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Navigational Location and Attitude (NAV) Instrument Handbook

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ARM

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Acronyms and Abbreviations

ACAPEX	ARM Cloud Aerosol Precipitation Experiment
ADC	ARM Data Center
AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
GPS	Global Positioning System
INS	inertial navigation system
MSL	mean sea level
MWACR	Marine W-band ARM Cloud Radar
RPH	roll, pitch, and heave
RV	Research Vessel
SBP	submarine broadcast processor
SCP	Secure Copy Protocol
UDP	User Datagram Protocol
UTC	Coordinated Universal Time

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1.0 Instrument Title

iXSea or iXBlue HYDRINS III Global Positioning System (GPS)-aided inertial navigation system (INS)

Prior to December 2012, the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) second ARM Mobile Facility (AMF2) used a Kearfott SEANAV INS system model KN-5051-G S/N 1001. The SEANAV Ring Laser Gyro reached its end of life and its cost to repair was considered too high to continue maintaining it. The AMF2 HYDRINS system has been equipped with firmware to produce the SEANAV ID1 protocol directly, but also adding a date stamp to a previously unused field. Thus, it is okay to refer to the new system as the SEANAV since it emulates the original SEANAV. (Martin 2013, 2)

2.0 Mentor Contact Information

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(HYDRINS Quick Start Guide 2010, 31)

4.0 Instrument Description

HYDRINS is an inertial navigation system that provides true heading, attitude, speed, and position. It is dedicated to surface hydrographic survey (multibeam echo-sounder, submarine broadcast processor (SBP), sonar). HYDRINS includes a high-level inertial heart based on fiber-optic gyroscopes coupled to an embedded digital signal processor that runs a Kalman filter specially developed for marine applications. The HYDRINS Kalman filter holds GPS hybridation for surface alignment purposes and accurate position and altitude computation. (HYDRINS User Guide 2010, 3)

5.0 Measurements Taken

INSs provide high-accuracy motion data in three translational frames and three rotational frames of reference. Data fusion of the INS and GPS datastreams is performed using Kalman filtering to produce high-accuracy and drift-free location, attitude, and motion data. The three translational axes are X, Y, Z or surge, sway, and heave. The three rotational axes are roll, pitch, and yaw. The SEANAV coordinate system is shown in the figure below. Note the sign-sense of each axis. Example: positive surge is forward motion, positive roll is port side up, etc. Ship "attitude" refers to the combined roll, pitch, and yaw (or heading) angles. (Martin 2013, 2)

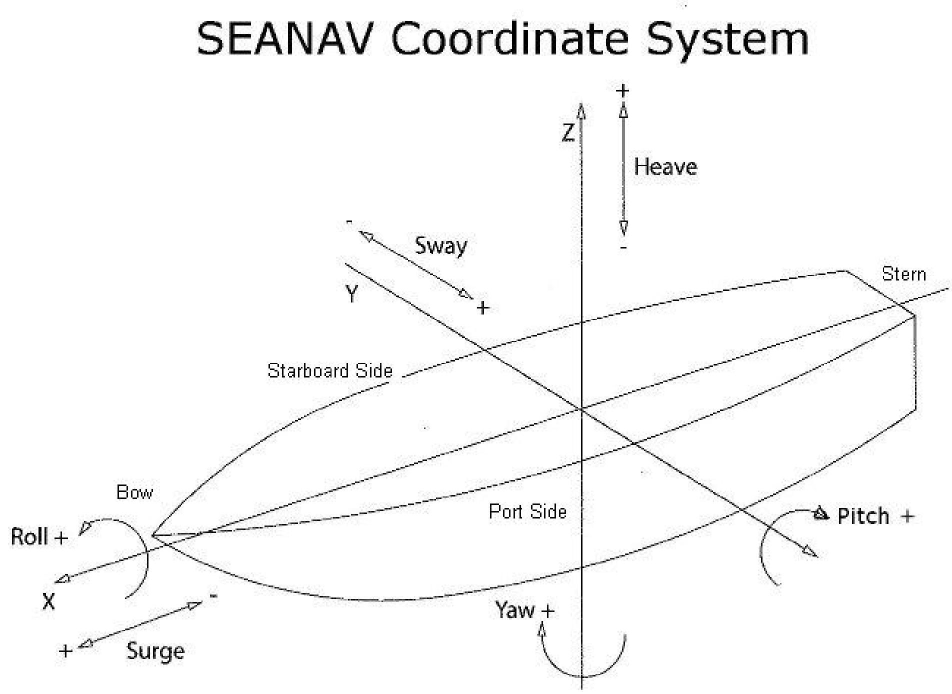

Figure 1. SEANAV coordinate system.

6.0 Links to Definitions and Relevant Information

iXBlue website: http://www.ixblue.com/

6.1 Data Object Description

The SeaNav virtual machine (VM) received input from the HYDRINS unit in the SEANAV ID=1 raw binary output data format. This format consists of fixed-length records of 56 bytes. The 56 bytes are as follows: $AA, $01, $34, D1, D2, D52, CX where $ defines fixed hexadecimal values, D1–D52 varying data values, and CX the exclusive OR of all preceding bytes in the record except the start byte $AA. Format and definition of bytes D1 thru D52 are defined below. Note that all binary data bytes must be sent in little-endian order. That is, the least significant byte must be sent first. Note that the SEANAV ID=1 protocol has been modified in that the "BHEIGHT" D17, D18 bytes are replaced with two coded date bytes specified below.

Table 1. SEANAV navigation data fields.

Byte#	Name	Description	Units	Data Type
D1, D2	cycles	Record counter (0 thru 65535)	NA	U16
D3	mode	Alignment mode	NA	Bits
D4	monitor	navigation aid status	NA	Bits
D5-D8	latitude	Latitude (-90 to +90 deg)	$180*2^{-31}$	S32
D9-12	Longitude*	Longitude (-180 to +180 deg)	$180*2^{-31}$	S32
D13-D16	depth**	INS depth (negative altitude MSL)	cm	S32
D17, D18	date***	bit coded year, month, day	NA	U16
D19, D20	roll	port up positive (-180 to +180 deg)	$180*2^{-15}$	S16
D21, D22	pitch****	bow up positive (-90 to +90 deg)	$180*2^{-15}$	S16
D23, D24	yaw	true heading from N (0 to 360 deg)	$180*2^{-15}$	U16
D25, D26	X velocity	forward velocity (-32 to +32 m/s)	2^{-10} m/s	S16
D27, D28	Y velocity	toward port vel. (-32 to +32 m/s)	2^{-10} m/s	S16
D29, D30	Z velocity	up velocity (-32 to +32 m/s)	2^{-10} m/s	S16
D31, D32	X accel	forward accel (-32 to +32 m/s*2)	2^{-10} m/s	S16
D33, D34	Y accel	to port accel (-32 to +32 m/s*2)	2^{-10} m/s	S16
D35, D36	Z accel	up accel (-32 to +32 m/s*2)	2^{-10} m/s	S16
D37, D38	roll rate	(-4 to +4 radians/sec)	2^{-13} rad/s	S16
D39, D40	pitch rate****	(-4 to +4 radians/sec)	2^{-13} rad/s	S16
D41, D42	yaw rate	(-4 to +4 radians/sec)	2^{-13} rad/s	S16
D43-D46	Time*****	UTC time since 00:00:00	2^{-14} sec	U32
D47, D48	surge	forward + (-64 to +64 m)	2^{-9} m	S16
D49, D50	sway	port + (-64 to +64 m)	2^{-9} m	S16
D51, D52	heave	up + (-64 to 64 m)	2^{-9} m	S16

* Note that SEANAV longitude is -180 to +180 degrees rather than 0 to +360 as HYDRINS.
Correct logic is as follows: if (longitude>180.0) longitude = longitude-360.0
** Note that depth shall be negative altitude in centimeters from MSL.
Correct logic is as follows: if(alt!=0) alt = -alt (because we don't want negative zero)
*** The SEANAV "BHEIGHT" bytes are replaced here by date, coded in 16 bits as follows:
yyyyyyymmmmddddd : yyyyyyy is year since 1970, mmmm is month 1-12, ddddd is day 1-31
**** Note that pitch and pitch rate are opposite sign sense as HYDRINS.
Correct logic is as follows: if (pitch!=0.0) pitch = -pitch (we do not want negative zero) ***** For D43-46: If MSB=1, then GPS time is not yet received and time is seconds since turn on.
If MSB=0, then GPS time is available and time is seconds since start of day.
For GPS dropouts, extrapolated time may be used and MSB=0.

MODE bit values
$00 = Alignment not started
$06 = Fine Alignment with GPS
In addition to the SEANAV ID=1 input format, the SeaNav MV provides three output formats that include the WINAV, TSINV, and MANAV. These output formats are described below:

The WINAV record has the following comma-separated format:
$WINAV,yyyymoda,hrmnsc,latitude,longitude,sog,cog,pitch,roll,yaw,*CS

Table 2. WINAVe record format.

Record Part	Data Represented
$WINAV	Record Type Indicator
yyyy	Year
mo	Month
da	Day
hr	Hour
mn	Minute
sc	Second
latitude	Latitude
longitude	Longitude
sog	Speed Over Ground
cog	Course Over Ground
pitch	Pitch
roll	Roll
yaw	Yaw
CS	XOR byte Checksum

The TSINV record has the following comma-separated format:
$TSINV,yyyy,mo,da,hr,mn,sc,latitude,longitude,heading

Table 3. TSINV record format.

Record Part	Data Represented
$TSINV	Record Type Indicator
yyyy	Year
mo	Month
da	Day
hr	Hour
mn	Minute
sc	Second
latitude	Latitude
longitude	Longitude
heading	Yaw

The MANAV record has the following comma-separated format:
$MANAV,yyyy,mo,da,hr,mn,sc,latitude,longitude,roll,pitch,yaw,cog,sog

Table 4. MANAV record format.

Record Part	**Data Represented**
$MANAV	Record Type Indicator
yyyy	Year
mo	Month
da	Day
hr	Hour
mn	Minute
sc	Second
latitude	Latitude
longitude	Longitude
roll	Roll
pitch	Pitch
yaw	Yaw
cog	Course Over Ground
sog	Speed Over Ground

6.2 Data Ordering

The summary plots of HYDRINS (NAV) data are available via the ARM Data Discovery tool. On ship, these plots are updated hourly. These plots are also sent to the ARM Data Center (ADC) daily.

6.3 Data Plots

Note that summary plots of HYDRINS (NAV) data are available via the Data Discovery tool. On ship, these plots are updated hourly. These plots are also sent out daily via the Iridium satellite network and are an excellent means for any user to examine the NAV motion data as well as displaying the quality of the leveling control for the Marine W-band ARM Cloud Radar (MWACR) antenna mounted on the roll, pitch, and heave (RPH) motion table. (Martin 2013, 4)

6.4 Data Quality

While reading data from the HYDRINS unit, errors are possible. Some errors may be from communication with the HYDRINS unit, corrupt data, or loss of signal. When an error occurs, the system will stop processing and remove the current output file so that other systems do not read old or corrupted data. The system will attempt to re-start processing as soon as possible to minimize the amount of missing data.

6.5 Instrument Mentor Monthly Summary

This report has been discontinued.

6.6 Calibration Database

The translational motion data including velocities and accelerations are in the ship frame of reference. Note that yaw or heading is the direction the bow is pointing, NOT what direction the ship is actually moving. For the ARM Cloud Aerosol Precipitation Experiment (ACAPEX) in 2015 off the U.S. west coast, the INS system was installed to agree within one degree with the *RV Ron Brown* gyrocompass.

7.0 Technical Specification

7.1 Units

All time data is presented in 4-digit year, 2-digit month, 2-digit day, 2-digit hour, 2-digit minutes, and 2-digit seconds. Latitude and longitude are measured in degrees. Roll, pitch, and yaw are measured in degrees from level. Speed over ground is measured in meters per second and course over ground is measured in degrees from true north.

7.2 Range

Operating/storage temperature	-20 to 55 °C / -40 to 80 °C
Rotation rate dynamic range	Up to 750 deg/s
Acceleration dynamic range	± 15 g
Heading/roll/pitch	0 to + 360 deg / ± 180 deg / ± 90 deg
Mean time between failures (computed/observed)	40,000/80,000 hours
No warm-up effects	
Shock and vibration proof	

(HYDRINS Quick Start Guide 2010, i)

7.3 Accuracy

Position accuracy Real Time	
With GPS	3 times better than GPS
No aiding for 1 min/2 min	0.8 m/3.2 m
Position accuracy post-processed	
With GPS	4 times better than GPS
No aiding for 1 min/2 min	0.2 m/1 m
Heading accuracy	0.01 deg. secant latitude
Roll and pitch dynamic accuracy	0.01 deg.
Heave accuracy (Smart Heave)	2.5 cm or 2.5%

(HYDRINS Quick Start Guide 2010, i)

7.4 Repeatability

For ACAPEX, the INS system was installed to agree within one degree with the *Ron Brown* gyrocompass. The INS system was mounted in the operations van near the center line of the ship. See Figure 1.

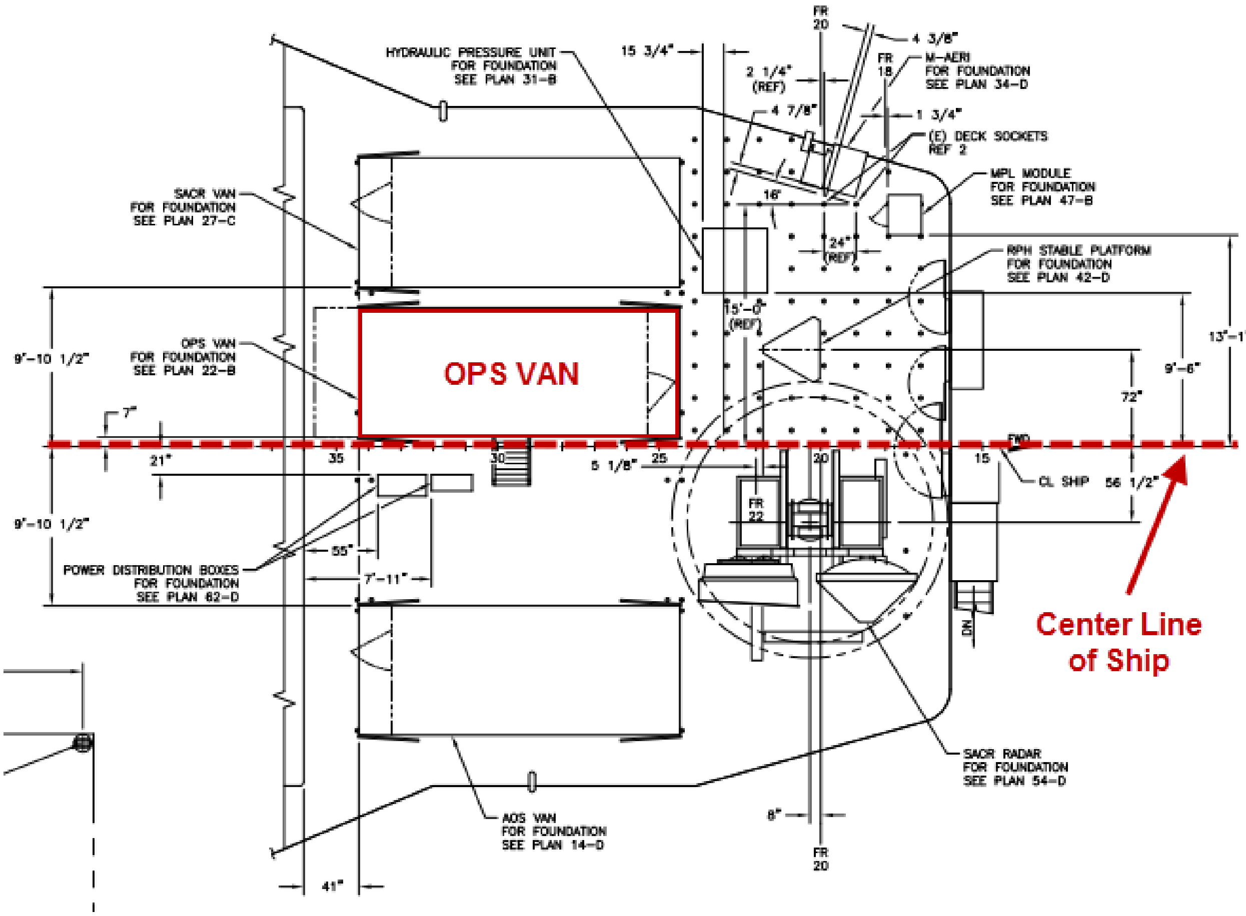

Figure 2. Operations van placement on the *RV Ron Brown* during ACAPEX.

7.5 Sensitivity

The HYDRINS fiber-optic gyroscopes, manufactured by iXSea, cover the medium- to very high-performance range: from 0.1 degree per hour bias to 0.0003 degree per hour bias (for space applications). (HYDRINS User Guide 2010, 1-4)

7.6 Uncertainty

The accuracy of the data computed by the pure inertial system depends on both the accuracy of accelerometers and gyrometers sensors and on the initial attitude, velocity, and position errors obtained after the alignment. Since the gyrometers and accelerometers data are integrated over time, and because the velocity, position, and attitude computations form a closed loop, all these errors propagate with time and influence each other. (HYDRINS Quick Start Guide 2010, 1-6) Other external factors that can impact the accuracy of the data include physical shock to the device and inaccurate GPS input data.

7.7 Input Voltage

The HYDRINS unit runs on 24 volts using 15 watts (HYDRINS Quick Start Guide 2010, 11).

7.8 Input Current

The HYDRINS unit uses 2.5 amperes (iXSea website).

7.9 Input Values

The HYDRINS unit reads coordinates and date/time values from a Hemisphere A100 GPS device.

7.10 Output Values

The HYDRINS combines GPS latitude, longitude, and date/time with the course over ground, speed over ground, roll, pitch, and yaw and sends them out over RS232 connection.

8.0 Instrument System Functional Diagram

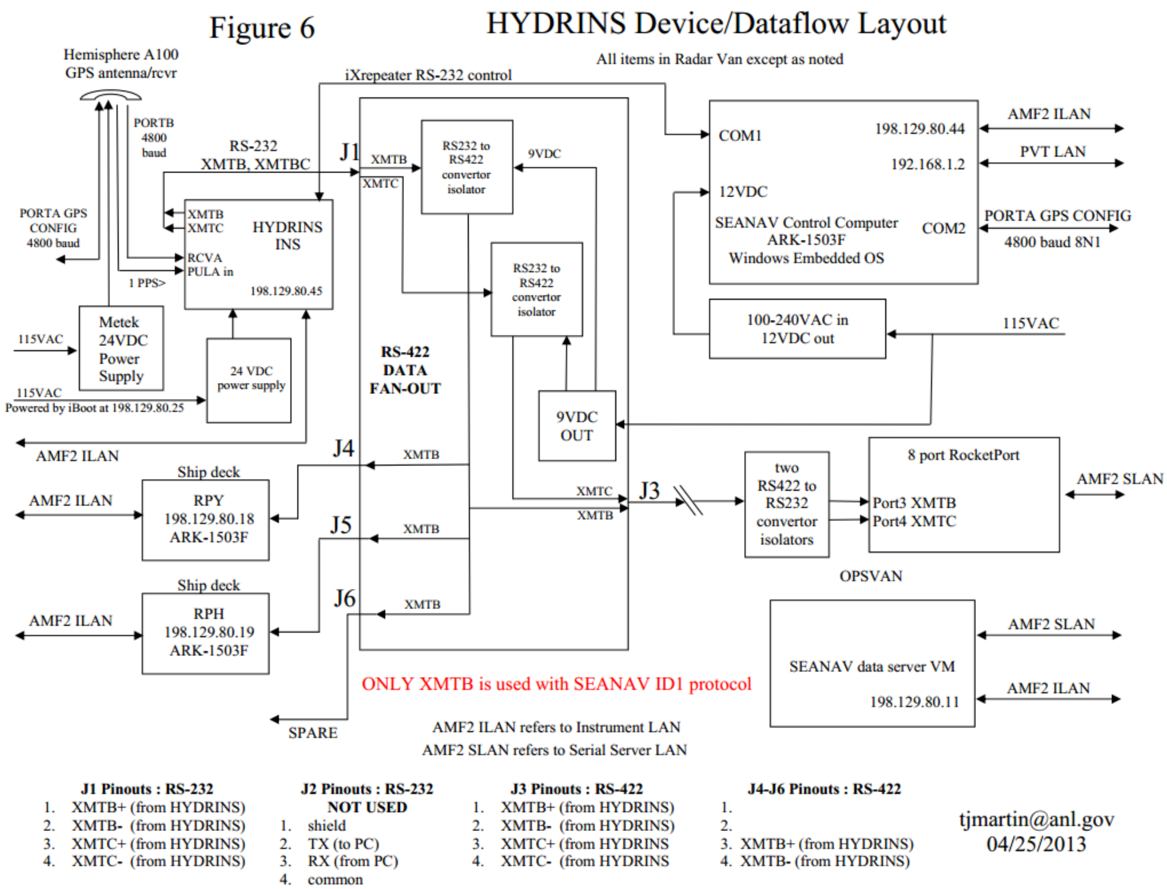

Figure 3. Instrument system functional diagram (Martin 2013).

9.0 Instrument/Measurement Theory

A fiber-optic gyroscope is a 2-wave ring interferometer made of multi-turn fiber coil enclosing an area. Light entering the interferometer is split into two counter-propagating waves that recombine perfectly in phase after having traveled along the same path in opposite directions. When the gyroscope is rotating, a relativistic effect, known as Sagnac effect, induces a difference of transit time between the two waves that can be measured by interferometric means. The difference of transit time is proportional to the product of the rotation rate and the area enclosed by the coil (counted as many times as the fiber coil turns around). The gyroscope sensitivity can be increase by increasing the number of turns of the fiber coil and/or the fiber coil diameter. Fiber-optic gyroscopes manufactured by iXSea cover the medium- to very high-performance range: from 0.1 degree per hour bias to 0.0003 degree per hour bias (for space applications). (HYDRINS User Guide 2010, 1-4)

10.0 Setup and Operation of Instrument

To setup the HYDRINS unit, the unit must first be mounted to a fixed position in the operations van. Next, connect the cables for the digital outputs on the front of the HYDRINS unit, the GPS, the fan out box, and the Moxa serial board. Once everything is connected, plug in and power on the Moxa, fan out box, GPS, and HYDRINS unit. When the HYDRINS is powered up, it will automatically begin its coarse alignment. While this is happening, connect to the HYDRINS via the web browser to access the web application for setup and verification of settings. You will need to enter the offset from the center of gravity of the ship to the HYDRINS unit. Once these settings are entered, return to the status page of the web application and verify that the status is correct.

Once the HYDRINS is running, you need to verify that the program seanavlogd is executing and producing the winav.txt and appropriate data files. Note that the $WINAV and $TSINV data records are only sent if valid HYDRINS data are being received. If the HYDRINS data flow is interrupted, or the navigation mode is substandard, the $TSINV output as well as the winav.txt file will be missing. The “oper” user has a crontab that runs /home/oper/seastart every two minutes. The function of “seastart” is to check that “seanavlogd” is running and start it if necessary. The “seastart” logfile is at /home/oper/seastart.log. Errors from the seanavlogd program appear in /home/oper/data/nohup.out. The “searead” program is available on the SEANAV VM for examining the raw seanavyymmddhh.dat files that collect in /home/oper/data. Type “searead” for help. Type “searead 1 seanav12100212.dat” to dump all records from the file for Oct 2, 2012 starting at 1200 UTC. To examine every 20th record, type “searead 20 seanav12100212.dat”. Another useful function of searead is to count records, data gaps, and checksum errors in files. This can be done by using the argument -1 for all files in a day as follows: “searead -1 seanav121002*.dat” will examine all files for Oct 2 2012. (Martin 2013, 5)

11.0 Software

The HYDRINS unit has a web server and web application to setup/verify settings on the device as well as check the current status of the device. In a case where the HYDRINS web application is not available or responding (due to network issues or otherwise), the manufacturer has provided a Microsoft Windows application named ixRepeaterIns that will communicate with the HYDRINS unit directly via serial communication. This allows the user to setup/verify settings on the HYDRINS unit as well as check the current status of the device.

On the SeaNav VM is seanavlogd, which reads and manipulates the data for other instruments to ingest. The seanavlogd program reads data in the SEANAV ID=1 format from the HYDRINS unit. When appropriate, the program then sends out the various record formats ($WINAV, $TSINV, and $MANAV). These records are either sent out via serial communication, broadcast as User Datagram Protocol (UPD), or pulled via Secure Copy Protocol (SCP) from the other instruments.

12.0 Calibration

As soon as HYDRINS is powered on, it starts its alignment phase with the manually input position stored into HYDRINS PROM. During the first five minutes after powering on, HYDRINS performs its coarse alignment. After the first five minutes, HYDRINS switches to “fine alignment” phase to improve the accuracy of roll, pitch, and heading estimations. The fine alignment is ended automatically by HYDRINS when the heading covariance is below 0.1 degree. (HYDRINS Quick Start Guide 2010, 25)

13.0 Maintenance

Regular inspections of the equipment, wires, and cables should be made to ensure that there is no damage. Software updates should be made only if there is an issue or an additional feature needed.

14.0 Safety

All safety procedures for the area of operation should be followed. The HYDRINS unit should have at least 210mm of clearance on the side where the cables connect. (HYDRINS Quick Start Guide 2010, iii-3). All wires, cables and equipment should be inspected for damage before connecting or using.

15.0 Citable References

HYDRINS User Guide. 2010. iXSea.

HYDRINS Quick Start Guide. 2010. iXSea.

Martin, TJ. AMF2 HYDRINS Operation. 2013. U.S. Department of Energy, Argonne National Laboratory.

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