

The Use and Testing of Compasses and Magnetometers at the National Data Buoy Center

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Abstract—The buoys deployed by the National Data Buoy Center (NDBC) measure many environmental variables, both oceanographical and meteorological. Three of these measurements in particular—atmospheric winds, ocean currents, and surface water waves—require that a horizontal direction reference be used. Although there are several types of instruments and methods that can provide this direction reference, NDBC has found compasses and magnetometers to be the best choice for the application.

The characteristics of the Earth's magnetic field at the location where a buoy is deployed are usually well known. For most of the cases, a computer model of the Earth's magnetic-field vector produces its magnitude values in the three-dimensional directions (components) at the geographic coordinates (latitude and longitude) of the buoy station. At other times a direct in-situ measurement of the Earth's magnetic-field vector is obtained. A magnetic compass or a triaxial magnetometer (and sometimes both) installed on the buoy provides the values of the magnetic heading of the buoy's hull and superstructure. This is the direction reference that the buoy's other instrumentation needs in order to provide the angular orientation relative to Earth for the other measured variables. The propeller-vane anemometers deployed by NDBC measure wind direction relative to the buoy's hull. The magnetic heading of the hull, as determined by a magnetic compass, and appropriate calculations by the buoy's data processor permit reporting wind-direction values referenced to Magnetic North. When the local magnetic variation is known, one further calculation relates wind direction to Geographic North. Similarly, the sensors that measure water currents and surface-water waves need the buoy-hull magnetic heading values for referencing their measurements to an Earth-fixed angular orientation. In the case of sea surface waves, a magnetometer is used to measure the buoy's pitch and roll motion as well as buoy azimuth. The measurement of the buoy's heave, along with the pitch and roll angles determined from the measurement of magnetic field components provide all the information necessary to estimate wave directionality.

Many different designs of electronic remote-reading magnetic compasses and magnetometers have been used at NDBC. Flux-gate, Hall-effect, magnetoresistive, and magnet/rotating coded card designs, to name a few, have been deployed. The testing of these magnetic instruments is routinely done at NDBC's "compass-rose" test stand. More recently a triaxial Helmholtz coil test fixture installed inside a walk-in environmental temperature chamber has been placed into operation.

I. INTRODUCTION

The National Data Buoy Center (NDBC) deploys buoys that measure and report, via the Geostationary Operational Environmental Satellite

(GOES), meteorological and oceanographic measurements from all the Earth's oceans. Fig. 1 shows a typical NDBC 3-meter discus-hull buoy and the general arrangement of the hull, superstructure, sensors, communication and electrical power systems. Other buoy sizes deployed by NDBC are the 6-meter (boat-hull), the 10-meter (discus-hull), and the 12-meter (discus-hull). The "payload" or sensor/data-gathering equipment on all these different buoy sizes is very similar.



Fig. 1. An NDBC 3-meter discus-hull buoy dockside.

The measurements made by these buoys of atmospheric winds, ocean currents, and surface-water waves require an auxiliary measurement of the azimuthal orientation of the buoy's hull or the sensor's reference mark relative to the Earth. These environmental variables are vectors. Other variables measured by the NDBC buoys, such as barometric pressure, air temperature, and water temperature, are scalar quantities and do not require a direction reference to Earth's Geographic North. Magnetic compasses or magnetometers installed on the buoy, as well as the knowledge of the magnetic variation at the deployment site (measured in-situ or derived from a computer model), are used in all cases to provide the azimuthal orientation of the environmental sensor.



Fig. 2. A 3-meter discus-hull buoy undergoing a “buoy spin” magnetic sensor test.

Gyrocompasses are not used for obtaining direction reference measurements when the buoys are deployed. They consume too much electrical power. However, a gyrocompass is installed on a buoy during dockside and in-the-water “buoy-spin” tests, as shown in Fig. 2. Here the buoy is rotated around its vertical axis, and the azimuthal direction measurements (by the magnetic compasses and magnetometers) are compared to the true geographic azimuth measured by a gyrocompass.

II. OCEANOGRAPHICAL AND METEOROLOGICAL VARIABLES

On NDBC buoys, ocean currents are measured. These sensors are rigidly attached to the buoy's hull, and their flow transducers are located a few meters below the surface of the water. The two-axis electromagnetic current meters built by . The two-axis electromagnetic current meters built by Marsh-McBirney and by Interocean have been deployed on NDBC 3-meter discus buoys. Acoustic current meters have also been deployed. The Aanderaa two-axis single-point design has been installed on 3-meter and 6-meter buoys. RD Instrument's Acoustic Doppler Current Profile (ADCP) systems have been used to determine the flow speed and direction in the water column below 10-meter and 12-meter discus-hull buoys in the Pacific Ocean. Recently ADCP systems have also been deployed on some NDBC 3-meter discus buoys like those shown in Figs. 1 and 2..

Surface-water waves, another oceanographical variable, are also measured by NDBC buoys. The wave amplitude and the wave direction are determined using accelerometers, pitch-roll sensors, and algorithms that interpret the wave-induced buoy motions measured by these sensors. The nature of the water waves that caused the motion is thus determined.

Anemometers are supported on masts above the buoys (Figs. 1 and 2). They measure the speed and direction of the wind, which is a vector quantity. Propeller-vane anemometers manufactured by RM Young are almost exclusively used. The anemometer's propeller measures the magnitude of the wind vector, regardless of the buoy's azimuthal in the horizontal plane. The vane or tail

of the anemometer aligns with the direction of the air flow past the buoy. However, here the propeller-vane anemometer measures only the relative angular orientation between the buoy and the anemometer's vane. A compass is needed to obtain Earth-referenced wind direction.

For the complete determination of the oceanographical and meteorological variables described above, it is necessary that the azimuthal orientation of the platform (buoy) that supports the measuring systems be known. At NDBC this angular position (heading) of the vector is sensed by a magnetic sensor, such as a compass or a magnetometer. The magnetic compass provides the instantaneous values of the buoy's magnetic azimuth (reference to Magnetic North). The algebraic addition of the local magnetic variation angle (which can be positive or negative) to this angular measurement of the buoy's magnetic heading yields the geographic azimuth (reference to Geographic North) of the buoy and the measurement systems on board. The local magnetic variation angle at the buoy's deployment site is determined either by in-situ measurements or is derived by computations using Earth magnetic-field mathematical predictor models.

III. COMPASSES AND MAGNETOMETERS

Several of the environmental variables that are monitored by the NDBC buoys are vector quantities, and their true orientation must be referenced to the Earth's geographic coordinates. Wind and water current direction, as well as the direction of propagation of surface-water waves of different amplitudes and frequencies, are all reported relative to the Geographic North direction. In order to obtain a direction reference on buoys, both the magnitude and direction of the Earth's magnetic field are sensed. If only direction measurements are needed, as for wind-direction determinations, magnetic compasses are installed on the buoys. When more detailed sensing of buoy-hull motions (pitch, roll, yaw) are required, as for surface-water wave measurements, triaxial magnetometers are added to the complement of inertial sensors that form the buoy's wave-measurement system.

Some of the magnetic sensors presently used by NDBC are shown in Fig. 3. Other designs, such as the Digicourse model 101 grey-coded, gimballed magnetic card compass, and the fluid-gimballed flux-gate compass units manufactured by Magnavox for sonobuoys have been used in the past. On the left of Fig. 3 is shown a model FGM-301 triaxial flux-gate magnetometer with analog voltage output manufactured by Watson Industries. At the top center is a compass built by Ritchie Navigation. Their model MS-100 with digital output is used in conjunction with the buoy's propeller-vane anemometers. A model TCM-2 combination compass and magnetometer manufactured by Precision Navigation is shown at the center bottom of Fig. 3. On the right side is the model TAMS magnetometer built by General Oceanics. It is also of the flux-gate design and has analog voltage output signals for each of its three orthogonal axes.

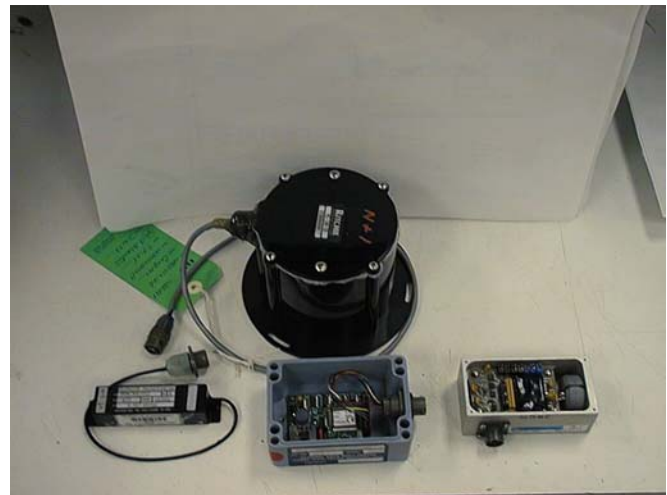


Fig. 3. Some typical compasses and magnetometers that are installed on NDBC buoys.

IV. COMPASS ROSE

For the routine testing of compasses and magnetometers, a facility was installed by NDBC in an open field well away from buildings, structures, and other objects that might cause distortion to the magnitude and direction of the Earth's local magnetic field.

This "compass rose" magnetic test stand consists of a central platform surrounded by a ring of marker posts (Fig. 4). The platform (Fig. 5) is an extremely rigid welded assembly consisting of four vertical legs made from five-inch diameter aluminum pipe sections that support a horizontal three-foot diameter flat circular top. This top, (Fig. 6) which is fabricated from one-inch-thick aluminum plate, is three feet above the ground. A square concrete slab with stainless steel reinforcing wires (nonmagnetic) is on the ground under the platform to provide further stability to the test stand.

The platform's top, on which the compasses and magnetometers are placed during testing, has thirty-six radial scribe marks at precisely ten-degree intervals. The zero-degree scribe mark is aligned with the Geographic North direction. A very detailed Global Positioning System survey was made to adjust the test platform accurately to this geographic orientation. The Magnetic North direction was not used for reference-mark alignment in order to avoid future reorientations as the local magnetic variation gradually changed with time. At the center of the test platform is a small turntable that permits easy rotation on the horizontal plane of the magnetic sensors when they are being tested.

Also at the "compass rose" are marker posts arranged in a large circle (thirty-foot radius) around the central test platform. The twenty-four marker posts are spaced at fifteen degrees and are aligned with the local Magnetic headings. They are used when anemometers with attached magnetic-heading sensors are tested by visually pointing their reference axis to the more distant marker post instead of to the scribe lines on the top of the test platform.



Fig. 4. The NDBC "compass rose" magnetic sensor test facility.



Fig. 5. The platform that supports the sensors at the center of the "compass rose."



Fig. 6. Top plate and turntable on the center platform of the “compass rose.”

V. HELMHOLTZ COILS

The testing of compasses and magnetometers at the NDBC “compass rose” facility can only subject these sensors to the value of the Earth’s local magnetic field as it exists at this test site. The magnitude and direction of this local field cannot be controlled. Instead, the orientation of the magnetic sensor under test must be set at different angles with respect to the local magnetic field vector in order to determine the sensor’s magnetic angular response. At no time during the testing at the “compass rose” can the magnitude of the Earth’s magnetic field vector be changed.

Since the NDBC buoys are deployed at many different oceanic locations, the Earth’s magnetic field at these deployment sites will, in general, have a different magnitude and dip angle (declination) from that at the NDBC “compass rose” site.

To be able to test the compasses and magnetometers under magnetic field conditions, identical to those that exist at different Earth locations, a triaxial Helmholtz-coil test apparatus was built and installed inside NDBC’s testing laboratory. This triaxial Helmholtz coil has three electromagnetic coil pairs that are orthogonally arranged. Each coil pair produces a magnetic field with a direction that is perpendicular to the plane of the coils. The magnitude of this field is proportional to the electrical current flowing

through two windings of the coil pair. Also, the sense (direction) of the magnetic field can be reversed by changing the direction of the current flow in the windings.

Fig. 7 shows the NDBC triaxial Helmholtz-coil magnetic testing apparatus. The diameter of the largest two coils is 1.52 meters (60 inches), and their separation is 0.76 meters (30 inches), as per the Helmholtz-coil design criteria. The other two coil pairs have diameters of 1.37 meters (54 inches) and 1.22 meters (48 inches), with separations of 0.68 and 0.61 meters (27 and 24 inches) respectively.

Three DC power supplies provide the direct current excitation to the coils. These power supplies are computer controlled (via an RS-488 interface bus), and are capable of output polarity reversal. Their maximum ratings are approximately eight amps at twenty-four volts.

The overall size of the triaxial Helmholtz coils was determined by the size of the walk-in environmental chamber in NDBC’s testing laboratory. Its test section is approximately 2.25 meters high, 2.25 meters wide, and 4.80 meters deep. The chamber is shown in Fig. 8 with its access door opened. By placing the Helmholtz-coil test fixture inside the walk-in chamber, the performance of magnetic sensors under different environmental temperature conditions can be determined.



Fig. 7. Triaxial Helmholtz-coil magnetic field test fixture.



Fig. 8. Walk-in chamber in the NDBC testing laboratory. Front door opened.

VI. CONCLUSION

Magnetic compasses and magnetometers can be used effectively to assist in the measurement of environmental variables that are vector quantities. The use of magnetic sensors is advantageous when the orientation of the vector quantity must be referenced to the Earth's geographic directions.

When the azimuthal orientation of the platform that supports a sensor system changes in an unpredictable and random manner, as is the case with NDBC buoys, compasses and magnetometers that sense the “unchanging” Earth's magnetic field can provide a steady direction reference. This method is simple, reliable, proven, and inexpensive.

Compasses and magnetometers can be tested using the Earth's local magnetic field as it exists at the site of the test facility. However, a more versatile and effective method is to use a triaxial Helmholtz-coil test apparatus that is able to apply, in a controlled manner, a magnetic field of any magnitude and direction. The magnetic field condition that is present at any location on the surface of the Earth can be simulated with this testing system. In addition, the placement of the Helmholtz-coil test apparatus inside a thermal environmental chamber permits magnetic sensors to be evaluated under controlled thermal conditions.