THE NAUTICAL BRANCH OF THE U.S. NAVAL OBSERVATORY

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While the activities of the Naval Observatory in so far as they concern astronomical work and the publication of the *Nautical Ephemeris* are comparatively well known, the same cannot be said of the operations of the naval division of the Observatory which are described hereunder and which, as a rule, are much less widely known.

The nautical branch of the Naval Observatory is the material section of the Bureau of Navigation, except for printing presses, ships' libraries and band instruments, which are handled directly in the bureau itself. The nautical section is supervised by the assistant superintendent; the superintendent is, of course, head of both the nautical and astronomical branches. The work of the nautical branch is divided among three divisions: equipage — navigational instruments, less compass material; maintenance — the repair shop, time service, inspections, purchase of spare parts, and purchases for the Observatory itself; compass — magnetic and gyro-compas material.

EQUIPAGE DIVISION.

This division has cognizance over navigational allowance lists (less compasses, compass instruments, and peloruses), is charged with the development of navigational instruments, preparation of specifications, review of reports from ships, and with action on surveys. It has close liaison with the Bureau of Aeronautics in developing certain types of instruments used for navigation of aircraft. The Bureau of Aeronautics assisted by the Bureau of Navigation designs and develops compasses, sextants, drift instruments, and binoculars. Full use is made of the facilities of the Observatory for maintenance and repair of navigational and aerological instruments used by the Bureau of Aeronautics. No mention is made of precision time pieces for aeronautics, but these instruments are purchased by Aeronautics and tested at the Observatory. The desk also prepares opinions on inventions and suggestions pertaining to navigational instruments. The Bureau of Supplies and Accounts procures navigational instruments, under specifications prepared at the Observatory. The central distributing points for navigational instruments are the Navy Yard, Washington, D. C., and the Navy Yard, Mare Island, Calif. The distributing point for magnetic compasses and articles pertaining thereto is the Navy Supply Depot, Hampton Roads. The Navy Yard, Norfolk, is the supply point for all gyro-compass material. Previous to placing the distribution of navigational material under the Bureau of Supplies and Accounts, the Observatory carried a large stock of material. At present, except for chronometers and certains spare parts for navigational instruments, it has on hand only samples. In order to keep track of material, all navy yards and supply depots report annually the amounts on hand. The Observatory passes on requisitions to insure that purchase is made under the latest specification while the Bureau of Supplies and Accounts checks as to quantity. Inspection is generally made by the inspector of navigational material, in New-York. There are now on hand about 1,000 chronometers. Many of these were purchased a number of years ago; replacement now would cost about $ 450 each, or a total cost of $ 450,000. The allowance for battleships and light cruisers has been reduced to two chronometers. This has resulted in such a surplus of chronometers, that many chronometers can be furnished in an emergency. In addition to the stock of navigational instruments in store for issue at the navy yards, outfits are held in reserve at Philadelphia, San Diego, and Pearl Harbor, for the decommissioned destroyers at those localities. Requisitions for navigational material, other than inexcess requisitions, are acted on directly by the navy yard where a ship is located.

The Observatory prepares the annual estimates for the instruments and supplies appropriations. As a rule the cost of navigational equipment in use on board ship is surveyed or expended at the rate of 10 per cent per year, except for gyro-compass material which is 5 per cent per year, and these arbitrary figures have been found to function very satisfactorily.

That navigational instruments have not developed very rapidly, is to a certain extent due to the excessively large quantities of war time purchases still in stock. The sale of obsolete material is being effected as rapidly as possible. Loss by sale of this material cannot be borne by the instruments and supplies appropriation, and recourse must be had to the law which relieves the appropriation of the loss by sale of all material obsolete prior to March 1, 1921. The bureau has also recommended transfer to a reserve of all excess sounding machines, taffrail logs, boat clocks, stadimeters, and surveying sextants. This will reduce stocks so as to permit the purchase of improved instruments for current needs, while having a stock sufficient for the use of auxiliary vessels.

Despite the handicaps of excess material, the Observatory has made real advances in many respects, and with the sale or transfer to reserve now contemplated, the position will be much improved.

Among the developments for the past few years are :

(1) An improved type of endless tangent screw sextant, with micrometer drum reading attachment, to replace high grade sextants with vernier reading device. In this sextant the arc of the instrument carries a gear rack on its lower edge, meshing with an endless tangent screw, on the shaft of which is the micrometer drum. The graduations of the micrometer drum run from 0 to 59 minutes and 30 seconds. The drum can be read at a glance without the use of the battery lamp at any time there is sufficient light to see the horizon. Improvements in the sextants to be purchased are reduction in weight and simplification in the optical system. One telescope objective will be provided with three eyepieces of two, four and six power. The 6-power eyepiece will carry cross wires for adjusting the telescope holder, to insure parallelism with the plane of the instrument.

(2) Binoculars. — All 10-power binoculars of war-time purchase have been declared obsolete and sold. Six-power war-time binoculars have been reconditioned at the Washington Navy Yard, with new lenses and prisms. A large quantity of 7×50 glasses has been purchased, to replace the old 10-power glass. This choice was made after consideration of the various characteristics of a prismatic binocular, which are power, field, light transmitting qualities, and weight. Generally speaking, the field decreases with additional power. To obtain the best light transmission increase in the size of the objective becomes necessary ; and considerations of practical weight limit this to about fifty millimetres. The reflection of light by the prisms of a prismatic binocular limits its maximum light transmitting power to 50 per cent. A Galilean glass having no prisms has higher light transmission, but has a very limited field for high powers. When a binocular is well focused the emergent pencils of light are nearly parallel and have a diameter equal to the diameter of the objective lens in millimetres divided by the power. In the case of the 7×50 glass, the diameter of these light rays, called the exit pupil, is seven millimetres, which equals the diameter of the iris of the human eye dilated at night. Hence the full light absorbing power of the eye is used by the 7×50 glass. The exit pupil of the 6×30 is five millimetres, the 8×40, five millimetres, and the 10×50, five millimetres ; hence none of these binoculars are as good at night as the 7×50. The 7×50, 8×40, 10×50 each weigh about the same and this is twice the weight of the 6×30. If we accept six or seven power as sufficient, then the 6-power glass, on account if its light weight, is satisfactory for ordinary all round use, and the 7×50 is the most superior marine binocular now manufactured. The weight makes it an inconvenient glass to carry for long periods and it is issued to the service only in such numbers as to have one available for the captain, executive, navigator, signal officer, and one spare. The Bureau of Navigation and the Optical Shop, Navy Yard, Washington, are now experimenting with a bakelite body. If this is successful then the weight disadvantage of the 7×50 glass will be removed. To summarize : we may dismiss the present 10×50 binocular as having too small a field, and unnecessary power for a glass held in the hand ; the 8×40 may be discarded also, although an excellent glass, as the extra power over the seven is overbalanced by the large loss in light transmission. This narrows our choice to a 6- or 7- power binocular with the various advantages and disadvantages of each to be considered according to the use of the glass.

(3) Entirely new spyglasses have been designed capable of focusing like a binocular. At present all spyglasses focus with a draw tube, an objectionable feature. It is believed that the number of types of spyglasses issued, namely, officer of the deck, quartermaster's low power, medium and high power, are excessive, and that one spyglass of about the size and power of the present officer of the deck spyglass, twelve and one-half power, will suffice. When higher power glasses are required on the bridge, the ship's telescope, twenty and forty power, will be avaiblale.

(4) Anemometers with recorders are now being bought to replace the old buzzer type.

(5) An improved telescope, with simplified focusing, is now being used, and thought is being given of even superseding this telescope with a large monocular, variable power, mounted on a simple vertical stand.

(6) The Bureaus of Navigation and Aeronautics are purchasing and experimenting with bubble sextants. The latest purchase is an improved type of DAVIS-RADFORD sextant, which is under test. In this sextant the sun or star is astigmatized, making contact with the bubble more accurate. The sextant can be used also with the natural horizon without the bubble feature. Sextants of this type are expensive instruments and those so far purchased have cost \$ 500 each.

(7) The Observatory is testing on surface vessels accurate watches regulated to mean and sidereal time. These watches are necessary for aircraft and would be valuable timesavers for the navigator of a surface vessel. The best type is set to the exact minute and second by starting the mechanism at the proper time. In the case of the Greenwich mean time watch, it is only necessary to set the instrument to read five hours ahead of 75th meridian noon and to start the mechanism with the noon Naval Observatory time signal. With the sidereal chronometer, the navigator might start his sidereal timepiece shortly before taking star sights. He would have to work out the G.S.T. corresponding to a certain Greenwich and local mean time, or, in the case of both mean and sidereal chronometers, they could be kept running continuously and the error determined each day. In setting the sidereal chronometer the same sidereal interval could be used daily. Any mean time watch or chronometer may be made to keep sidereal time by regulating the timepiece to gain three minutes and fifty-seven seconds daily over mean time. The saving in work for a navigator in taking a round of star sights and marking his time directly from a sidereal chronometer is apparent. Specifications have been prepared for a number of these sets which will be delivered and tested at the Observatory for the Bureau of Aeronautics.

The Bureau of Navigation has recently completed reprinting navigational allowance lists to include all corrections since last printing in 1928. A study of these allowance lists will show that the most important items for the navigator have either already been improved, or are in course of development. Such items as clinometers, drafting machines, sounding machines, protractor, psychrometers, rulers, stadimeters, barometers, etc., are standard equipment with few changes in design. While clocks may be considered standard articles, electric setting clocks for large vessels would be an advance. Here again, however, we are faced with the proposition of coast, and disposal of a large quantity of old clocks. The largest opportunity, however, for the improvement of navigational instruments lies in the field of optics. The successful manufacture of excellent optical glass in the United States since the war has resulted in great strides in the optical field. When the first 7×50 binoculars were purchased, no glass of these dimensions was made in the United States, and the contract went to a foreign concern.

MAINTENANCE DIVISION.

This division is concerned with the upkeep of the navigational instruments, a function distinct from the actual acquisition of such material. It is divided into the following sections : (*a*) time service ; (*b*) repair ; (*c*) inspection ; (*d*) shipping ; (*e*) accounting.

The time service determines time with scientific precision, and distributes the results throughout a large portion of the world. Almost all the time used in the continental United States is based on these determinations. If a person in the United States sets his watch by comparison with a jeweler's regulator, by telegraphic signals, or by time given over the radio for advertising purposes, the chances are that the original source was the Observatory. Of course the accuracy of such secondhand information is apt to be doubtful. The time signals furnish accurate time for navigation to a large portion of the vessels on the oceans. They are also extensively used in Canada and other countries in North and South America. Even in Europe and other foreign countries the U. S. Naval Observatory time signals are received in connection with special investigations.

Time signals are actually sent daily, at 3:00 a.m., noon, and 10:00 p.m., Eastern standard (75th meridian) time. The noon signal was the original one, and is the only one distributed extensively by telegraph. The Western Union Telegraph Company uses this signal as the basis of its time service throughout the country. After radio became available as a means of time distribution it was found desirable to add a night signal, so as to take advantage of the improved reception after dark. Consequently the 10:00 p.m. signal was established. As a result of the increased availability of the signals, and of the greatly increased precision which radio made possible, many new signal uses of scientific and technical nature arose. For some of these purposes, such as precision surveying, it was necessary that the signal occur close to the time when it was desired to use them, so as to avoid errors arising from the use of secondary timepieces. For other purposes it was found that consecutive signals were required, the interval between which was less than the interval between noon and 10:00 p.m., in order to make possible the determination of short period rates. For these and other reasons, the 3:00 a.m. signal was added. A special advantage arises in that the 3:00 a.m. signals are receivable over a larger portion of the Pacific than the other signals.

The radio stations at Arlington and Annapolis are directly controlled by the Naval Observatory clock during the emission of the time signals. A wide range of frequencies, or wave lengths, are used. With reasonably good receiving apparatus, the higher frequencies may be regularly heard as far west as the 180th meridian, and they have been received as far as Australia. Under ordinary circumstances one or more of the frequencies may be received throughout most of Europe. A considerable number of observations of Naval Observatory time signals have been received even in South Africa.

The ordinary uses of the time signals, such as in everyday life and for the navigation of ships at sea, are generally known. The special uses are not so well understood. Four of these uses are discussed herewith, as examples of the scientific and technical utility of the signals :

(*a*) In ordinary surveying, the position of land is determined with reference to some base line. The position of the fundamental base lines must be determined by means of astronomical observations. By far the most accurate and convenient method of determining positions so far as longitude is concerned is by the determination of local time from astronomical observations, and the comparison of the results with the time of some established meridian, as indicated by time signals. The United States Coast and Geodetic Survey and similar organizations in Canada and other countries utilize Naval Observatory time signals for this purpose. The positions of national, state, and local boundaries, and indirectly the boundaries of smaller parcels of land, are thus dependent on time signals. Likewise all maps are based on such determinations.

(*b*) Astronomers in various parts of the world receive Naval Observatory time signals for use in connection with their own observations and for scientific comparison and study.

(*c*) The pull of gravity is not the same at all points on the earth's surface. Owing to the rotation and ellipticity of the earth, gravity is stronger at the poles than on the equator. In addition, there are local variations over the earth's surface, depending on the character of the geological formations. The only feasible method of measuring the value of gravity at any point is by rating a standard pendulum, the period of which has been determined at a station of known gravity. For rating such pendulum it is necessary to establish a standard time interval, which may be conveniently accomplished by means of consecutive time signals. These gravity measurements are of great importance not only in geodetic research, but also in investigating the presence of mineral and oil deposits.

(*d*) The increased crowding of the available channels for radio communication makes necessary very high precision in the measurement of radio frequencies or wave length. These measurements are generally made by comparison with a standard frequency oscillator. The eventual standard must be rated by a determination of the number of oscillations in unit time. For this purpose very accurate time intervals must be established, which may be conveniently done by reception of time signals.

After each time signal is sent out, the actual times of emission recorded on each of several radio frequencies, as shown by the chronograph sheets, are measured. Also, many star sights for time determination are taken, making possible improved corrections to the standard clocks. As a result, it is possible to send out corrections for the signals emitted. The average value of the corrections so computed, for 113-kilocycle frequency, is about 0.03 of a second. For the other frequencies it is slightly more. These corrections are unimportant for ordinary purposes. However, for special purposes, such as those listed above, it is desirable to apply every possible correction. The Naval Observatory issues correction sheets to all who desire to receive them, giving the data for all signals. The corrections are utilized by observatories in the United States and foreign countries, by surveyors, geodesists and physicists doing work involving time, by the large electrical and radio companies, and also by a considerable number of special workers and investigators, including watch manufacturers.

The three RIEFLER clocks that are now being used were purchased in 1903, 1904 and 1907. These clocks are old and their daily rates vary more than they should for such precision timepieces. Since these clocks were purchased a new clock has been developed in England, called the SHORTT clock, which is much more accurate than the RIEFLER. This clock has been in use at the Observatory at Greenwich for some time and has been very satisfactory. One of these clocks is now being purchased for the Naval Observatory and it is hoped to be able to replace all of the RIEFLER clocks with SHORTTS as soon as funds are available.

There are two astronomers and two line officers assigned to duty in the time service. These officers perform the same duties as the astronomers, which include taking celestial observations, calculating the errors and rates of the clocks and sending out the time signals and corrections.

The repair section maintains a repair shop at the Observatory, where any repairs can be made to navigational instruments and timepieces. A balanced work load for this shop is assured through the establishment of cordial cooperative relations with various government activities requiring occasional precision repair work. This occasional work is not permitted to interfere with the repair shop's service to the fleet. Precision instrument repair shops are maintained in several of the navy yards; but owing to lack of equipment and experienced personnel, these shops only undertake minor repairs to instruments. Instruments surveyed as unfit for use are returned to the Observatory where they are broken down and the usable parts salvaged to repair similar instruments.

In addition to this, all chronometers in use on the east coast are returned to the Observatory every four years for cleaning and adjustment. After this cleaning and adjustment each chronometer is put under test and accurately rated for a period of about seventy-five days. These tests are conducted in a specially prepared test room in which the temperature is electrically controlled and the chronometers are rated at temperatures ranging from 55 to 90 degrees. From these tests a temperature rate curve is constructed from which the rate of the chronometer can be picked off for any temperature within the range of the curve. The chronometers in use on the west coast are cleaned and repaired by contract at San Francisco.

The Naval Observatory is the source of supply of all spare parts for the repair of nautical instruments, magnetic compasses and clocks, both afloat and ashore. The average number of instruments repaired per month is well over six hundred, and all of these instruments require major repairs.

The inspection section inspects a large proportion of all new navigational equipment that is purchased, including a large part of the aerial navigational equipment including spare parts. This inspection runs up to well over two thousand instruments and parts per month.

COMPASS DIVISION.

This division is concerned with the administrative details involved in the development, procurement, and supply of gyro and magnetic compass equipment and of all instruments and articles pertaining thereto for the naval establishment, including the repair, upkeep, and inspection of such material. This office also acts in an advisory capacity in the detail, training and distribution of officers and men experienced in gyro-compass work. The annual and semiannual reports and inventories of compass equipment are reviewed and filed here. The *Compass Office Bulletin*, by means of which information and instructions are published to the service concerning the operation, adjustment, repair and development of gyro-compass material, is prepared and issued here. During recent years developments in the compass field have been confined mostly to gyro-compasses and their accessories, although there has been some other progress.

The standard Navy magnetic compass has been altered and improved little during the past twenty years. However, at the present time effort is being made to obtain a satisfactory and stable petroleum distillate, less palatable than the usual alcohol-water solution for these compasses. The Engineering Experiment Station has done considerable research along this line at the instigation of the compass office and sample oils are now under test to determine their suitability. Difficulty has been experienced in obtaining an oil that does not change color and obscure the compass card after exposure to sunlight for a long period of time. The use of oil for the compass solution will tend to permit the use of hardened steel pivot points (not feasible due to corrosive action in present solution) and eliminate the necessity of using albumen paint for the compass interior. Albumen paint now employed for the compass card and bowl is made with the whites of fresh eggs. This paint is difficult to mix to the proper consistency and is even temperamental to the atmospherical conditions under which it is prepared. An oil solution will permit the use of cellulose paint. Another problem is the procurement of a satisfactory gasket material that can be substituted for rubber in the present compasses. A pressed cork gasket, similar to that used with the oil-filled aircraft compasses, is now being experimented with.

Efforts are also being made to develop a repeater system suitable for use with magnetic compasses. An experimental equipment, the design features of which give promise of satisfactory operation, will be purchased for test. The transmitter of this system is designed to be mounted on top of a standard Navy compass in its binnacle. It is claimed that the transmitter will not affect the compensation of the compass. The source of electrical power for the transmission system is to be an ordinary 12-volt storage battery. The system is capable of operating several repeaters and, if it proves satisfactory, will permit eliminating the steering and auxiliary magnetic compasses on vessels.

All vessels are now supplied with bearing circles, more rugged instruments than the standard azimuth circles and suitable for observing bearings of terrestrial objects. Azimuth circles are still supplied for use in taking sun azimuths. The new telescopic alidade, about to be distributed to vessels, consists of a 4-power telescope permanently mounted on a bearing circle. The prism arrangement of the telescope permits the operator to observe a distant object, the reading of the repeater card, and the spirit level without removing his eye from the eyepiece. This instrument also has a high angle prism attachment for azimuth observations of stars or the sun.

The recent developments and improvements of gyro-compasses have been extraordinary. From a purely navigational point of view the 1920 edition of gyro-compasses was satisfactory. The recent developments have been influenced mainly by the demands that the accuracy of gyro-compasses satisfy the requirements of present-day long-range fire-control equipment. Development of more accurate compasses than are at present obtainable is dependent somewhat upon the development of an accurate gyro-compass sea-testing equipment, utilizing high speed moving picture cameras to record observations for compass errors. Such an equipment is now being assembled, and will be tested out in the near future.

The two concerns in the United States that manufacture and supply gyro-compasses to the Navy have followed slightly different principles in their design and development work. The SPERRY Company has stressed the employment of larger, heavier, and higher speed gyro-rotors to obtain greater directive force and thereby greater accuracy. The ARMA Company has developed a stabilized compass and has stressed more the design features which tend to eliminate the causes of gyro-compass errors.

In the specifications for the earlier gyro-compasses, the repeaters were required to follow the indications of the master compass to within 0.5 degree, and the presence of a "hunt" in the repeater card was considered a desirable feature as it enabled an observer to note at a glance whether or not the repater was "alive". These earlier type repeaters were operated by a direct current step-by-step transmission system and it was necessary to synchronize each repeater with the master compass each time the system was put in operation.

The present specifications call for self-synchronizing repeaters which operate without any "hunting" movement and follow the indications of the master compass within 0.03 degree. The higher accuracy is attained by the employment of two motors in the repeater, each motor being energized by a separate transmitter on the master compass. The 1-to-1 speed motor operates when the repeater is first connected up to bring the repeater card within a few degrees of synchronism with the master. The 36-to-1 speed motor controls the movement of the repeater card under normal operating conditions, although both motors are inter-connected by suitable gearing.

A vacuum tube control for the follow-up system of the master has been a feature of the ARMA compass for several years, and recently such a system in a different form has been developed and will be used with the latest type SPERRY compasses. Some idea of the complications involved in the design and manufacture of modern high accuracy gyro-compasses is indicated by a comparison of the costs of manufacture ($ 40,000 for modern duplex equipments; $ 8,000 for the earlier types).

Other navigational equipment and instruments used in the gyro-compass system are the SPERRY self-synchronous alidades and the ARMA dead-reckoning tracers. The self-synchronous alidade is a form of pelorus repeater which operates an azimuth telescope mount. The distinctive operating feature of this instrument is its action in maintaining the azimuth telescope on any set "true" bearing regardless of changes in the ship's heading. An example of the utility of the instrument is its employment by a vessel while maintaining position on a line of bearing. The telescope can be set on the correct "true" bearing and subsequent thereto a glance along the line of sight of the telescope indicates whether the ship is ahead or behind position, irrespective of how much the steersman may be off his course.

Arma dead-reckoning tracer equipments, including the course component recorders, tracking tables, and latitude-longitude indicators, are now standard for all battleships and light cruisers. The input to the dead-reckoning tracer system consists of a gyro-compass repeater and a connection to the mechanical Cumming's all-shaft average counter through an electrical transmitter, located in the engine-room.

By setting a dial on the course component recorder to the revolutions-per-mile reading, corresponding to the speed, this instrument converts the total revolutions and the course into "miles east" (or west) and "miles north" (or south) and transmits electrically these factors to the tracking table and to the latitude-longitude indicator. The path of the ship is reproduced on the tracking table to any scale desired between one mile and eight miles to the inch. The latitude-longitude indicator converts the two factors into difference of latitude and departure. The latitude and longitude dials when once set for a known position of the vessel will continue to indicate the dead reckoning position at any instant thereafter. These instruments indicate accurately to within 0.5 per cent when the revolutions-per-mile dial on the course component recorder is properly set. They do not, however, make allowances for currents.

The Hydrographic Office is now preparing to issue plotting sheets for use with the dead-reckoning tracer tracking table, each plotting sheet to be so constructed that the scale at the middle latitude of each sheet will be seven miles to the inch.

A combined latitude-longitude indicator and course component recorder has been proposed for installation on destroyers where space and weight restrictions do not permit the installation of the standard equipment. So far there has not been sufficient demand for such an equipment to warrant its development, but the necessity for something of the sort may soon develop.

COMPASS COURSE.

Another actively connected with the compass office is the compass school, conducted for the practical instruction of officers of the Navy in the compensation of magnetic compasses under conditions simulating those to be expected aboard ship. Special equipment has been provided for this instruction, consisting of a turn-table contrivance called a Scoresby stand, upon which are mounted a standard Navy magnetic compass in its compensating binnacle, an assortment of permanent bar magnets and horizontal and vertical soft iron. By means of this equipment, the influences that operate to produce deviation in a compass aboard ship can be demonstrated and analyzed.

A short course of instruction, which may be covered in three days, serves as a refresher course for officers ordered as navigators for the first time, and gives to them experience in effecting compass compensation. Such practical experience is very difficult to obtain at sea for it is very seldom if ever, in these days, that the navigator is given the opportunity to carefully compensate his magnetic compasses.