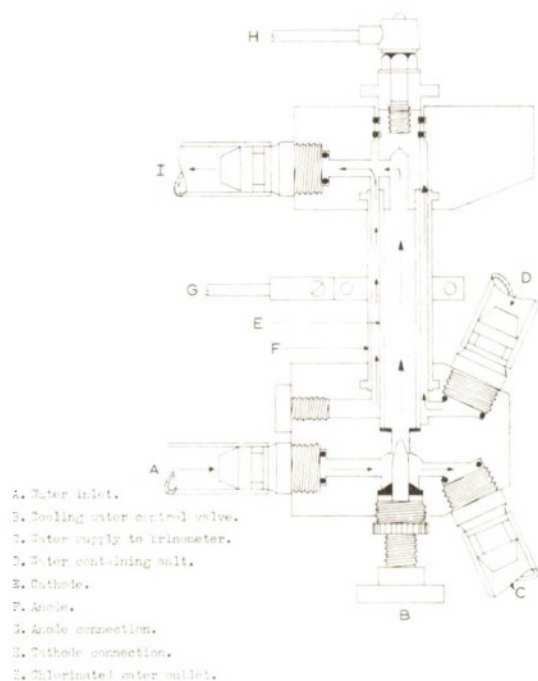


FIG. 1. Schematic of Steriliser.

Current is applied to the electrodes which are closely spaced, and a thin film of salt solution is allowed to pass upwards between the electrode faces, and emerge from the outlet as electrolytic sodium hypochlorite. So simple is the control, that the sterilising dose may be accurately fixed and adjusted when necessary, by setting an ammeter needle at the required spot by means of the dose control on the panel of a Rectifier and Control Unit which forms part of a complete Clorocel equipment.

The amount of electricity needed is relatively small, the actual voltage applied to each pair of electrodes normally ranging from 4 to 10 volts, and the current from 0.5 to 500 amps according to the size of the plant.

Investigations

Preliminary tests were carried out in the laboratory, to obtain information on the minimum contact time for complete destruction of *E. coli* by free chlorine in distilled water of Neutral pH (7.2), and at 74°F (23°C).

The results of the tests demonstrated:-

- (i) In the presence of 0.5 p.p.m. of chlorine, 30,000 organisms per ml. were completely destroyed within $\frac{1}{4}$ minute.

- (ii) 0.2 p.p.m. chlorine was effective with a contact time of $1\frac{1}{2}$ minutes.

At the Admiralty Distilling Experimental Station, distilled water from a 450 gallon capacity tank, was fed to the Clorocel unit, and continuously infected prior to entry, with water heavily inoculated with organisms, pumped from a holding tank. Samples of infected chlorinated water were collected from the outlet of the plant, and the chlorine removed with sodium thiosulphate after specific contact times. After transfer to the laboratory each sample was cultured, after suitable dilution, and counts of viable organisms carried out after incubation.

Using *E. coli* as the infecting organism, in concentration ranging from 3,000 to 80,000/ml of feed water, and a chlorine content of 1.0 to 1.2 p.p.m., no viable organisms were demonstrated at the outlet, after a contact time of 3 minutes. With infecting doses of 2,000 to 40,000/ml, and available chlorine of 0.7 to 0.8 p.p.m. samples yielded no viable organisms in culture after contact times varying between 2 and 4 minutes.

The Clorocel appears to be even more effective with a coccal organism, and using *Streptococcus faecalis* at an infecting dose of 5,000/ml, no viable organisms were cultured after 1 minute contact with 0.8 p.p.m. chlorine.

Discussion

Many unpleasant diseases can be water borne, particularly typhoid, dysentery, and cholera, and most natural waters are liable to contamination with other organisms.

Of the several well known methods of water sterilisation the most usual involves the use of chlorine, and this method is used on a large scale in most of the major waterworks throughout the world. Chlorine does not destroy all bacteria, but, given suitable conditions, it is a powerful and reliable germicide in respect of the bacteria of water borne diseases.

For maximal effect the water to be chlorinated should be reasonably clear and bright, or rendered so by filtration or other means because the presence of suspended matter impedes chlorination by absorbing chlorine, and by protecting bacteria.

Made water from a distilling plant is suitable for chlorine treatment and in the event of a major leak from the cold condenser while distilling from sea water, salinity readings would indicate a fault before impurities and suspended material inactivates chlorine.

The Clorocel unit is a small, compact, but efficient chlorinator, requiring a contact time sufficiently low for the water to be safely used for domestic consumption almost immediately. A minor disadvantage is that control of salt supply is required, and supervision to ensure a constant regulated dose of chlorine.

The properties of silver as a water sterilant has been known for many years, and both the Sterasyl candle and Katadyn unit liberate silver ions when water is passed through them. The amount of silver which water can retain however, is very minute indeed, and whereas with chlorine normal residuals are measured in terms of 0.1 to 0.5 p.p.m., the residual silver in treated water is of the order of 0.01 p.p.m. However, even at this very low concentration, silver is an efficient sterilant. Prolonged storage of silver sterilised water does not reduce its germicidal quality, and the retention of sterilising power may remain for a month even though re-infected daily. According to Zimmermann (1952), the bactericidal effect is believed to be that the silver ions, carrying a positive charge, are adsorbed on to the surface of the bacteria which carry a negative charge.

The operating cost of the Katadyn unit is low, and the consumption of the electrodes depends upon the amount of silver ions discharged during the water treatment, but for bacterial sterilisation of water, an electrode will treat about 800,000 gallons, giving a final silver concentration within the range 0.0025-0.025 p.p.m. The unit is noiseless in operation and operates efficiently in all climates. The manufacturers state that the water to be sterilised should have a minimum conductance of 20 micro mhos for the unit to work at maximum efficiency. Water from the distilling plant has a conductance of between 3 and 6 micro mhos at 68°F (20°C) and difficulty was experienced in attaining a concentration of 0.01 p.p.m. of silver. Although in laboratory investigations, the Katadyn gave similar results to the Sterasyl candle in sterilising efficiency, lack of sufficient conductivity in water from distilling plants would prove a disadvantage to an otherwise efficient and labour saving sterilising unit.

The effective life of a Sterasyl candle depends on the character of the water and the frequency of cleaning. In normal domestic use a candle should last for two years or more,

and the sterilising effect lasts as long as the candle is serviceable. This type of Kieselguhr candle has a double sterilising action, first, by filtration of bacteria, and secondly, by the release of silver ions which enables the filtrate to be stored for long periods without deterioration by re-infection.

The yield of sterile water from the household type filters varies according to filter size, from 15 to 25 gallons per hour, with a clean supply of water and a pressure of 40 lb. p.s.i. A minimum pressure of 10 lb. p.s.i. or a fall of 15 ft. by gravity feed is necessary.

This method of sterilisation applied to water from distilling plants, presents no difficulty in control of operation, the only labour involved being occasional inspection and dismantling to clean the candle as necessary. Katadyn treated water requires a delay of three or more hours between treatment and consumption, in order to exert its sterilant action, whereas the Sterasyl candle filters off bacteria and yields consumable water of good quality.

Conclusions It is concluded from the results of these investigations that all the sterilisers tested were satisfactory from the bacteriological point of view and would be suitable as post-process sterilisers for ship-board use.

Acknowledgements

Our thanks are given to the Medical Director-General (Naval), Surgeon Vice-Admiral E. R. Bradbury, and the Medical Officer-in-Charge of the Institute, Surgeon Rear Admiral J. Watt for permission to publish this article. Thanks are also offered to Lieutenant Commander R. N. Jackson, R.N.E.S., of the Admiralty Distilling Experimental Station, Portland, and Mr. A. Wallace, Director General Ships Department, Bath, for their invaluable help and advice.

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NOTES AND NEWS

Admiralty Materials Laboratory

Mr. C. Selby, Experimental Worker Grade II, has been awarded the Imperial Service Medal. Mr. Selby has served at RNCF and AML continuously since 1926, and the medal was presented to him by the Director Dr. R. G. H. Watson in the presence of many colleagues.



Dr. G. A. Heath, SPSO, joined AML on 13.4.71 to take up his appointment as Assistant Director (Chemistry).

Dr. K. J. Balakrishna joined AML for two months on loan from the Indian Government.

Dr. D. R. Messier (AMMRL) Department of the Army (U.S.A.) joined AML on 19.7.71 on an exchange visit with Dr. M. W. Lindley, PSO, under the auspices of TTCP.

A series of Research and Management Discussions have been held during the year covering the following subjects: Personnel Management, Tribiology, Experimental Services, Electron Optics, High Strength Metals Corrosion Research, The Work of AEE Winfrith, The Role of the Navy (DNOR).

A full Staff Inspection by the Inspectorate of Establishments was carried out during the month of August.

Visits have been received from the Science Society of Canford School (18.10.71). Members of the DSAC Weapons Board (5.3.71), Advanced Marine Engineering Course (10.9.71), Materials Committee of the ICI Engineering Conference (6.5.71), Marine Materials Course (1.4.71), and the Engineering and Science Dept., Eastleigh Technical College (19.4.71).

Mr. J. M. Taylor, PSO, transferred to Central Dockyard Laboratory, on 1.6.71.

Dr. D. K. Ross, SSO, attended Second Operational Analysis Course at Royal Military College of Science, Shrivenham, and subsequently transferred to AUWE.

Dr. J. Catchpole, PSO, and Mr. J. J. Elphick, PSO, transferred to CNR.

Mr. P. J. Stanley, Experimental Officer and Mrs. E. Stanley (Information Officer) transferred to CDL Portsmouth.

During April Mr. D. Birchon presented a paper on "The Philosophy and Practice of Structural Validation and In-Service Monitoring" at the ASTM Conference on Predictive Testing in California, and attended a working meeting of TTCP in addition to visits to NRL, NSRDC, NAUSEC and NMAB in Washington. In May, in company with Mr. C. Halman of DGS Bath the use of the AMLEC instrument for crack detection was demonstrated to USN representatives at Norfolk Navy Yard, Virginia, and the USN are now evaluating MOD(N) technique for eddy current weld inspection.

Dr. D. J. Godfrey attended the April 1971 meetings of the Technical Co-operation Programme Panel P2 "Inorganic Non-metallic Materials" which were held in Australia. He presented a paper dealing with the fibre reinforcement of silicon nitride at a TTCP sponsored symposium on Defence Applications of Ceramics, and visited several laboratories with the TTCP Panel.

"The Effect of Some Chemical and Biological Factors on the Degradation of Crude Oil At Sea" by C. A. Parker, M. Freegarde and C. G. Hatchard, in "Water Pollution by Oil", Ed. Peter Hepple, Institute of Petroleum, London, 1971, p. 237.

It was with deep regret that the news of the death of **Bob Redmill** was received by his colleagues in AML. He was on holiday in Canada visiting his daughter, son-in-law and their family when he suddenly collapsed and died on Monday, 23rd August 1971.



He was born in 1918 in Malta, where his father was an Inspector in H.M. Dockyard and lived there until 19 years of age when he came to Portsmouth to complete his apprenticeship as an engine fitter. He entered the Torpedo Tube Design Office in September 1939 as a temporary draughtsman and moved to West Howe, Bournemouth, when this section was transferred there. In 1959 under the "Way Ahead" re-organisation he moved to Portland with his colleagues in ULE, but returned to Bournemouth on appointment to AML Holton Heath in January 1962 where he continued to serve until his death.

He will be greatly missed in many ways not least for his practical advice on anything mechanical.

He leaves a widow, son and daughter to whom we offer our deepest sympathy.



Admiralty Research Laboratory

It is with deep regret that his colleagues at A.R.L. heard of the untimely death of **Mr. G. C. MacNiece** on Wednesday, 6th October, after a prolonged period of ill-health.



"Mac" joined A.R.L. just before the war in 1939, and was at first connected with the development and use of Infra-Red Image Forming Devices. In 1951 he joined the team engaged on television application, and played a leading part in the development of Underwater Television, which made possible the searches for the Submarine *Affray* in April 1951, the V-Bomber which crashed in the Irish Sea in 1952 and the Comet which came down in the Mediterranean, substantial parts of which were eventually recovered off Elba. Subsequently, he applied these techniques to Hydrodynamic Research in the kinder and more hospitable environs of the laboratory.

Because of his long and varied career, Mac knew everybody and was known by all within A.R.L. He spent an appreciable portion of his time ungrudgingly in giving help and advice to all who needed it, particularly to the younger members of the Staff. His good nature and strong sense of humour, endeared him to everyone, and he will be missed by all. Our deepest sympathies are extended to his wife and family.

Captain Murray, R.N. together with 42 students of the R.N. Staff course toured the establishment on the 5th October.

Dr. J. Cook is attending a one year course at the National Defence College, Latimer; and Mr. H. G. T. Rissone is attending the Senior Officers War Course for five months at the R.N. College, Greenwich.

Having completed the three months Staff Course at the Royal Military College, Shrivenham, Mr. N. Wood has made a level transfer to the Polaris Performance Analysis Group, M.O.D. Whitehall, after four years service at A.R.L.

In September Mr. F. Steele was transferred on promotion to the Management Computer Division in Whitehall. Appointed to A.R.L. in 1952 he joined the Mathematics Group, and apart from a spell of two years with the Mediterranean Fleet as Fleet Scientific Adviser, has remained with it ever since, becoming Group Leader in 1965.

The following papers have been published:

"The Casella Mk.2 Cascade Impactor, A Comparison of Observed with Calculated Stage Mass Media Diameters" by Dr. B. W. Soole, (*Aerosol Science*, **2**, 281 - 288, 1971).

"The Attenuation of X-radiation Generated at Constant Potentials Sufficient to Excite K-Radiation in a Tungsten Target" by Dr. B. W. Soole (*Physics in Medicine and Biology*, **16**, No. 3, 427 - 437, 1971).

"Concerning the Calibration Constants of Cascade Impactors, with Special Reference to the Casella Mk.2" (*Journal of Aerosol Science* **2**, No. 1, 1 - 14, 1971).

"Fish Echoes on a Long-Range Sonar Display" by Dr. D. E. Weston and J. Revie (*Journal of Sound and Vibration*, **17**, 105 - 112, 1971).

"Multiple Frequency Studies of Sound Transmission Fluctuations in Shallow Water" by Dr. D. E. Weston, K. J. Stevens, J. Revie and M. Pengelly (*Journal of Sound and Vibration*, **18**, 487 - 497, 1971).

"Waveband Studies of Shallow-Water Acoustics Attenuation due to Fish" by Dr. D. E. Weston and Miss P. A. Ching (*Journal of Sound and Vibration*, **18**, 499 - 510, 1971).

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Admiralty Surface Weapons Establishment

Professor H. Bondi, FRS MA, the Chief Scientific Adviser to the Ministry of Defence, recently visited the Establishment in order to obtain an overall picture of its current activities with particular emphasis on research implications. In that he worked in the Admiralty Signal Establishment during the last war, Professor Bondi's visit was, at least in small measure, a return to familiar surroundings. Other recent visitors to ASWE have included Major-General Sir John Anderson, CBE, C.Eng., FIEE, the Assistant Chief of Defence Staff (Signals).



Professor Bondi with Mr. Pout, Director, ASWE, and Captain F. Bruen, M.V.O., D.S.C., Director Weapons Equipment Surface (Naval).

At the invitation of the Royal Swedish Navy Dr. D. G. Kiely and Mr. J. R. C. Thomas visited Stockholm and Karlskoga on 6th to 10th September 1971. Presentations were made by the Swedish Naval Staff, the Swedish Defence Research Laboratory and the Bofors Company, of current studies, research and equipment developments in the field of Naval weapons and sensors.

In October, Mr. J. R. C. Thomas, Capt. J. B. D. Miller, R.N. and Mr. R. J. Poole visited NATO Headquarters Afnorth at Kolsas near Oslo to take part in a long-term study of military operations in the Arctic. The location of the exercise was immediately christened "Troll Mountain" by the Canadians and there was some apprehension that the party might emerge somewhat changed at the end of the fortnight; but in the event, only the Working Paper met this fate.

At the invitation of the French, a small delegation headed by Mr. S. E. Shapcott, of ASWE consisting of Captain G. Hayne, DWES, and Mr. L. Knight and Mr. R. Stallard of RARDE, visited various installations in France between 13th September and 17th September 1971. The purpose of the visit was to inspect the test installations and production facilities used in the development and manufacture of the French radio proximity fuze used by the French Navy. The delegation visited the firing range at Gavres near Lorient and observed trials of French VT fuze ammunition fired against different targets.

Visits were also made to the production facilities operated by the company Thomson-CSF at St. Egreves near Grenoble, and to the research laboratories of the company at Velizy-Villacoublay near Paris.

Mr. A. K. Redhouse recently visited the Institute of Aeronomy at Lindau in the Federal German Republic in order to attend an AGARD meeting on radar propagation in the Arctic. The sessions presented a variety of statistics about the auroral ionosphere and opportunity to suggest where further or new work was seen to be needed.

The Establishment has recently welcomed a number of newcomers who include Mr. N. H. Rock from the CVD Office in Washington and who is now working in the Infra-red/Optics Group at Funtington, and Mr. R. J. Sherwell from the CVD Office in London who has joined the Post-Design Division.



A number of former members of the Establishment's staff were also welcomed on their return to Portsmouth. Mr. E. R. Billam rejoined at the end of August following his two-year exchange appointment with Dr. Peter Sewell of Pilkington Bros. Ltd. The photograph above shows the Director, Mr. H. W. Pout (left) making a presentation to Dr. Sewell upon his departure. Mr. Billam is now devoting himself to a study of Action Information Organisation systems. Mr. A. L. P. Milwright also rejoined at the end of August on the termination of his appointment as Scientific Adviser, Far East Fleet. Mr. Milwright is now engaged on terminal equipment for Communications Centres.

Mr. D. J. Mabey has returned from Canada whilst his fellow exchange-scientist, Mr. R. E. Erickson has returned to the Defence Research Establishment at Valcartier. Mr. B. P. Blades will be away for several months attending the National Defence Staff College at Latimer, Bucks. Mr. H. M. Gilmour has returned from Washington after handing over his appointment as Scientific Adviser (Radio and Radar) to Mr. R. F. Kyle, and is now working in the Electronic Warfare Division.



Frederick George (Ted) Burden has recently retired as the Officer-in-Charge of the workshops of the Experimental Department of H.M.S. *Excellent*. His time in the Navy, which he joined as an apprentice in 1923, culminated in his promotion to Commissioned Ordnance Officer, and gave him wide experience of gunnery matters which well-fitted him to the problems posed at H.M.S. *Excellent*. This experience, coupled with his inventive mind, stood him in good stead over the 21 years and his mark has been left on a variety of weapon stowage and handling equipment currently in service with the fleet.

‡ ‡ ‡

Mr. Jack Davis, one of ASWE's Chief Experimental Officers, who is shortly due to retire, recently produced the photograph on facing page of H.M. Signal School's cricket team as it was in 1924. The photograph is of exceptional interest in that it includes both Mr. H. Morris-Airey, the Signal School's Chief Scientist between October 1919 and June 1927, and Mr. G. Shearing who held the same post from June 1927 until August 1941 when the new title of Admiralty Signal Establishment was created. The photograph also includes Mr. J. D. S. Rawlinson, C.B.E., who later held office as Superintendent Scientific Personnel. Cdr. G. C. Candy was Experimental Commander of the Signal School between July 1922 and October 1924. Mr. Davis' own father is also shown in the photograph. The list of staff, where now known, is as shown below the illustration.



Standing: 1 F. Spencer 2 ? 3 ? 4 ? 5 Rawlinson 6 Baverstock 7 ? 8 Challons 9 J. O. Davis 10 ? 11 G. Shearing

Seated: 1 G. A. Irving 2 Lillington 3 Cdr. G. C. Candy OBE, RN 4 Captain C. Seymour DSO, RN 5 H. Morris-Airey CBE 6 Bland or Brand 7 A. McPherson

Admiralty Underwater Weapons Establishment

The following higher degrees have been obtained by members of AUWE since the end of 1970. In December 1970, Mr. I. Roebuck was awarded the Ph.D. degree of Dundee University for his thesis "Refraction and diffraction of high frequency waves at an interface between stratified media". In July 1971, Mr. D. Leadheater was awarded the Ph.D. degree of Bristol University for his thesis "A novel method of static frequency changing employing asymmetrical modulation techniques". Also in July 1971, Miss E. Marshall was awarded the M.Sc. degree of Leicester University in Applied Mathematics; her dissertation was entitled "Optimal control theory of distributed parameter systems".

The following papers were presented by AUWE members at British Acoustical Society meetings in the first half of 1971. At a symposium on "Scattering phenomena in acoustics" in February in London: "A comparison of geometrical features as acoustic scatterers within a fluid" by Dr. A. Freedman. At the Spring Meeting in April in Birmingham: "Transducer design based on filter theory" by Dr. J. C. Morris, "Heuristic study of sound propagation to long ranges in the shadow zones below surface ducts" by Dr. I. Roebuck, "Transducer bandwidth" by Dr. D. Stansfield.

The following paper has been published in the March 1971 issue of the Journal of the Acoustical Society of America: "Farfield of pulsed rectangular acoustic radiator" by Dr. A. Freedman.

At the beginning of the year Dr. Freedman was appointed to the Editorial Board of the Journal of Sound and Vibration.

Recently, Dr. L. J. Lloyd, a member of the Assessment Division, attended a conference organised by the NATO Advisory Panel on Operational Research. The conference was held at the NATO Headquarters, Brussels, and the specific topics discussed were: Field Trials, and the acquisition of Tactical Operational Data. The primary aim of the conference was to examine the purpose, planning, data collection, analysis and resources needed to carry out field trials associated with operational research. Professor R. Sheppard of the Royal College of Military Science was the conference Director and Chairman.

In spare time activities AUWE and the Apprentices Association were again very successful in this year's Weymouth Carnival, each gaining first prizes in its own class. AUWE entered two galleons depicting the English and Spanish fleets in battle at the time of the Spanish Armada. The Apprentices' float was an enormous elephant, Dumho 747, painted to caricature a Jumbo Jet.

Mr. W. J. McCarthy, "Mac" to his many friends both in AUWE and in Weymouth and District Scouting circles, has retired from the Royal Naval Scientific Service after 35 years service.



In the New Year's Honours List this year "Mac" was appointed a Companion of the Imperial Service Order and he received the decoration at Buckingham Palace.

At a big meeting in AUWE North on Monday, September 20th, Mr. W. K. Grimley, O.B.E., Head of the Sonar Department (left in photograph) made the presentation of an inscribed silver salver and crystal glass from subscriptions from colleagues.

Mr. McCarthy, who with his wife lives in Chickerell has many outside interests. He has been the Scouts' District Commissioner for Weymouth and District for 12 years and an active Scout official for 40 years. He holds the special awards from the Chief Scout of the "Scout Medal of Merit" and the "Silver Acorn". He has been a member of the Board of Visitors of H.M. Borstal Institution, Portland for many years and was recently elected County Councillor for the Abbotsbury Division. "Mac" is also well known as a keen gardener, specialising in chrysanthemums and roses.

In his scientific work for the Royal Navy he spent a good deal of time before and during the war on sea trials with experimental sonar equipment in submarines and surface ships. For many years, up to his retirement, he has been Chief Experimental Officer and head of a group responsible for the development of large scale training equipment for the R.N. Modern Sonar Command Team Trainers are highly complex Computer Controlled Systems installed in special buildings in which the operational environment can be realistically reproduced and anti-submarine actions simulated.

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Naval Scientific and Technical Information Centre

The Naval Scientific and Technical Information Centre (NSTIC) has now combined with the defence part of the ex Mintech Technical Reports Centre (TRC) to form the Defence Research Information Centre (DRIC).

The Centre will continue to be located at St. Mary Cray and will be responsible for providing a scientific and technical information service to the defence and aerospace communities.

All requests from the Ministry of Defence, its contractors and other associates should be addressed to DRIC which will hold the stock of all defence classified and defence controlled material and will obtain any unlimited documents it does not hold from other sources, including a new information centre for the civil community being set up at the same location by the Department of Trade and Industry.

All services previously offered to the Navy Department by NSTIC will continue under the new title.



The photograph above shows Vice Admiral Sir A. Griffin, C.B., Controller of the Navy, with your Editor at the Royal Navy Equipment Exhibition held at the Royal Naval College, Greenwich, 21 - 25 September.

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Services Valve Test Laboratory

As a result of the Defence Reorganisation Programme, SVTL is being closed on or about 31st December 1971. The Laboratory has been in existence at Haslemere since 1952 and has provided a supporting service, in the field of electronic tubes and semiconductor devices, to various Government organisations and to NATO. The work will in future be accomplished by other means. *i.e.* some of the research work has been transferred to SERL Baldock. The development measurements and performance work will in future be done by project Design Authorities or, under CVD auspices, by manufacturers' development laboratories. Standardisation measurements and Quality Assessment work will be undertaken by EQD Bromley as a supplement to their work on the BS 9000 programme.

Individual members of SVTL scientific staff have taken up or will take up other duties as follows:—

Messrs. G. J. Halford, B. Ingrey, E. G. Robus, R. W. Moorey, C. E. Poole, and B. E. Stamp have transferred to ASWE Portsdown.

Mr. H. Lewis has transferred to RRE Malvern. Messrs. K. A. Wakefield and D. E. Lloyd have transferred to SERL Baldock.

Mr. C. F. Ward has transferred to Ordnance Board, Kensington.

Mr. P. H. Holland has transferred to DSTI London.

Mr. R. W. Sage has transferred to NPL Teddington.

The remaining members of the scientific staff will take up other duties when the closure is completed.



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