# ADVANCES IN NAVAL GUN FIRE CONTROL

BY

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> The Electrical Firing Wires are to be frequently tested by the Gunnery Officer . . . sending a trustworthy man to make the necessary corrections and place his hands to take the shock.
>
> *Admiralty Circular No. 135 of 27th February 1873*

## INTRODUCTION

As in all aspects of modern warfare, technology has made a huge impact in gun fire control—an impact in techniques, in size, in cost, in dependability. This article looks at these enormous changes by showing how the complex task of naval gunnery was solved in earlier systems, and examines how the electronic revolution of the 1970s and 1980s has been used in the latest system (GSA 8) which is being fitted in the later Type 22s and the Type 23 frigates.

This article is not the correct place to consider the merits and role of the naval gun, but it may be observed that inclusion of a medium calibre gun in these ships is a shift in policy. In the 1970s priority was given to missiles in the LEANDER conversions and design of the Batch I and Batch II Type 22 frigates. The Falklands war provided a reminder that naval bombardment is the most simple and economical method of providing artillery support to the Army's seaward flank and during amphibious operations. The provision of naval gunfire support to the Army is the prime role of the medium range gun, but an important secondary role is economical anti-ship warfare. This is particularly appropriate against minor war vessels and in peacetime police actions.

### The Naval Fire Control Problem

There are three main elements to the overall task of hitting a target with a shell fired from a ship-mounted gun:

(*a*) *Tracking*

The position of the target is measured in relation to the ship's axes, and then transformed to a stabilized 3-dimensional set of Cartesian axes. Velocities are derived.

This requires the solution of lengthy equations in spherical trigonometry which, before the advent of digital computation, could only be approximated. Filtering is required to smooth the raw target data, and this filtering introduces time delays of a magnitude which depends inversely on tracking quality.

(*b*) *Prediction*

Prediction of the target's movement during the projectile's flight. This requires the solution of three simultaneous non-linear equations and compensation for processing delays.

Until recently the predictor assumed that the target would either maintain its angular and range rates; or hold its course and speed during the time of flight of the shell. This is a major source of error against fast targets.

(*c*) *Gun Corrections*

The gun has to be trained and elevated (in ship axes) so that the projectile will arrive at the future position of the target. This is done by adding corrections for effects on the projectile's trajectory. These correction and allowances include:

gravity drop
wind speed and direction (at various heights if available)
air temperature, pressure and humidity
ship's latitude } among others, to compensate for
ship's course and speed } Coriolis effect on the shell
earth curvature }
ship geometry and fixed ship errors (e.g. misalignment between equipment seatings)
shell type
charge temperature
muzzle velocity.

These are clearly problems of some complexity. Today, we can be blasé about the solution; we have learnt the power of the digital computer even when applied to non-linear problems. We can perhaps better appreciate the power of modern technology by taking a short look at how the problem was solved when only analogue mechanisms were available, driven at first manually and later electrically. The effectiveness of this technology is well known. For instance, in heavy weather in the Denmark Strait, *Bismarck* sank *Hood* with her opening salvos at a range of 13 miles. In sea state 8 and snow showers in arctic twilight north of the North Cape of Norway, the Home Fleet engaged the battle cruiser *Scharnhorst*. In the opening action, the 8 inch cruiser *Norfolk* hit *Scharnhorst* with her 2nd or 3rd salvos at a range of 7 miles.

## Director Fire Control

Integrated gunnery fire control systems had their origins in developments made around the turn of the century. Many of these developments resulted from the efforts of a few gunnery officers, dedicated to the improvement of the prevalent staid and outmoded gunnery practices of the late nineteenth century, which had progressed little since Trafalgar.

About the turn of the century a typical battleship's gun fire control consisted of a central command position mounted high in the superstructure. This housed the fire control instruments consisting mainly of a large clock, a Dumaresq for calculating deflection and range using plots, together with an optical rangefinder. Range and deflection were transmitted to each gun mounting and applied to the gun sights causing the gun layer's and trainer's telescope to move off the aim point. Elevating and training the gun to re-align the local telescopes with the target applied the required tangent elevation and deflection for the range in use. The battle of Tsushima fought between the Russian and Japanese fleets in 1905 showed that effective long range gunfire was practicable providing fire control systems were improved, and that future sea battles could be fought at ranges in excess of British Fleet standards. The events at Tsushima helped stimulate further the need for the Royal Navy to improve its gunnery standards. One of the first improvements was the introduction of the Director Firing System whereby a master sight superseded the local gun sights. This was sited high to obtain a clear line of sight, above gun-smoke and spray. It directed all guns and fired them in salvos or broadsides.

The advantages of the director system were well illustrated in 1912 when H.M.S. *Thunderer* (FIG. 1), the first battleship fitted with a director system, was adjudged to have scored 60% hits at a range of 9000 yards during a competion firing with her sister ship, H.M.S. *Orion*. The latter's individually sighted four twin 13·5 inch gun turrets scored only 15% hits.

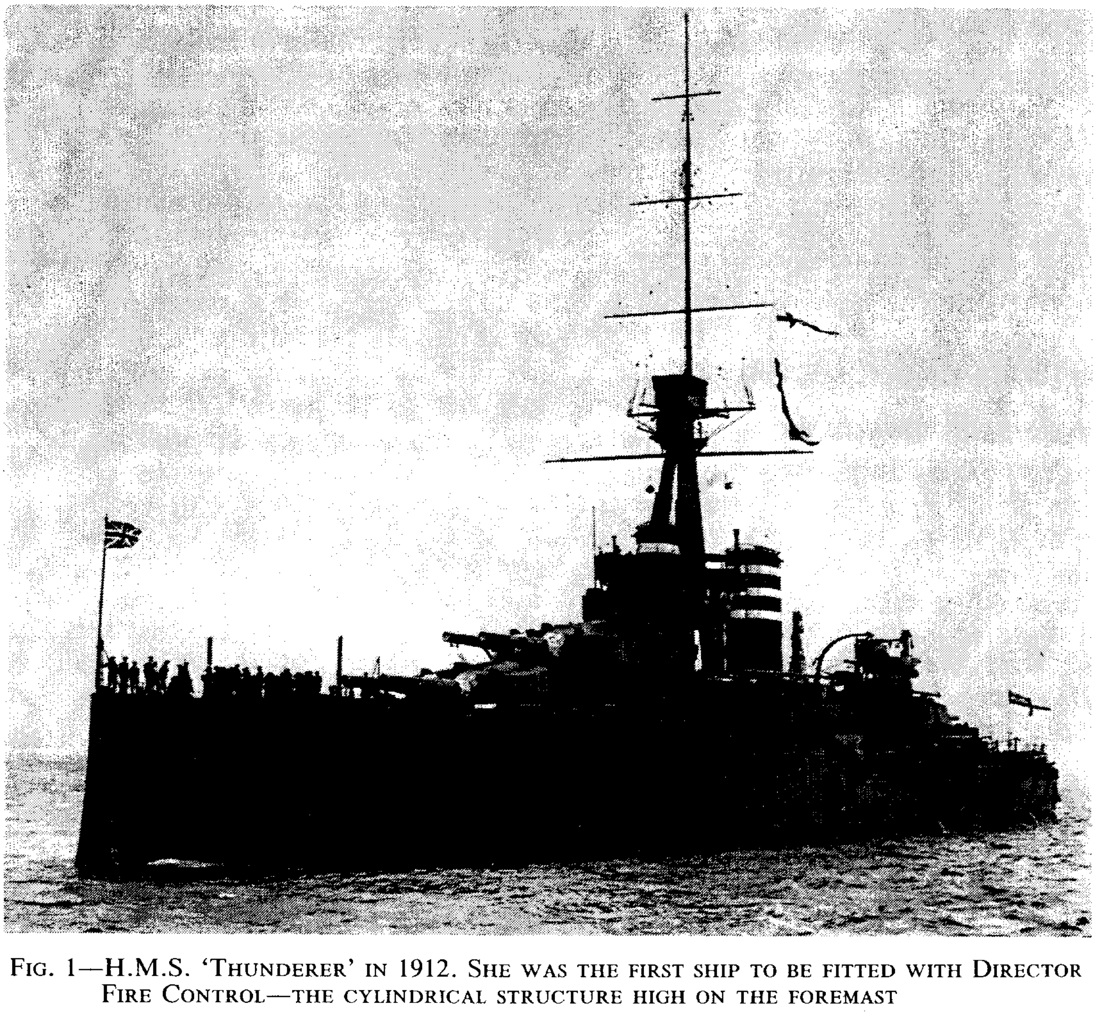

FIG. 1—H.M.S. 'THUNDERER' IN 1912. SHE WAS THE FIRST SHIP TO BE FITTED WITH DIRECTOR FIRE CONTROL—THE CYLINDRICAL STRUCTURE HIGH ON THE FOREMAST

## Centralized Fire Control

The next significant change was the integration of fire control instruments into a Fire Control Table. The first of these, the Dreyer Table, was first installed in 1917. Between the World Wars, considerable improvements were made in fire control equipment. Hydraulics were extensively used to provide power for directors (e.g. FIG. 2) which were large armoured structures housing gyro-stabilized gun sights (which incidentally were also hydraulically powered), a multitude of fire control instruments and a crew of some eight to ten officers and men.

Fire Control Tables, by now sited well below decks in the Transmitting Station, were first powered by pneumatics and then hydraulics and contained precision mechanical analogue devices for solving fire control problems in surface and bombardment modes.

The introduction of radar during World War 2 provided these quite sophisticated systems with an accurate all-weather, blindfire, ranging sensor, thus making first salvo straddle a reality, and greatly improving the time-consuming practice of ranging shots and spotting which had been used by the Royal Navy for many years. The typical light cruiser of 10 000 tons armed with nine 6 inch guns could now deliver over a ton of high explosive per minute within an area similar in size to the Oval cricket ground from a range of 12 nautical miles.

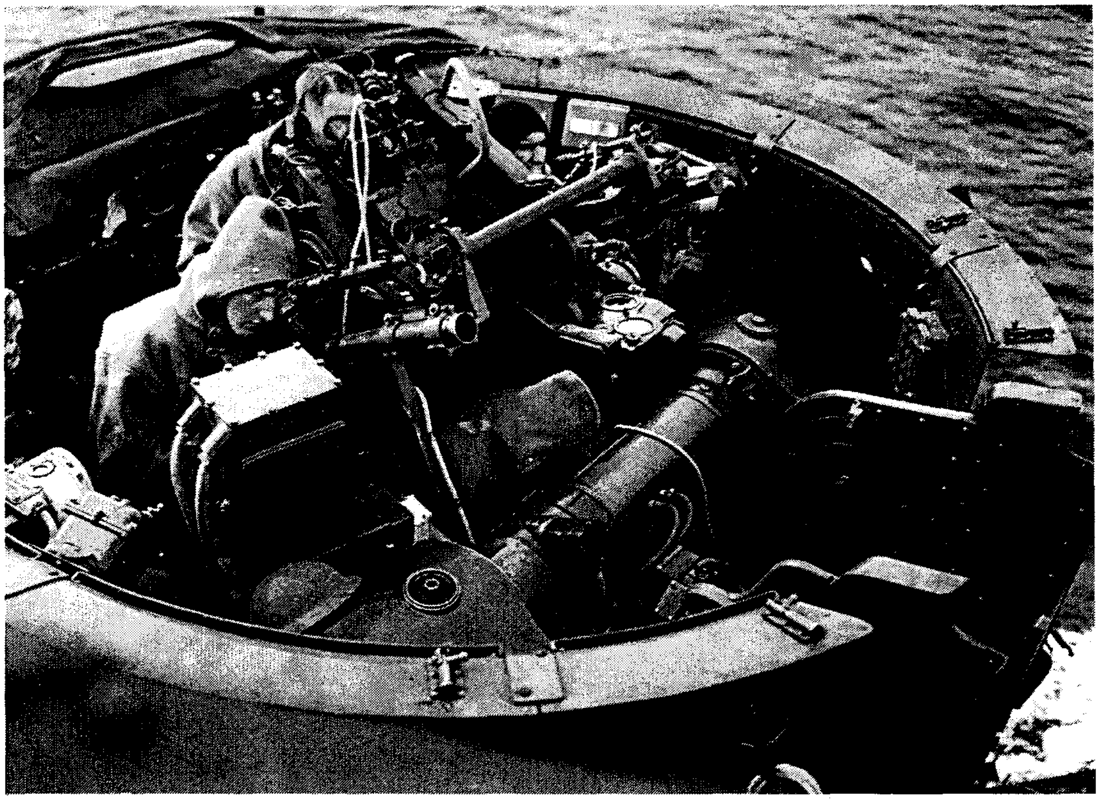

FIG. 2—SECONDARY ARMAMENT DIRECTOR OF H.M.S. 'KING GEORGE V'. NOTE THE OPTICAL RANGEFINDER

## AA Prediction

Up until the end of World War 2, anti-aircraft fire control systems had developed along similar lines to the surface systems.

Predictors, (notably the Fuse Keeping Clock (FKC) fitted in destroyers and the High Angle Control System (HACS) in cruisers and above) were mechanical. They worked in conjunction with optical height-finding rangefinders (and later radar) and were goniographic systems in that prediction was based on the target aircraft's speed and course. The drawback was not only the complication of prediction in the third dimension, height, but that the greater deflection arising from the higher speeds of aircraft targets could not be predicted accurately by these manually driven mechanical systems.

The 1950s saw the introduction of combined anti-aircraft and surface fire control systems based on electro-mechanical technology. The other significant innovation was that the AA predictor became a tachometric system, prediction being based on target rates. The surface predictor maintained the traditional mechanical computation of the previous decades. The progression of such fire control systems and predictors is shown in Table I.

Table I—*AA Fire Control Systems and Predictors before the introduction of digital prediction*

| *Year* | *System name* | *Director Radar* | *AA Prediction* | *SU Prediction* | *Crew* | *Ships* |
|---|---|---|---|---|---|---|
| Pre-war to 1972 | US Mk 37 | 275 | Electro-mechanical (part of system) | | 11 | Battle Class<br>H.M.S. *Eagle* |
| Early 1950s | MRS7 | 275 | SEDC | AFCC 1** | 10 | War Emergency Destroyers<br>Battle Class |
| Mid-1950s to 1980 | FPS 5 | 275 | Flyplane system | AFCB 10 | 9 | War Emergency Destroyers<br>Daring Class<br>Type 12<br>Type 81<br>Type 41 |
| Late 1950s to present day | MRS3 | 903 | MRS3 | AFCB 11 | 5 | Leander Class<br>Rothesay Class<br>Daring Class<br>Tiger Class |
| Early 1960s | MRS8 | CRBFD 262 | Electro-mechanical | | 4 | H.M.S. *Belfast*<br>Daring Class |
| 1960s | US Mk 63 | Mk 63 | Electro-mechanical | NIL | — | H.M.S. *Victorious* |

## Introduction of Digital Prediction

Digital computation became available for gunfire control in the 1960s and early 1970s, and was used in Gun System Automation 1 and 4 (GSA 1 and 4). The benefit was partly in accuracy but principally in the ease with which consistent performance could be maintained through the life of the equipment, repeated tuning and alignment of analogue servos becoming a thing of the past. Training, maintenance and other support costs reduced very notably. With GSA 1, data processing was centralized with that for AIO and other weapon control tasks.

However, time-sharing on a central main-frame computer brought unexpected problems largely associated with this lack of autonomy. Most notably, when gun control software was combined with that for other systems, it required extensive integration proving. This proving had to be done where the systems came together, namely in the ship; and ship time is expensive, hard to get, and subject to other priorities. It was also recognized that the new system was more vulnerable, both to action damage and equipment malfunction. These problems could only be solved by making systems more autonomous, and hence required more compact, less expensive processing. This became possible with the microprocessor revolution of the 1970s.

### Today's Technology

There are two obvious technological distinctions between systems such as GSA 8, and earlier digital systems.

Firstly, as foreshadowed above, processing is highly distributed, and a separate computer is allocated to each specific task or closely associated group of tasks within the system. GSA 8 has seven Single Board Computers (SBCs) handling such functions as director servo-control, prediction, and operator controls. In addition nearly every panel electronic component (PEC) has its own microprocessor. By comparison, GSA 1 shared all its own functions and those of other weapons with the ADAWS 4 main frame. As outlined above, the benefits of the distributed approach are fully realized:

(*a*) Software is easier to manipulate; hence proving, modification and control are greatly simplified.

(*b*) System reaction time is reduced since computations can be run concurrently.

(*c*) System vulnerability is reduced.

The second new feature is that digital techniques are now much more widespread. Earlier systems used digital methods principally only for computation, but now for example:

(*a*) Inter-unit cabling is further reduced by the use of dedicated point-to-point serial data highways for internal communication and by the use of serial multiplexed highways for external communication. Each of these techniques require the use of only one lightweight cable (twisted pairs).

(*b*) Position servo systems use digital techniques for implementation of the transfer function algorithms. This simplifies the use of more powerful shaping functions. It also removes the need for constant attention to drift and offset inherent in d.c. analogue systems.

(*c*) Less immediately obvious, but equally beneficial, is the use of more processing capacity to automate operator workload and enable more functions (such as curved course prediction) to be tackled.

We will now examine these developments as they apply to GSA 8.

## THE LATEST R.N. FIRE CONTROL SYSTEM—GSA 8

### General Description

GSA 8 is being fitted in the later Type 22 and Type 23 frigates for control of the 4·5 inch Mk. 8 Gun. It is a variant of the British Aerospace Sea Archer 30 family of gun fire control systems developed for the late 1980s.

The General Purpose Electro Optical Director (GPEOD) is an integral part of the system and is controlled from the same console by the same operator. It is the principal tracker for GSA 8, although target data (range, bearing, and angle of sight) can be made available to GSA 8 on the Combat System Data Highway from a multiplicity of sources. It should be noted that GPEOD can transmit target data similarly to other weapon systems; Sea Wolf could, for instance, be controlled in an optical mode using GPEOD.

GPEOD is therefore the successor to a long line of gunnery directors, and will be described below with the rest of the system. It uses much technology that is completely new to the Royal Navy, and in particular is the first major fit of infra-red (IR) sensors.

The system fitted in the Type 22s (GSA 8A) uses two GPEODs, mounted on the bridge roof giving overlapping arcs of view. The GSA 8B, in Type 23 (FIG. 3) has only one. Otherwise the two systems differ only in minor detail.

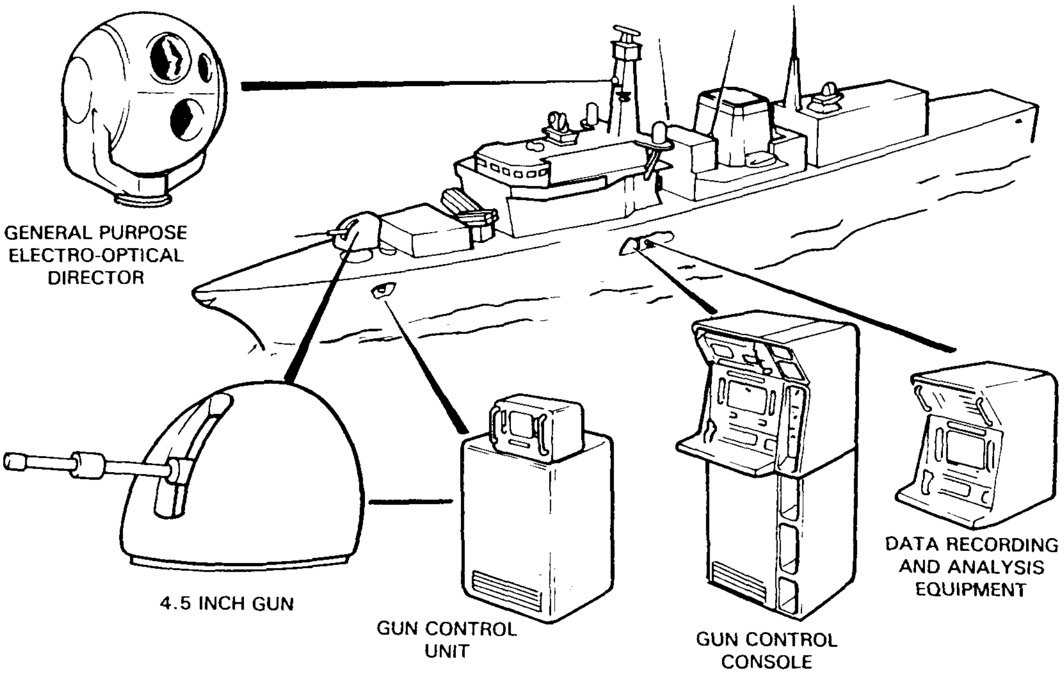

FIG. 3—GSA 8B SYSTEM IN TYPE 23

There is a significant degree of autonomy when compared with earlier systems. The Gun Control Interface Unit (or predictor) is the major computing element and is located in the gun bay. If either GPEOD or the Gun Control Console is damaged or unavailable, reversionary gun control is by means of the emergency fire control panel also located in the gun bay. The other noteworthy feature is the extensive use of data highways. Within the electronic cabinets a high bandwidth bus is used; between units the 1553B or RS422 data bus is used. The consequent reduction in cabling is substantial.

GPEOD (FIG. 4) presents a completely new capability to the ship's sensor suite; it complements radar by providing a passive tracking facility.

The Thermal Imager (TI) provides a video image derived from infra-red emissions in the 8–12 micron waveband. The picture quality is equally good at night since it is derived from the target's own heat emission. TV is provided so that the best source from the IR or visible waveband can be selected depending on the prevailing conditions. The operator is able to choose which video (TI or TV) is displayed on the monitor of his control console.

It is very difficult to jam Electro Optic (EO) sensors; any additional radiation from the target merely aids the imaging process. At these wavelengths, sidelobes are insignificant. Hence there is no equivalent of broad band radar jamming which obscures the target with 'snow'. Another particular value of GPEOD is that, being passive, it may be used in conditions of EM silence. Under jamming or EmCon, it may therefore be used in a surveillance mode—to investigate an ESM bearing or a threat sector for instance—using its pre-programmed search patterns. Further advantages of EO sensors are that they do not suffer from multi-path effects; and they provide discrimination between close-flying multiple targets, or between target and decoys. It has a subsidiary use for covert observation or blind pilotage (see FIG. 11).

The EO sensors are capable of detecting targets out to horizon ranges in favourable conditions. 'Favourable' conditions are of course dependent on the weather, and thus very variable; but it is expected that either the TI or the TV will be operable in winter in the North Atlantic for most of the time. IR radiation absorbtion depends on total (not relative) water content. Hence in cold conditions the TI may give better ranges than the TV but in hot humid conditions, much worse. It will not penetrate rain or thick fog, but can penetrate mist.

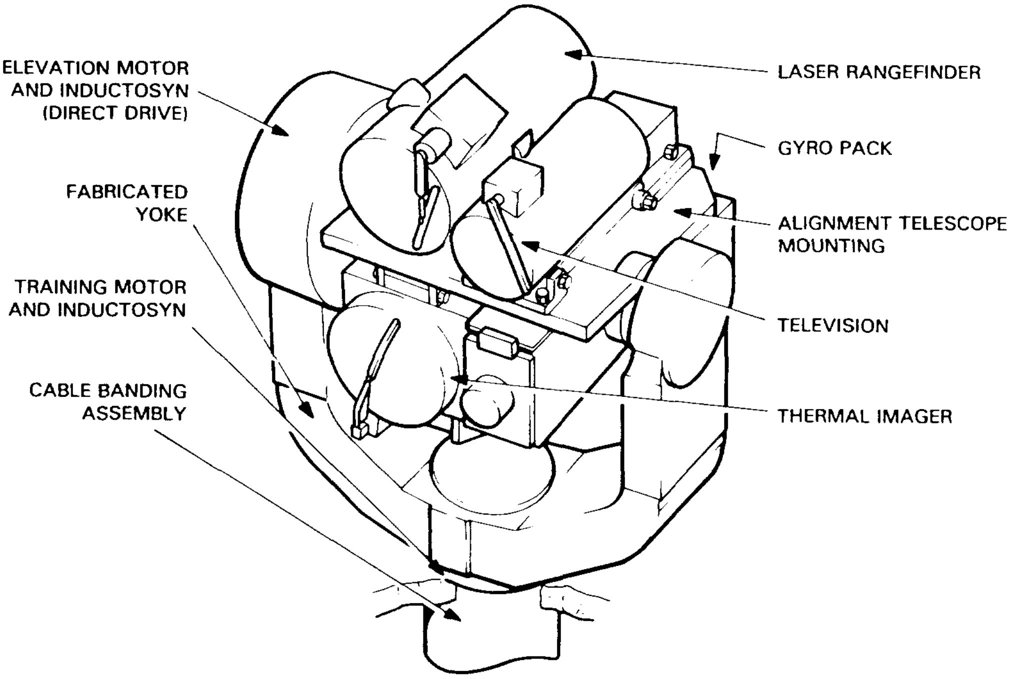

FIG. 4—GENERAL PURPOSE ELECTRO OPTICAL DIRECTOR, SHOWING TI, TV AND LASER SENSORS

Control of GPEOD is from the Gun Control Console below decks; it is the first RN Optical Director without an above decks operator. Lookouts are able to indicate targets by means of the visual sights when these are fitted. (Man has peripheral vision and an ability to detect moving targets against clutter, which is not yet superseded by the computer).

The director structure is designed to provide the requisite stability for the EO sensors—namely to provide a blur-free image under the most severe ship motion conditions. This demanding requirement conflicts with a need for low weight (the overall mass is less than 250 kg). Reduction in mass is achieved with a sophisticated fabrication in aluminium. The distinctive spherical cover functions principally to minimize unbalanced wind torques (a major source of servo error in unshielded systems). It also carries an outer r.f. shield and de-icing heaters.

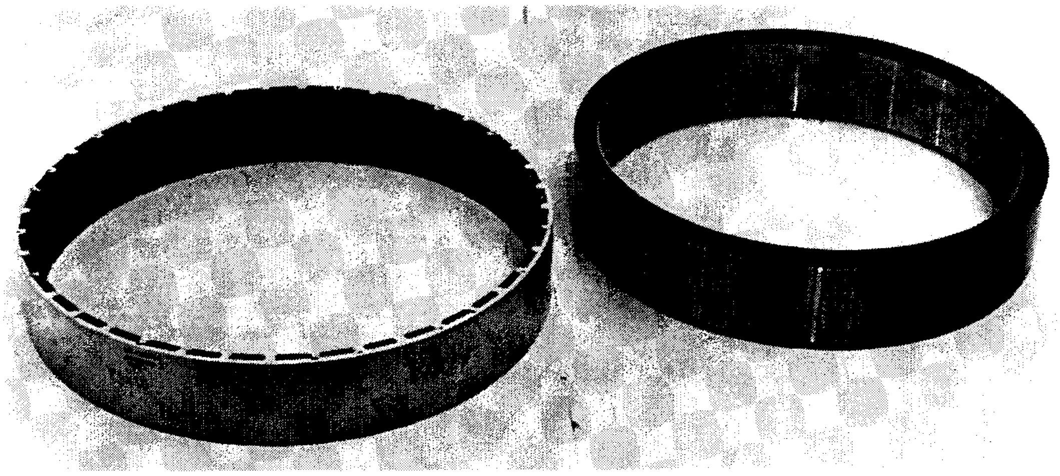

FIG. 5—FRAMELESS d.c. HIGH TORQUE SERVO DRIVE MOTOR. STATOR WITH SAMARIUM COBALT MAGNETS (LEFT); ROTOR (RIGHT)

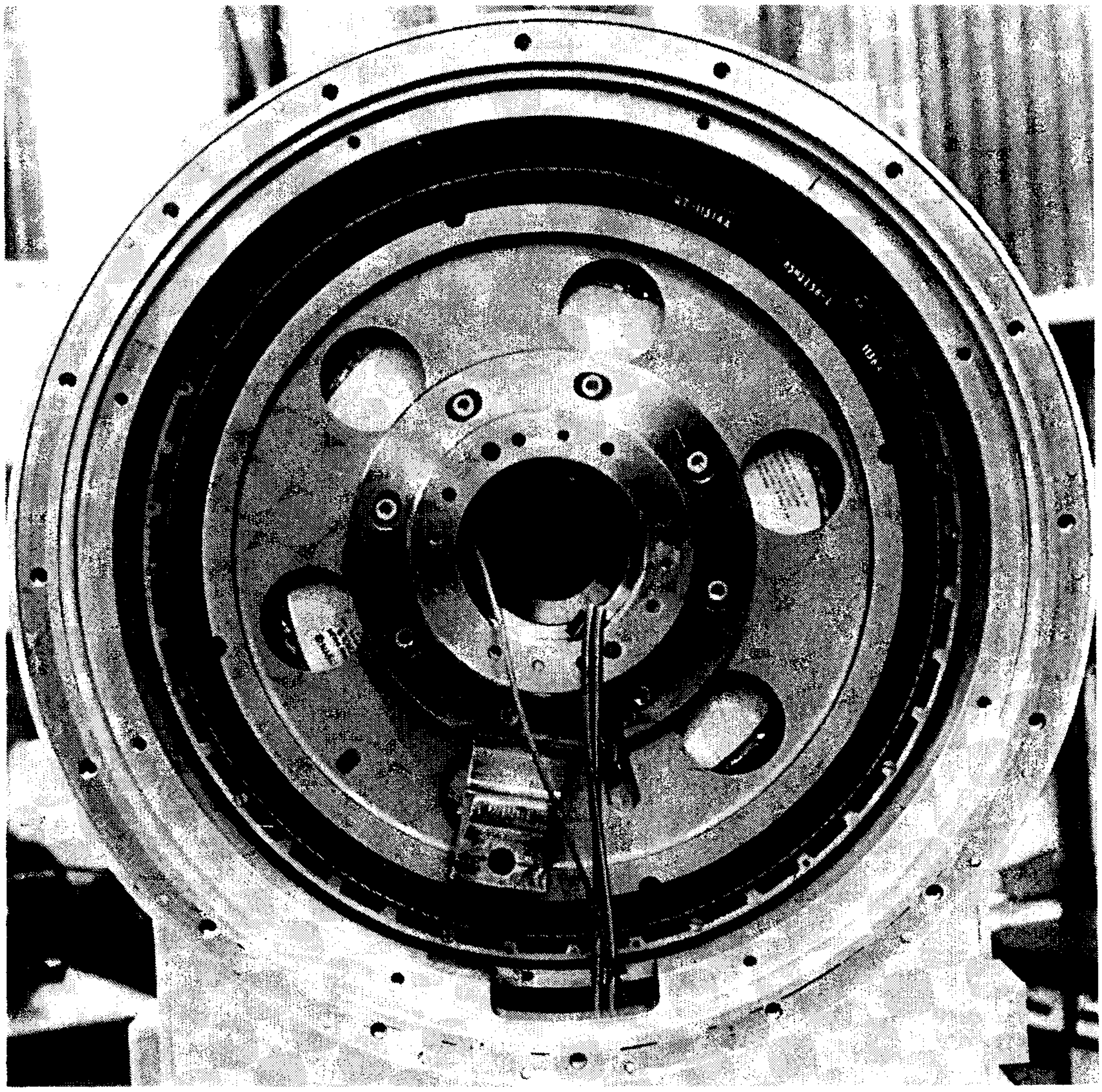

FIG. 6—GPEOD ELEVATION DRIVE BEFORE ASSEMBLY OF THE BRUSH GEAR. THE INDUCTOSYN ROTOR CAN BE SEEN THROUGH THE HOLES IN THE MOTOR SPIDER. NOTE THAT THE MAIN ROTOR IS MOUNTED DIRECTLY ON THE TRUNNION