

## Technical report on experimenting with SeaSoar improvements



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**Abstract**

The original hydraulic system controlling the SeaSoar owned by Geophysical Institute, University of Bergen having been completely out of order, it has been totally replaced by an electric device controlling a lead screw to action the wings. In order to keep space for scientific equipment, an additional underwater bottle hosting the electronics has been placed below the hull. Information from additional sensors as well as onboard instrumentation is available in real time on deck by two computers. One is used for controlling the SeaSoar and the other for data acquisition. A dedicated Labview application is running on the former computer to control the vertical position of the SeaSoar. Ship's navigation and bottom depth from echo sounder are supported. Due to project interruption, the system requires further calibrations and adjustments for being fully operating.

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# **SeaSoar**

Further Development

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## Summary

The original hydraulic system controlling the SeaSoar owned by Geophysical Institute, University of Bergen having been completely out of order, it has been totally replaced by an electric device controlling a lead screw to action the wings. In order to keep space for scientific equipment, an additional underwater bottle hosting the electronics has been place below the hull. Information from additional sensors as well as onboard instrumentation is available in real time on deck by two computers. One is used for controlling the SeaSoar and the other for data acquisition. A dedicated Labview application is running on the former computer to control the vertical position of the SeaSoar. Ship's navigation and bottom depth from echo sounder are supported. Due to project interruption, the system requires further calibrations and adjustments for being fully operating.

# 1. Introduction

The SeaSoar MkII owned by Geophysical Institute, University of Bergen, was damaged during a cruise along the Norwegian shelf in summer 2002. Damages were due to leakage of sea water into the hydraulic pump unit that supplies the necessary power to move and control the wings. This caused some metallic parts in the unit to rust. Subsequently, some small metallic particles were spread into the unit yielding further damages to the system.

According to the purchase documents, these damages were due to a construction failure at the responsibility of the supplier. Moreover, the supplier had the obligation to provide all necessary spares required for instrument repair. Because these were not fulfilled, the purchase office at University of Bergen took over the case in the hope of finding a solution with the supplier. After nearly two years, the case was abandoned to the disadvantage of the Geophysical Institute.

The idea of developing a control system for the SeaSoar rose at this point and serious work started during 2005. This project comprised extensive mechanical, electronic and software work. A first test in shallow water was performed in spring 2007 yielding very positive results. A second deep water test was planned to take place during summer the same year. Unfortunately, on deck tests revealed that the mechanical assembly was much too weak for the expected forces and some parts were damaged before deployment.

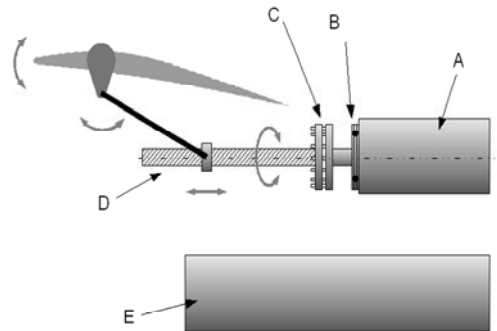
This report describes the new control system and presents also a list of items to perform in order to improve and terminate the instrument. Mechanical and electronic drawings are available in electronic form. Please note that mechanical parts may differ from the drawings due to last minute adjustments. This report assumes that the reader is confident about the SeaSoar system.



## 2. Design

Much of the older SeaSoar has been kept in order to limit development work.

Because of problems occurred with the hydraulic unit in both SeaSoars owned by Geophysical Institute, the main idea in developing a new system has been to replace the hydraulic part with electro-mechanical system. Additional advantages include also a faster response of the wings and the ability to position them in a preferred position. These together open for using the SeaSoar in other applications than an undulating vehicle only. However, an important drawback in using electro-mechanical parts is the necessity of designing a tight system. This is not an obvious task since moving mechanical parts have to be coupled to the low and high pressure sides simultaneously.



**Figure 1:** Mechanical Design

A small DC motor and a gear provide the rotation to a lead screw (D). The latter provides translation movement to a pair of arms which in turn rotate the wings. In order to avoid transferring axial vibrations from the wings directly into the motor, a special coupling (C) is required between the motor axis and the lead screw. Moreover, an axial bearing (B) is in addition required on the outside of the motor axis in order to take over high pressure forces from the outside.

The motor is controlled by a driver which receives commands from the surface. Additional electronic parts are required in order to interface the driver to the user. Due to the length of the sea cable (700m or more), electrical losses are reduced by providing the SeaSoar with a standard 220VAC supply. A dedicated power supply sitting in the electronic bottle generates the required voltages. Communication with the surface is performed through an RS-485 serial line allowing data to be transferred over a distance of at least 1200m (losses in the slip ring on the ship's deck should be taken into account when calculating the effective distance to the vehicle. This means that data from/to the different devices of the controlling unit cannot be transferred simultaneously. Instead, information is multiplexed and each device is connected to serial line one at a time. Multiplexing in the current configuration is performed at 5Hz. This is more than sufficient for controlling the SeaSoar which has a time constant of the order of one minute.

The electrical motor and the controlling electronics are mounted in separate bottles (A and E in **Figure 1**). Because the rotating axis of the motor has to be coupled on both pressure sides, having another bottle for the electronics reduces the risks of damaging all components at once.

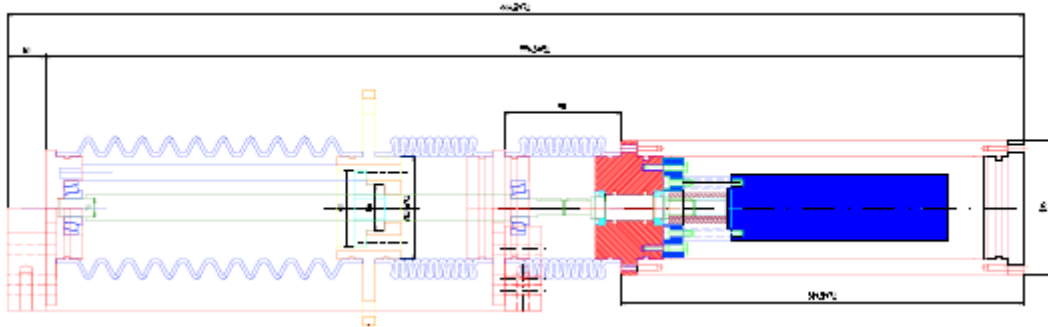
Originally, this SeaSoar was designed to host a Seabird CTD 911plus. The new system is designed to provide a place for the same instrument. The external pressure sensor used in the older system for controlling the vehicle has also been implemented.

At surface, an RS485 serial line is connected to a computer. Other onboard devices such as navigation and echo sounder can be connected to the same computer. It is strongly recommended to connect the

CTD to another computer running Seabird's acquisition software. The main reason is that the CTD sends data on the serial line at a rate of 24 measurements per seconds, allocating much of the available resources. The CTD's acquisition software on that second computer can be configured to output CTD values at a lower rate on another serial line to the controlling computer. This feature provides the controlling software with another pressure sensor.

### 3. Implementation

Lead screw rotation is generated with a DC electrical motor. A gear is used to reduce rotation speed to an acceptable value for movements of wings, but also to increase the moment that can be applied to these. The lead screw itself provides relevant moment amplification. Although better practices would have been to use step or even better torque motors, control interface for these is more complicated and requires more power and further components. This solution makes it difficult to integrate all parts into a small pressure case fitting the SeaSoar. An important disadvantage of the use of a DC motor is the lack of direct position control. The motor is steered with a DC voltage regulating the rotation speed. Position control, and subsequently wings orientation has been implemented in the software. Whichever method is applied, an absolute measurement of the wings angle from motor parameters is impossible due to mechanical limitations. Moreover, for general applications, the SeaSoar is expected to be controlled using a pressure sensor.



**Figure 2:** Wings controlling device

Rotation velocity of the motor, and hereby wings movements, is controlled by applying a DC voltage to the motor driver. The latter is placed in the electronic bottle and provides different control outputs like analogue signals for current consumption and rotation speed, as well as digital signals describing motor and controller state. These outputs are sent to surface for informative display and as inputs into the regulation algorithm.

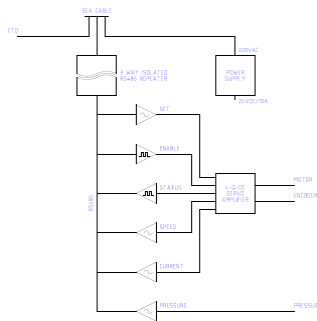
Transmission of rotation movements from the motor inside the pressure case (low pressure side) to the lead screw (high pressure side) is performed with the use of two special seals sitting between the rotating axis and the surface of the through hole in the case. Tolerance of the mechanical parts is very small and important. A too small room will lead to a much too high friction between the axis and the seals yielding damage and reduce effectiveness of the latter. Too much place will reduce tightness of the transmission. Moreover, axial misalignment between the inside and outside of the pressure case will lead to seals and axis damages. The room in between both seals is filled with non-soluble thick grease and connected to high pressure through a thin hole and a compressible tube sitting outside of the pressure case. This ensures a good lubrication of the seals and should reduce further the risk of leakage into the motor bottle. Special care and maintenance has to be applied to this part before and after each deployment in order to ensure tightness of the transmission.

A thrust ball bearing on the outside of the pressure case is required in order to support axial pressure forces exerted on the rotating axis. A further special coupling is implemented between the motor axis and the lead screw in order to reduce axial vibrations. These are expected to be quite large when the SeaSoar is towed at normal ship speed (typically 8 knot).

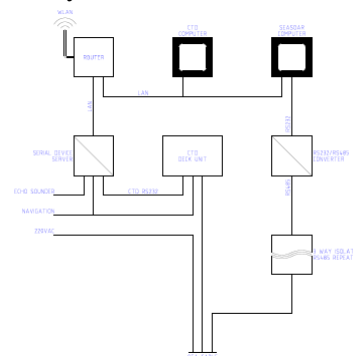
The lead screw sits between two tapered needle bearings placed in opposite directions. These are required for supporting both axial and radial forces. A ring connected to the original SeaSoar wings transmission is moving hereby along the lead screw, placing the wings at different angles.

Reduction of frictional loss on the lead screw is performed by enclosing the latter into rubber bellows filled with gear oil. In order to avoid another sealing point on rotating axis, such a filled bellow has also been placed between the pressure case and the lead screw. This has the additional advantage that oil is going to fill the motor case if the transmission sealing is damaged. Consequently, the motor and gear should not be destroyed.

Power to the system is applied from ships 220VAC mains, using two conductors of the sea cable. This method reduces considerably electrical losses along the cable. Furthermore, two conductors are used for data transmission between the controlling unit and surface. Although the CTD dedicated for the SeaSoar (Seabird SBE911) is connected to the electronic pressure case, this connection serves as a bridge to two additional conductors in the sea cable, avoiding hereby a subsea Y-termination.



**Figure 3:** Electronic bottle diagram



**Figure 4:** Deck unit schematic

The electronic pressure case contains the following elements

1. A bridge connecting transparently the Seabird CTD to the sea cable
2. A 24VDC 10A power supply required by all components.
3. A 3-way isolated RS485 repeater.
4. A 3-state RS485 to analogue output converter.
5. A 3-state RS485 to digital output converter.
6. An analogue input to 3-state RS485 converter.
7. A digital input to 3-state RS485 converter.
8. The motor control driver.

Transmission of all controlling parameters is performed using the same RS485 communication line. Consequently, signals to and from the SeaSoar have to be transmitted and retrieved or sequentially. Measuring and sending all parameters can therefore be performed within 1 second, without exceeding system resources. Due to the very long time constant of the SeaSoar, it should not affect the regulating possibilities of the system.

Due to the limited space available in the SeaSoar, the electronic bottle is placed on the outside, below the hull, in a dedicated cylinder that will reduce resistance in water and protect cable connections. Sea cable, CTD cable and connections to the motor bottle are placed at the rear of the SeaSoar.



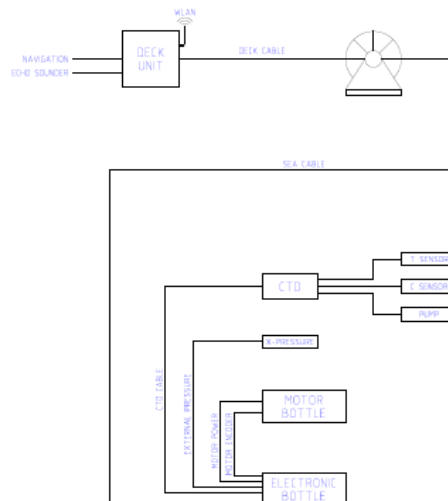
**Figure 5:** Electronic pressure case and its protection



**Figure 6:** Electronics and Motor pressure case

The CTD is placed into the hull, above the wings controlling device. An external pressure sensor is also implemented. It can be easily placed along the CTD and connected to the electronic bottle.

At surface, the sea cable is connected to ship 220VAC mains, the CTD deck unit, and another 3-way isolated RS485 converter. The other side of the latter is connected to the serial port of a computer through a RS232/RS485 converter. Navigation data from the ship need to be connected to the both the CTD deck unit and the controlling computer. The latter allows also bottom information from the ship echo sounder on a third serial port. It is strongly recommended to acquire CTD data from the CTD deck unit on a separate computer. In order to avoid too many serial connections, one can use the dedicated port servers to share serial data with several computers, as this is required for navigation data. The controlling software has also the possibility to read CTD serial data output from the CTD computer. This is achieved in the CTD logging software configuration and by enabling this input in the SeaSoar controlling software. Output data rate should not exceed 1Hz.



**Figure 7:** System interconnections

A dedicated application developed in LabView™ has been developed for controlling the system and display the important parameters. Because SeaSoar developments were aborted, it is still in a prototype form. However, the most important features are implemented and should allow further

testing of the system in the future. Wings control is regulated with a digital PID loop, based on the difference between the requested and measured pressure. The latter is taken either from the external pressure sensor or the CTD.

## 4. System Setup

### Before Deployment

Before system setup, verify that all power supplies are turned off and mains cables unplugged. Check that the CTD temperature and conductivity sensors are in place at the head of the hull.

First make sure the O-rings ensuring tightness around the motor axis have been inspected and the volume in between filled up with thick silicon grease.

Mount the motor bottle on the mounting frame. Make sure dummy plugs on the rear side of the bottle are installed.

Starting from the motor bottle to the end of the lead screw, install each bellow and fill it with normal gear oil. Filling each bellow separately before installing the next will make this step faster. Make sure no air bubbles are captured in the system by pressing back and forth the bellows. Close the system with the tap screw.

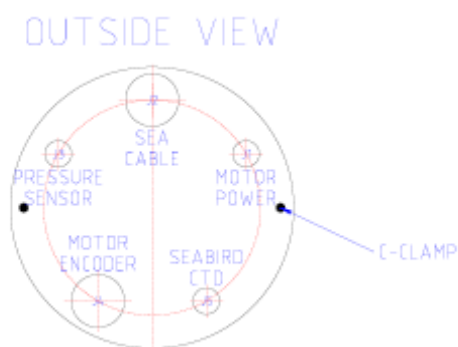
Install the mounting frame into the SeaSoar. This operation may be difficult due to the weight of the frame and the place available. Lowering the rear side of the motor bottle, try to have the dummy plugs to pass into the rear hole of the hull. Then, lower gently the rest of the frame until it is in place. Fasten the mounting frame into the brackets.

Make sure the dummy plugs are installed on all connectors of the electronic bottle. Then insert the bottle into the protecting torpedo tube. Make sure the plastic rings along the bottle are corresponding with the holes on the protecting torpedo tube. Fasten the bottle by screwing gently the 8 screws against the plastic rings. Secure the bottle by fastening the end ring on the protecting torpedo tube. Finally, fasten the tube with the electronic bottle below the Seasoar.

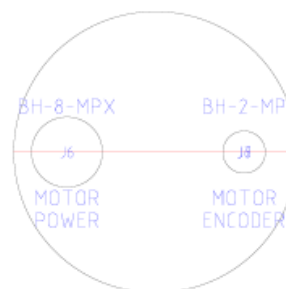
Install the CTD brackets above the controlling system, and mount the CTD main bottle. Make sure that sensors input of the CTD are placed at the head of the hull, towards the temperature and conductivity sensors.

Install the external pressure sensor along the CTD main bottle.

Install the sea cable as described in the original Seasoar manual. Connect the sea cable and all other interconnections between the CTD, temperature, conductivity and external sensor, electronic and motor bottles.

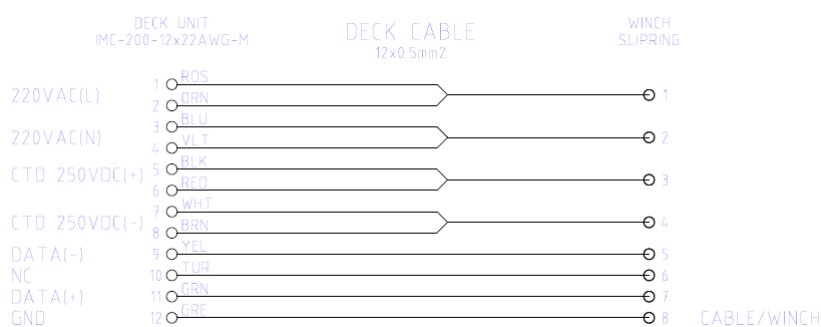


**Figure 8:** Connections on electronic bottle



**Figure 9:** Connections on motor bottle

On deck, connect the dry end of the sea cable. Connect Data+ and Data- to the RS485 3-way isolated repeater to their corresponding contacts. Connect the other side of the repeater to the RS232/RS485 converter and plug it into serial port of the controlling computer. Connect mains and CTD deck unit accordingly.



**Figure 10:** Wiring of sea cable

Output of the CTD deck unit must be connected to the CTD computer. If configured correctly, the software for the CTD can be setup to output values from CTD at a rate of 1Hz. This output can be connected to another serial port on the controlling computer.

On the controlling computer, start the controlling software. Configure all parameters in the *Configuration* tab. Power the system and switch the start button to position *ON*. When the running LED is green, perform a calibration of the wings. Deploy the Seasoar.

### After Deployment

Switch the start button to *OFF*. Remove all power from the system. Disconnect all connections. Inspect the O-rings on the motor axis.



## 5. Software

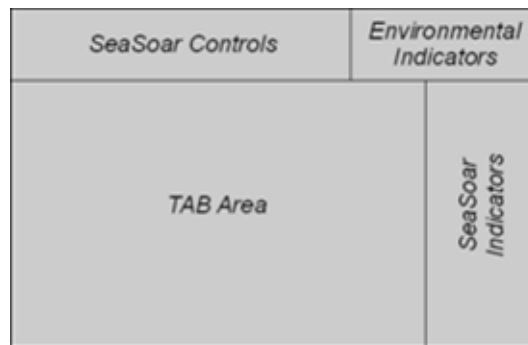
The controlling software has been developed in LabView™.

### 5.1 Installation

On the distribution CD, change directory to `Software\Compiled Code\SeaSoar_v4` double click on `setup.exe`. Agree with all questions and predefined settings until end of installation.

### 5.2 Main Window

The main window is divided into the following areas (**Error! Reference source not found.**).



**Figure 11:** Areas in main windows

#### 5.2.1 SeaSoar Controls

Controls required for piloting the vehicle.

#### 5.2.2 Environmental Indicators

Display measurements from environmental and external sensors.

#### 5.2.3 SeaSoar Indicators

Measurements from SeaSoar control parameters and sensors

#### 5.2.4 TAB Area

This area contains several TABs grouping configuration parameters or indicators for each specific activity performed on the system. These are *monitoring*, *deployment*, *calibration*, *configuration* and *debugging*

### 5.3 SeaSoar Controls



**Figure 12:** SeaSoar pilot controls.

### 5.3.1 ON/OFF

This is the main switch to start the system. It should be used only once the system has been completely setup; all cabling is in place and power supplies turned on.

### 5.3.2 OVERRIDE

Activating this switch will force the SeaSoar to surface.

### 5.3.3 Depth Control

This switch is used to either control the SeaSoar manually using the controls in the *SeaSoar Indicators* area, or let the system follow the deployment settings. Manual control is probably not obvious. However, it may be required during deployment and recovery operations.

### 5.3.4 Pressure Source

Select whether to use pressure measurements from the external pressure sensor or the onboard CTD. For the latter, a working CTD data transfer to the control computer is required (see section 4).

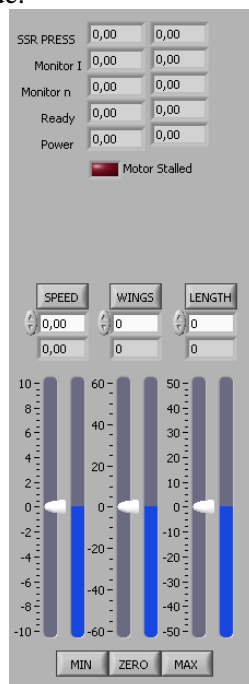
### 5.3.5 Motor

This switch is used to enable the motor. The *RESET* button is used to reset all motor settings. This is necessary if for example the current limit has been overridden.

Remaining LED indicators on the right display the selected deployment configuration (see *Deployment TAB*).

## 5.4 SeaSoar Indicators

Indicators above display measurements performed on the controlling system. The left indicator contains filtered values, while the right indicator shows the raw values. The filter used is low pass Butterworth of 3<sup>rd</sup> degree. Filtered values are used to both send feedback to the system and detect improper activities in the automatic mode.



**Figure 13:** SeaSoar Indicators

### 5.4.1 SSR PRESS

Display measurements of the SeaSoar pressure sensor (external pressure sensor).

### 5.4.2 Monitor I

Motor current drain.

### 5.4.3 Monitor n

Motor rotation speed.

### 5.4.4 Ready

Status indicator of the motor driver.

### 5.4.5 Power

Power supply voltage within the electronic box.

### 5.4.6 Motor Stalled

This indicator will light if the motor is not responding properly to the system. In such a case, the *RESET* button in the *SeaSoar Controls* area should be activated.

Indicators in the lower part of the area display the current value of the *motor speed*, *wings angle* and *position on lead screw*. These values are represented by the vertical blue bar. On their left, an indicator can be used to set manually the system in a particular situation. This is only possible if not in automatic mode, and only one of these parameters can be set. To select one parameter, activate its corresponding button. Shortcut buttons for *minimum*, *zero*, and *maximum* values can be used.

### 5.4.7 SPEED

Set or read motor rotation speed.

### 5.4.8 WINGS

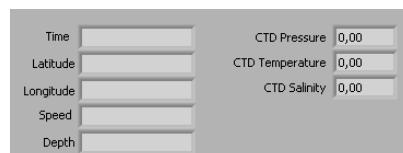
Set or read wings angle.

### 5.4.9 LENGTH

Set or read position along the lead screw.

## 5.5 Environmental Indicators

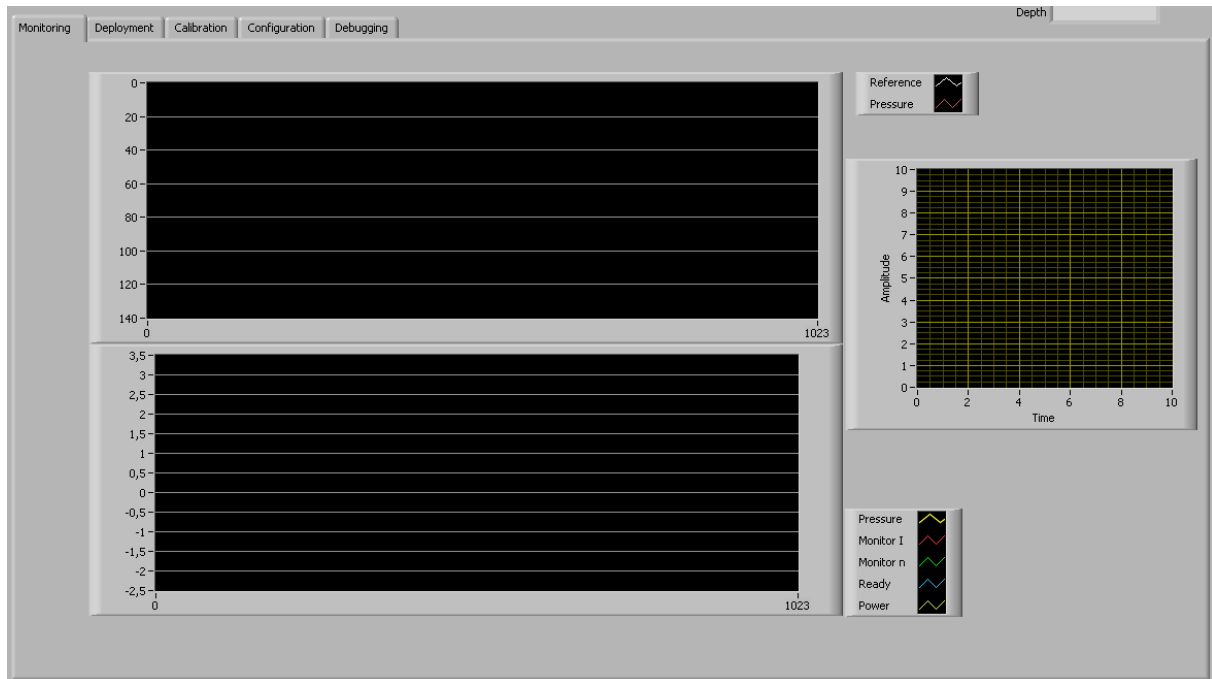
These indicators display data from other external devices such as navigation and CTD.



**Figure 14:** Environmental Indicators

## 5.6 Monitoring TAB

This view is used to monitor the behaviour of the SeaSoar. Upper time series plot displays current pressure (from the source selected by the *Pressure Source* switch). Its purpose is to control how the system is able to follow the given pressure curve (specified in the *Deployment TAB*). The lower plot displays motor parameters in real time so that system malfunction can be investigated.



The XY chart on the right is dedicated for CTD downcast plots. However, this feature is still under construction.

## 5.7 Deployment TAB

This area is used to select one of the following deployment types

### 5.7.1 Constant Depth

Select a deployment depth in meter.

### 5.7.2 Sinus Wave

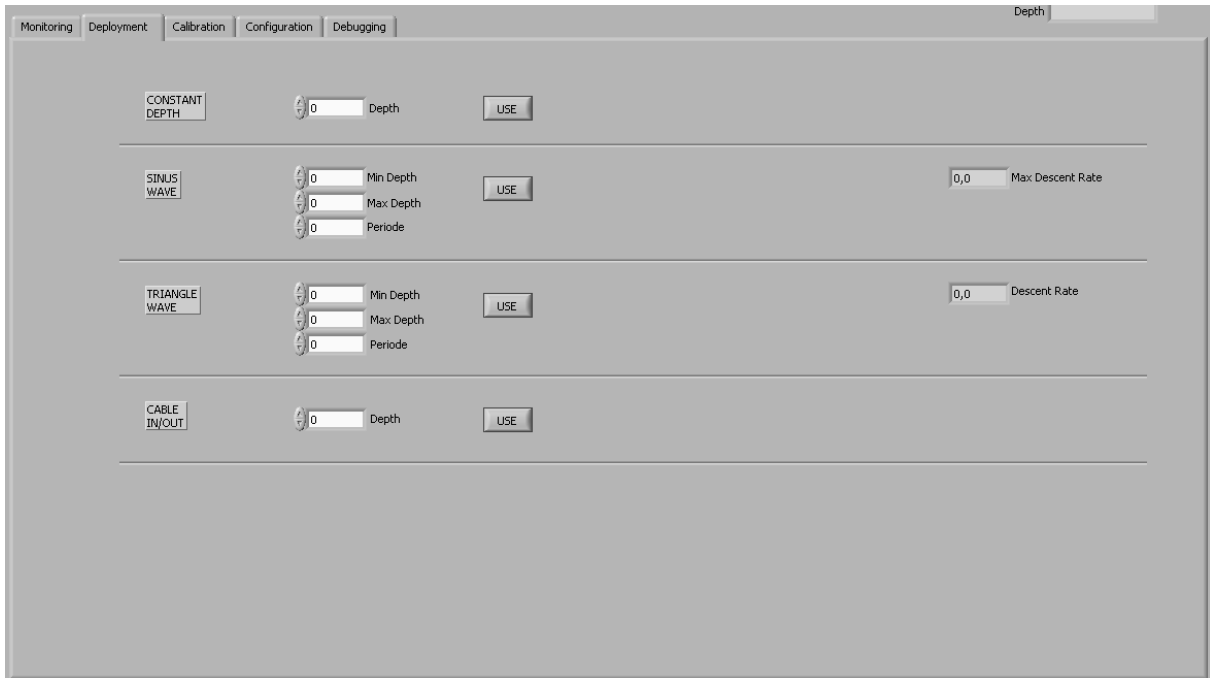
This type of deployment will generate a pressure reference similar to a sine function. It requires input of a maximum and minimum depth in meter, as well as a period in seconds. These parameters must be adapted to give an affordable ascending and descending SeaSoar rates.

### 5.7.3 Triangle Wave

Similar to the above, however a triangle is generated.

### 5.7.4 Cable In/Out

This is a deployment designed for situations of cable payload, transit legs, deployments and recoveries. Because these situations may be unexpected, select the constant depth in meter to use in such cases, before starting the system.



**Figure 15:** Deployment TAB.

In order to switch to another deployment type, press the associated button *USE*.

## 5.8 Calibrations TAB

This view is dedicated to system calibrations. In order to function properly, both the wings and the external pressure sensor need to be calibrated. The former is required in order to keep track of the position of the lead screw. The latter is only required if the *Pressure Source* switch is set to the external pressure sensor.

### 5.8.1 Onshore Calibrations

These need to be performed before deployment and consist in wings calibrations. The steps to perform should be sufficiently documented underway. Roughly, the purpose of this calibration is to count the number of turn between the minimum wing angle and maximum wing angle (or extreme positions along the screw lead). During deployment, the system takes into account of a security buffer length on both sides. However, extreme positions can be determined by the operator if necessary.

### 5.8.2 Offshore Calibrations

Although not implemented yet, a mean for calibrating the wings during deployment should be available.

### 5.8.3 Pressure Calibrations

Calibration of the external pressure sensor is straightforward if a reliable CTD is mounted into the hull. This feature has not been implemented yet.

### 5.8.4 CTD Calibrations

This area was originally designed to host CTD calibration parameters. However, CTD measurements have to be acquired by another computer and this feature does not make much sense.

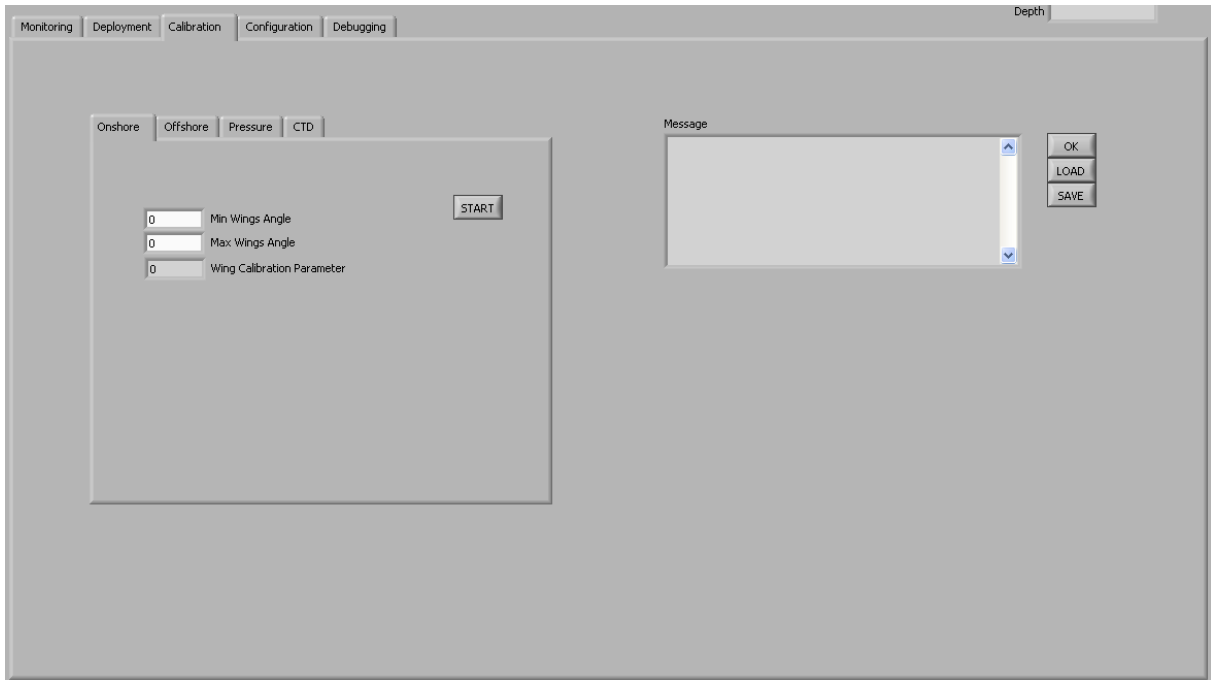


Figure 16: Calibrations TAB.

## 5.9 Configuration TAB

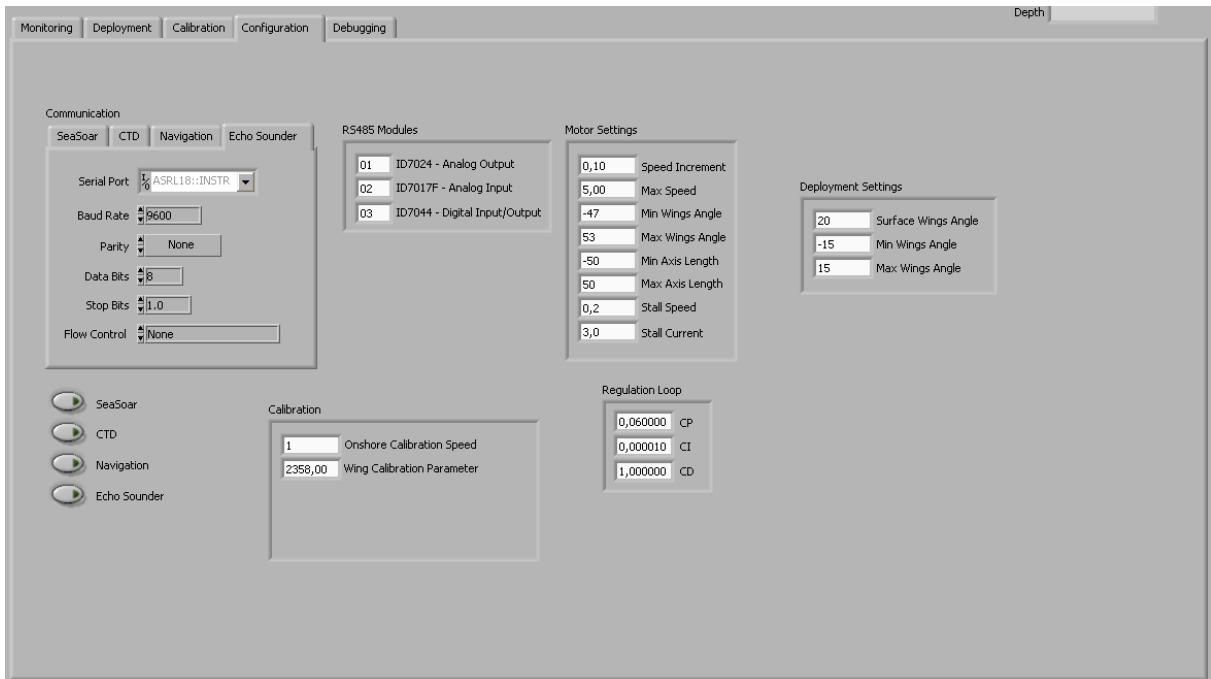


Figure 17: Configurations TAB.

### 5.9.1 Communication

Select first the device to be configured by pressing on the corresponding TAB. Available devices are *SeaSoar*, *CTD*, *Navigation* and *Echo Sounder*. Set the correct parameters for the selected device. Finally, press the button corresponding to this device in order to activate the channel.

### 5.9.2 RS485 Modules

These modules are placed in the electronic bottle and use all the same RS485 from deck to send or receive data. Therefore, they have their own ID in order to detect whether they should accept or ignore a command. This information should not be modified unless the modules ID are reprogrammed.

### 5.9.3 Motor Settings

Motor settings define values used to change motor values.

<b>Speed Increment</b>	Increment in term of Volts for changing motor speed.
<b>Max Speed</b>	Maximum motor speed command in Volts.
<b>Min Wings Angle</b>	Minimum wings angle, as measured during <i>Onshore Calibrations</i>
<b>Max Wings Angle</b>	Maximum wings angle, as measured during <i>Onshore Calibrations</i>
<b>Min Axis Length</b>	Placement of minimum position along lead screw in percent.
<b>Max Axis Length</b>	Placement of maximum position along lead screw in percent.
<b>Stall Speed</b>	Motor speed threshold in Volt. Any motor speed measurements below this value when the command is at this maximum will generate a <i>stall</i> event.
<b>Stall Current</b>	Motor current threshold in Volt. Any measured current consumption above this value will generate a <i>stall</i> event.

Motor speed is given in Volt because rotation velocity is regulated by a voltage input to the motor driver, and measured as an analogue voltage from the driver. Current consumption is also converted to an analogue voltage from the driver. Wings angle are measured in degree relative to top side of the SeaSoar. Minimum and maximum values correspond to those obtained during *Onshore Calibrations*. Minimum and maximum axes lengths are the positions on the lead screw in percent, with zero in the middle of the screw.

### 5.9.4 Deployment Settings

These are settings used during deployment. Parameter **Surface Wings Angle** is used if the *OVERRIDE* switch is activated. Parameters **Min Wings Angle** and **Max Wings Angle** are used as an additional security to avoid brutal depth changes.

### 5.9.5 Calibration

Parameter **Onshore Calibration Speed** is used during onshore calibration, while **Wing Calibration Parameter** is the result from the onshore wings calibration steps.

### 5.9.6 Regulation Loop

As mentioned above, the software uses a PID regulator for controlling the system. Parameters **CP**, **CI** and **CD** determine the behaviour of the regulation loop. It is out of the scope of this document to explain in details the effect of these parameters. However, one can roughly say that high values of *CD* will tend to have the system react faster, high values of *CI* will tend to stabilize the system in a longer term, and high values of *CP* will decrease settling time in between. Higher values of *CD* and *CP* will lead to instabilities, while higher values of *CI* will make the system slower as the effect will counteract that of *CD*.

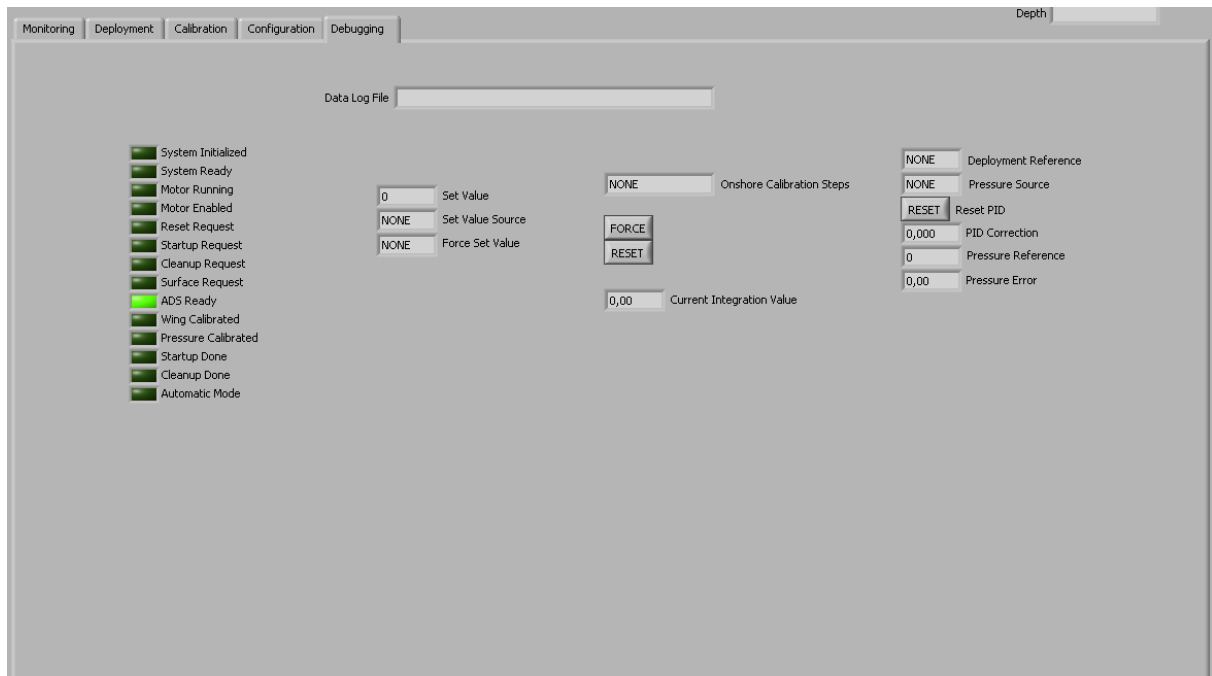
These parameters could not be adequately determined for the system. Optimal values will typically be different for different cable lengths, ship speeds and depths of SeaSoar. The main idea is find a combination that satisfies most applications.

There is no exact recipe to determine these parameters. In general, one has to find them out manually. A general trick is to (1) set all of them to zero and (2) start increase  $CP$  in order to reduce rise time. Then (3) increase  $CP$  in order to decrease overshoot. Finally, (4) increase  $CI$  in order to eliminate the steady state error and improve settling time. There are also many other design method to tune such controllers (Ziegler-Nichols Method, Internal Model Control ...). However they cannot necessarily be applied to the SeaSoar system.

## 5.10 Debugging TAB

This view displays the state of various flags and parameters. Its purpose was originally dedicated for debugging purposes during the development phase of the software. However, it is also useful in general for understanding the behaviour of the system.

It is out of the scope of this document to give a detailed description of this view, as it would require deep insight into the source code. More thorough information could be added if the project was resumed.



**Figure 18:** Debugging TAB.



## 6. Improvements

The following improvements should be considered:

### 6.1 Mechanical Design

The plate holding the controlling system should be more resistant against torsions.

Ball bearings at both end of the lead screw must be changed.

The way the controlling system is installed into the system should be improved in order to be easier.

### 6.2 Electrical Design

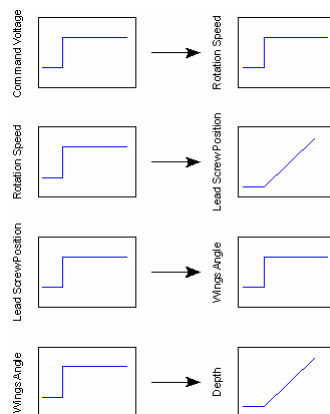
The motor driver must be configured in order have a limiting current of 5A. This should be performed in the lab and against measurements.

Experience has shown that the motor system is very strong and can produce unexpected forces to the mechanical fittings. Therefore, a backup current limiting hardware device could be installed in the electronic bottle.

Configuring the driver for torque control instead of rotation speed should also be considered. In this case, one will control directly the value of the current.

### 6.3 Software

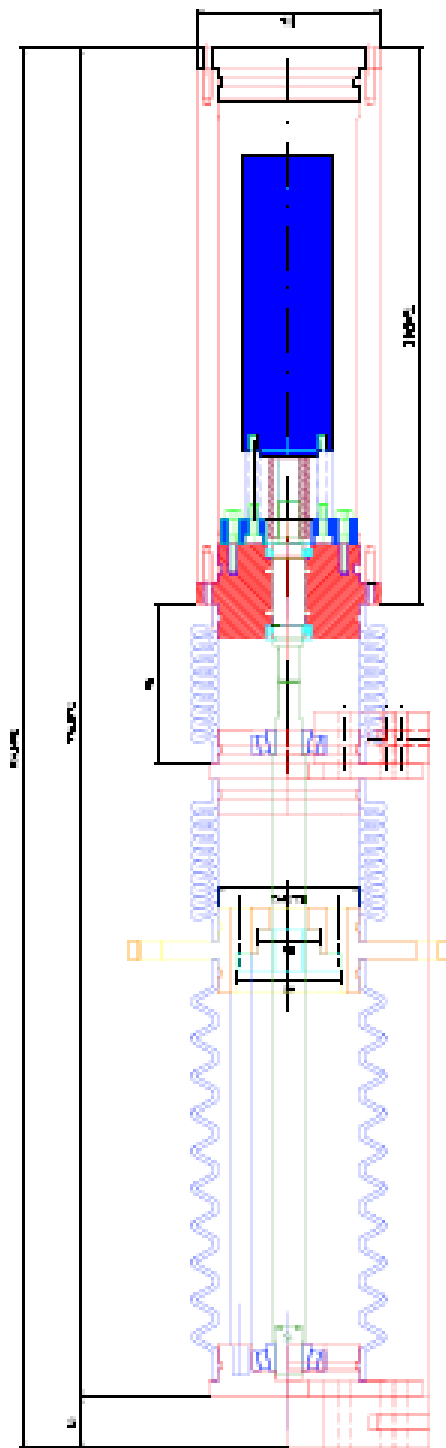
The PID regulator has been difficult to configure during testing. In general, very high values for  $CD$  and very low values for  $CI$  have been required. In theory, this type of configuration highly unwanted as it will lead to instabilities. However, a deeper look in the different steps of the command loop show that the SeaSoar system a double integrator (**Figure 19**). This fact explains the unusual parameter values for the regulator. While the computation of signal derivatives is not straightforward due to introduction of noise, one should consider a second derivative and noise reduction filter in order to improve the regulator.



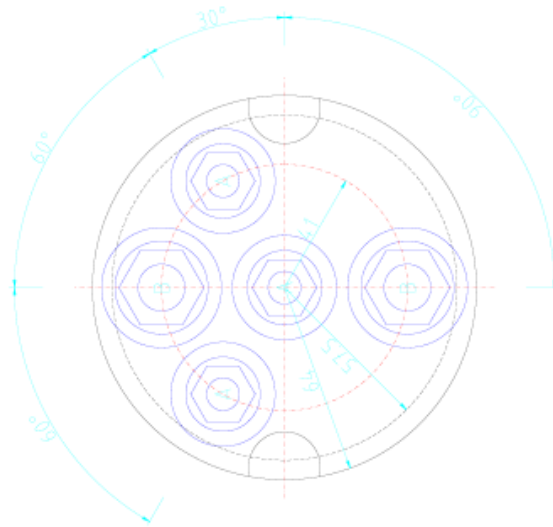
**Figure 19:** Overview of command loop

## **Appendix A. Drawings**

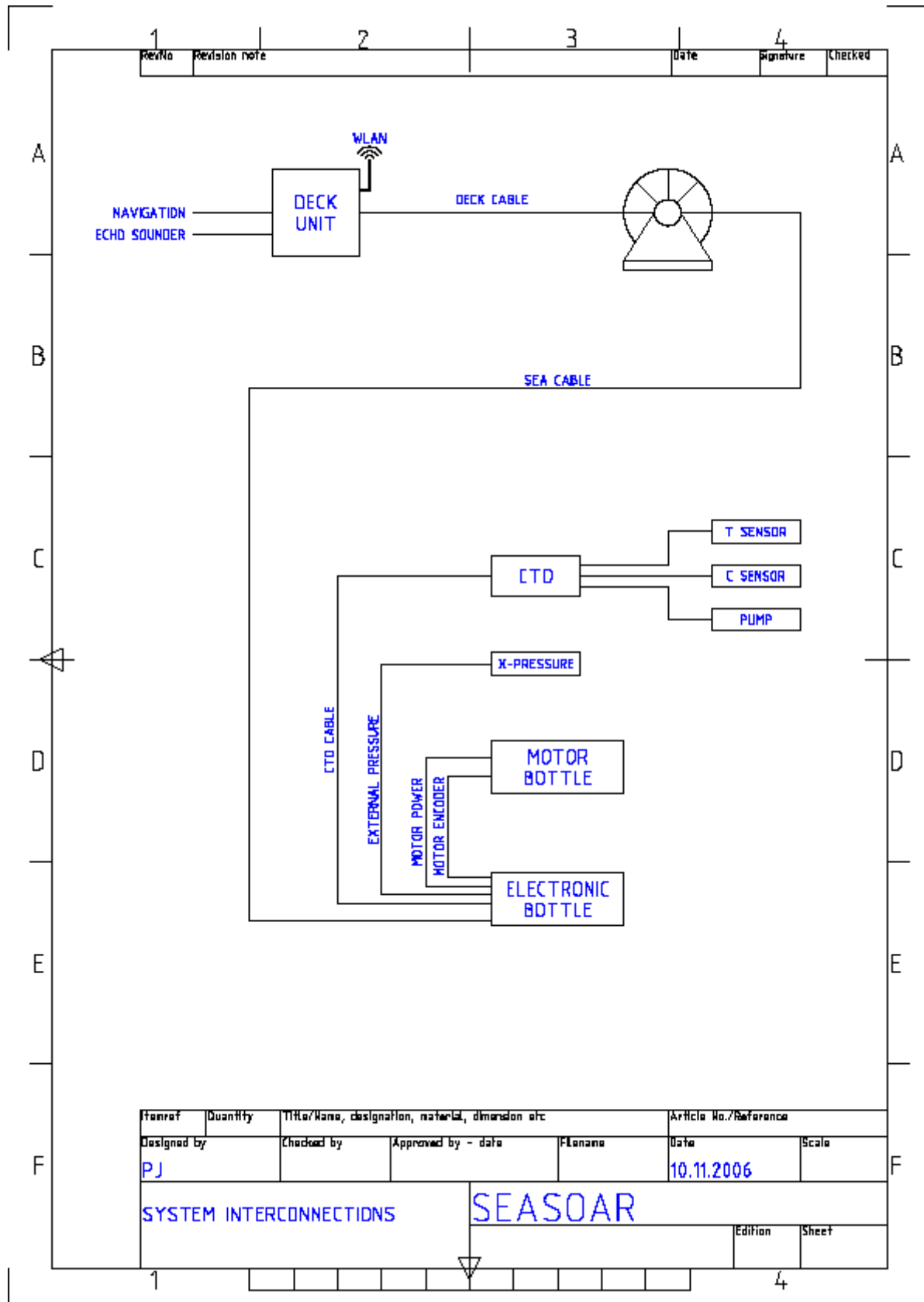
Most drawings of mechanical parts are available at Geophysical Institute.

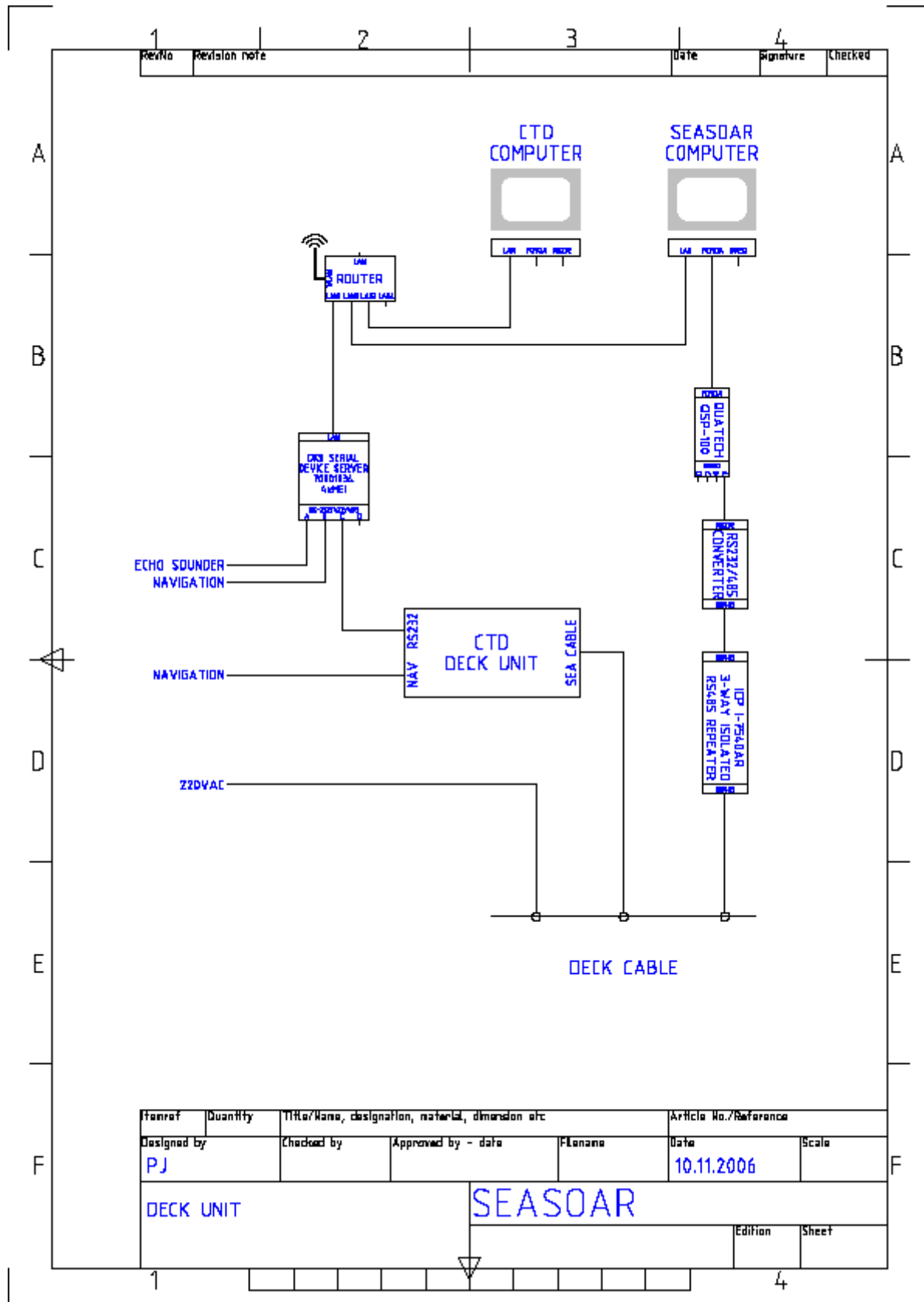


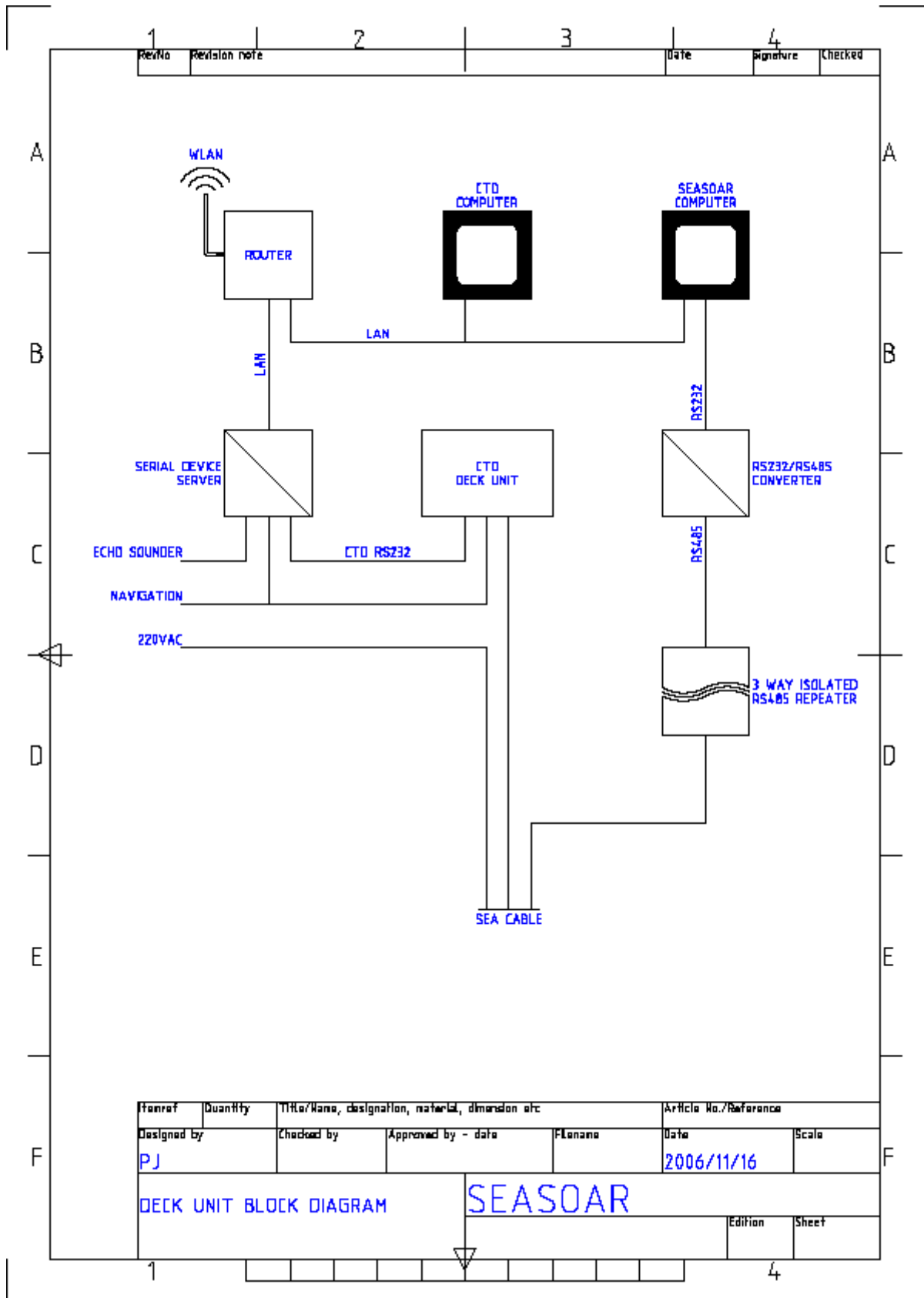




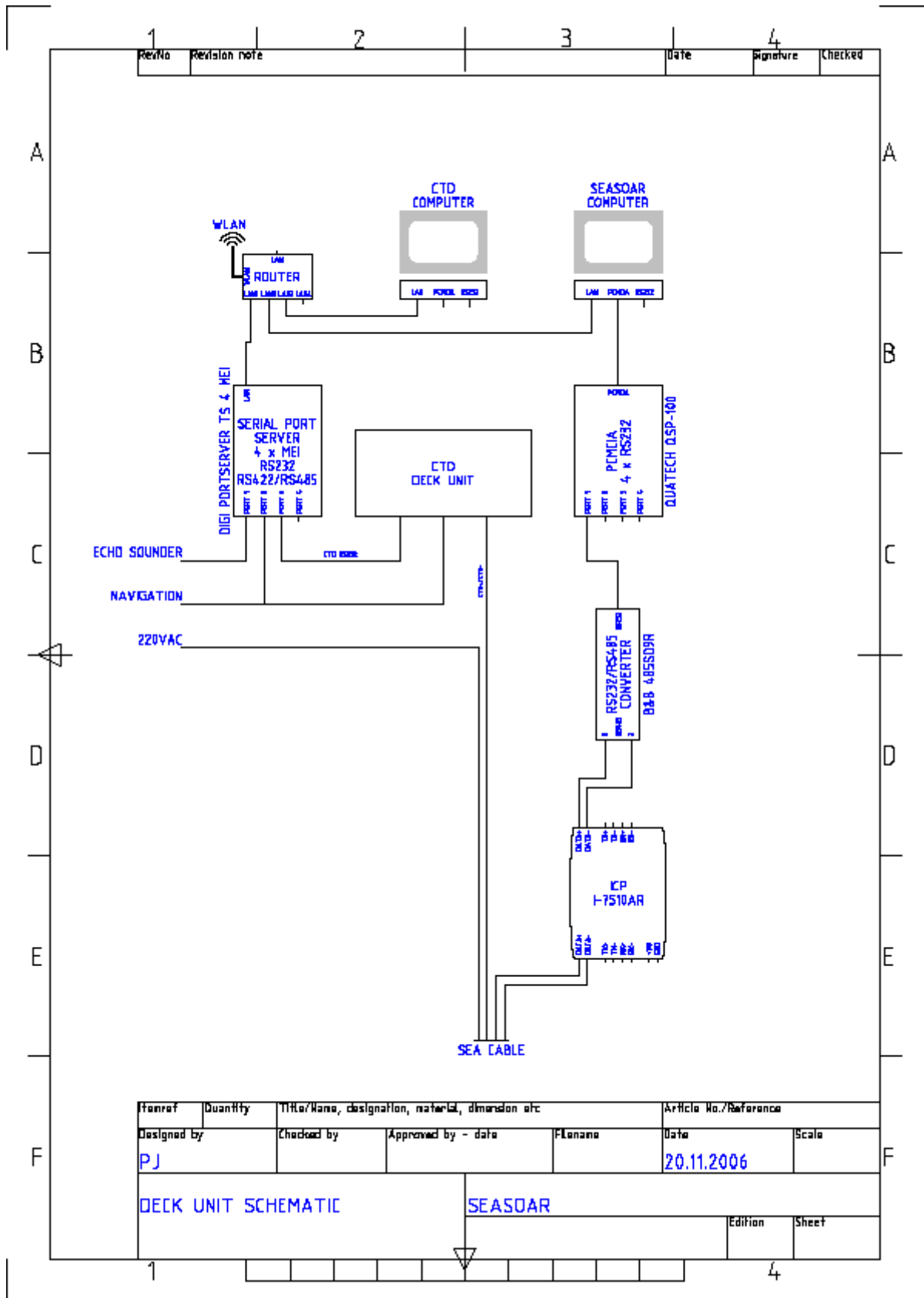
	A	B
Connector Type	BH-2-MP/FS	BH-8-MPX/FSX
Thread	7/16-20 UNF-2A	5/8-18 UNF-2A
min for O-Ring	> 22	> 29

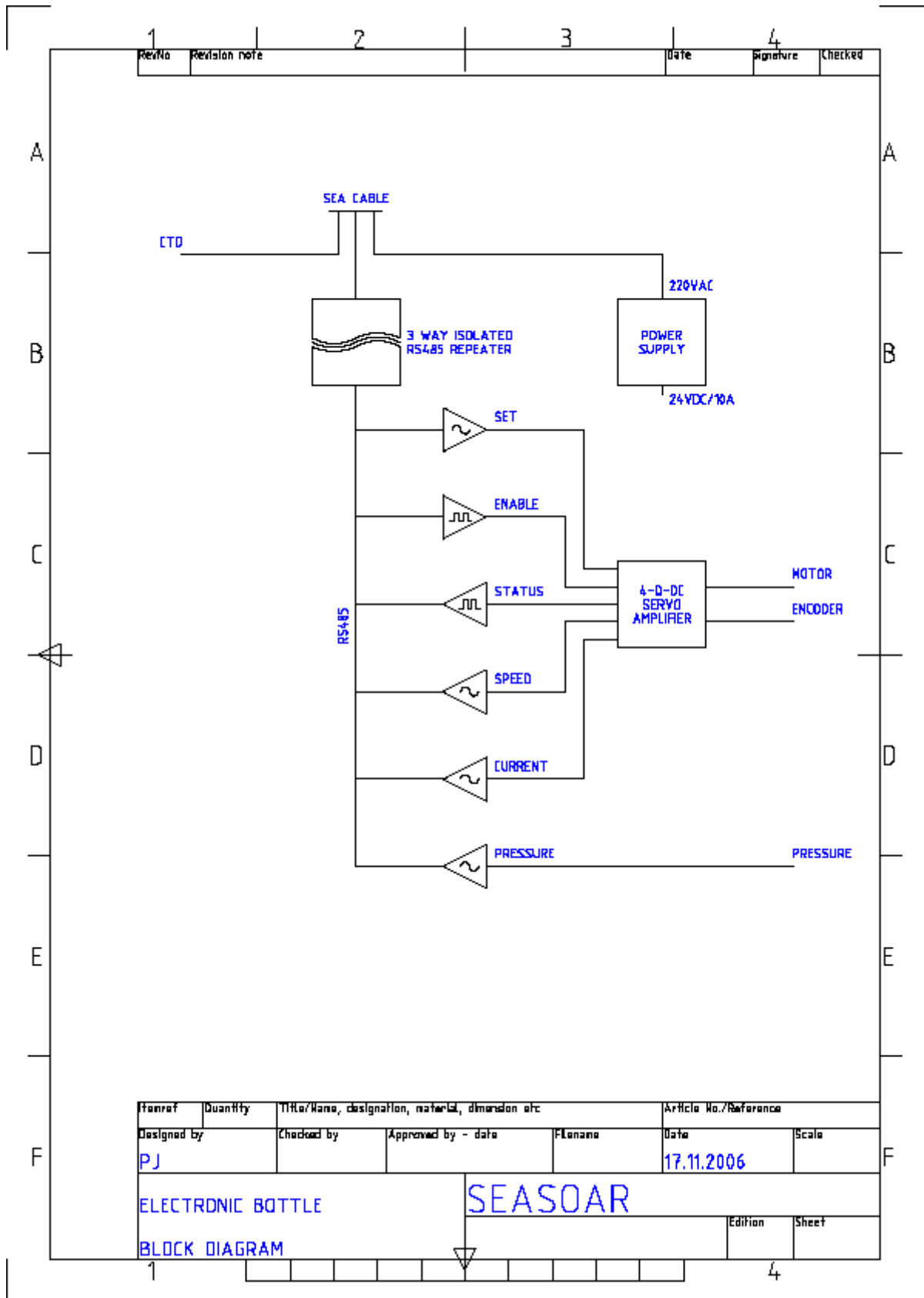




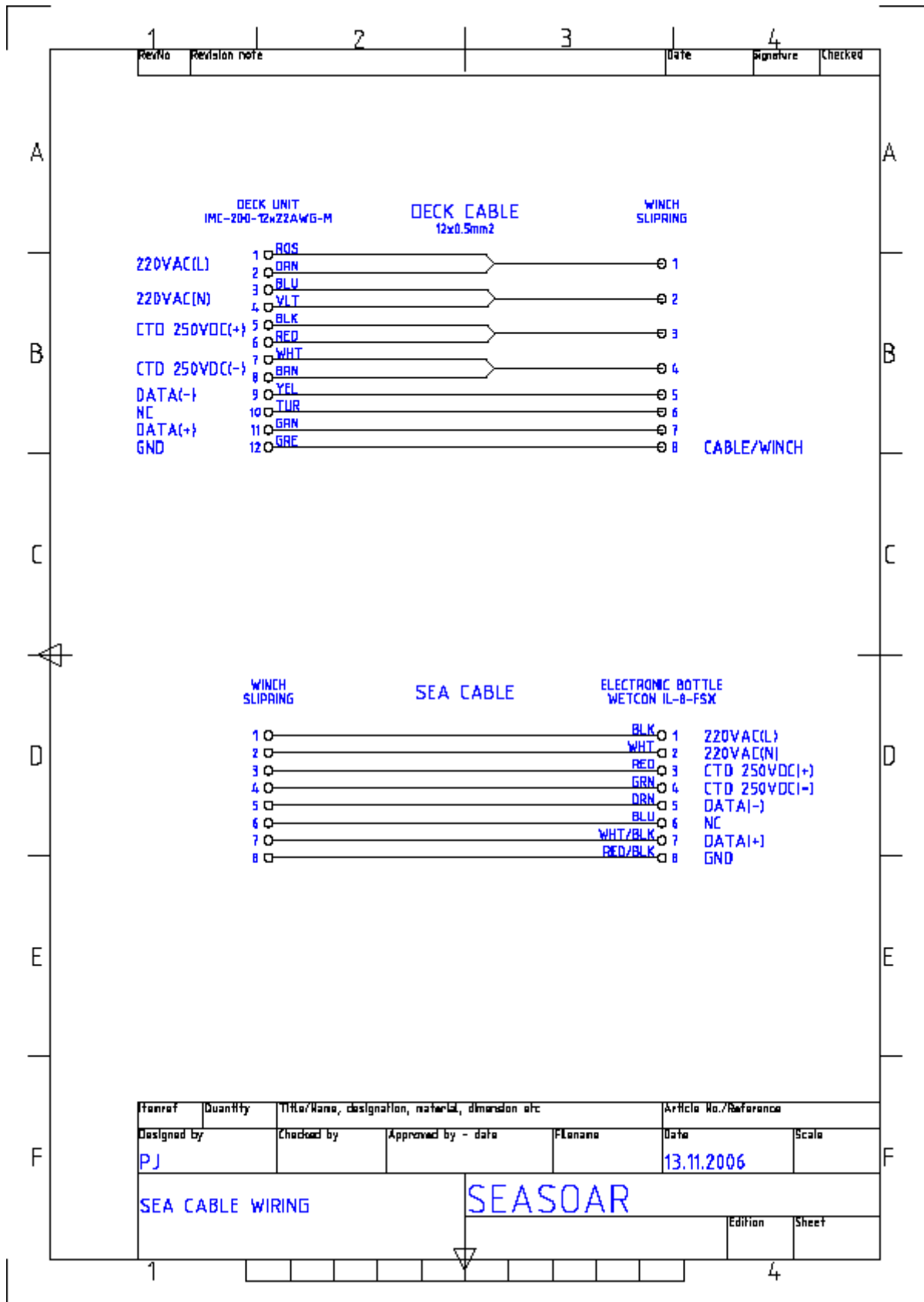


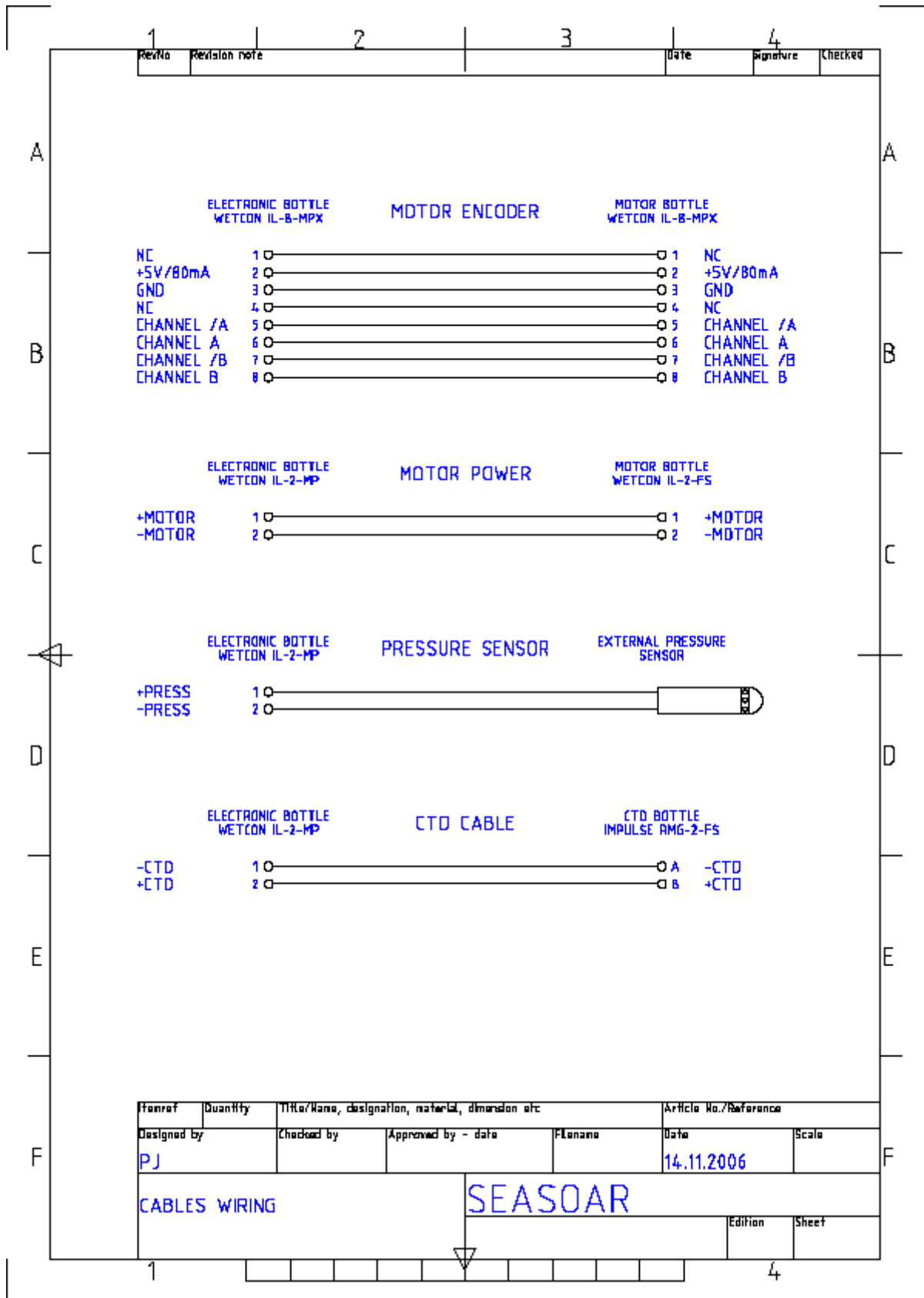


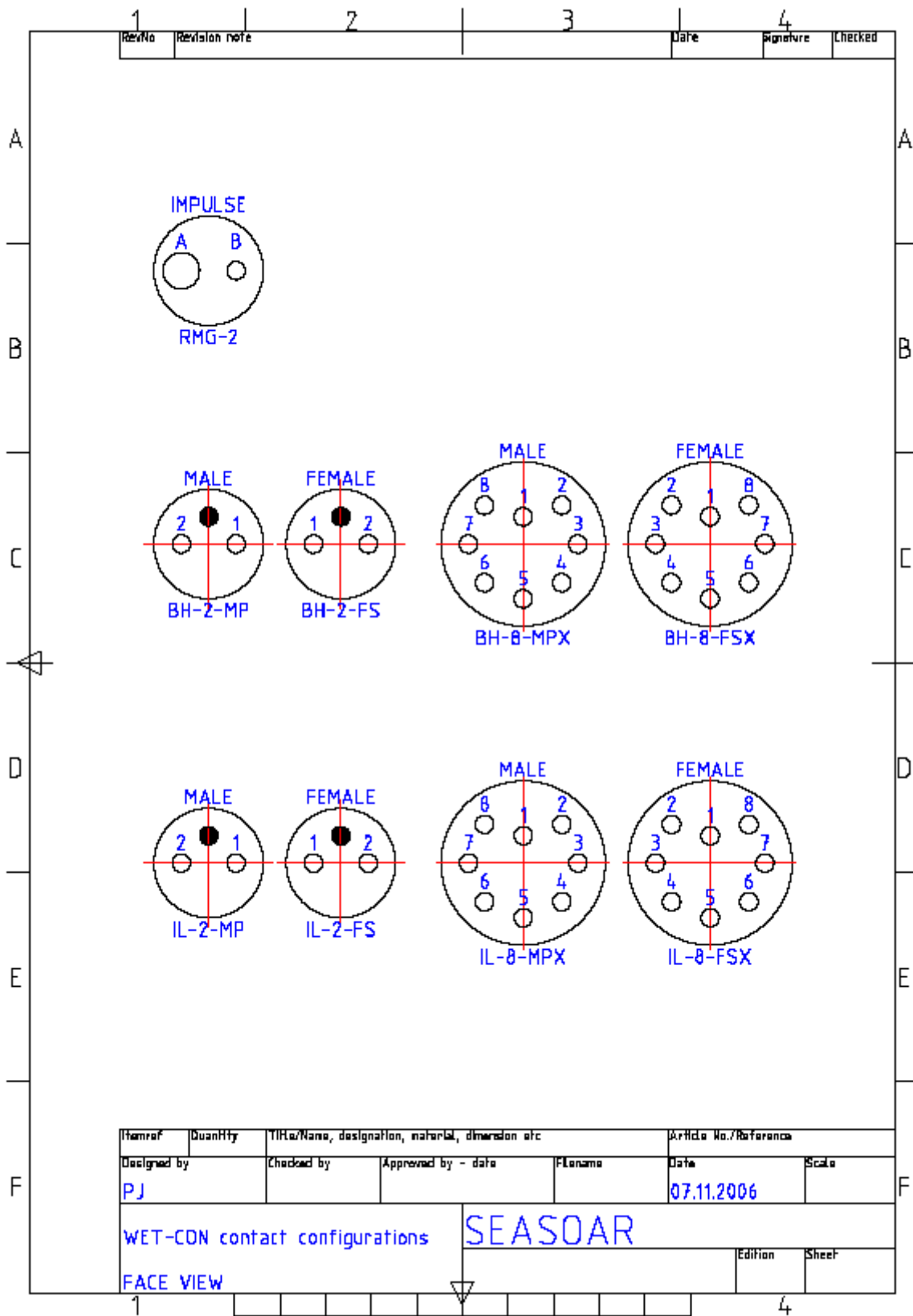


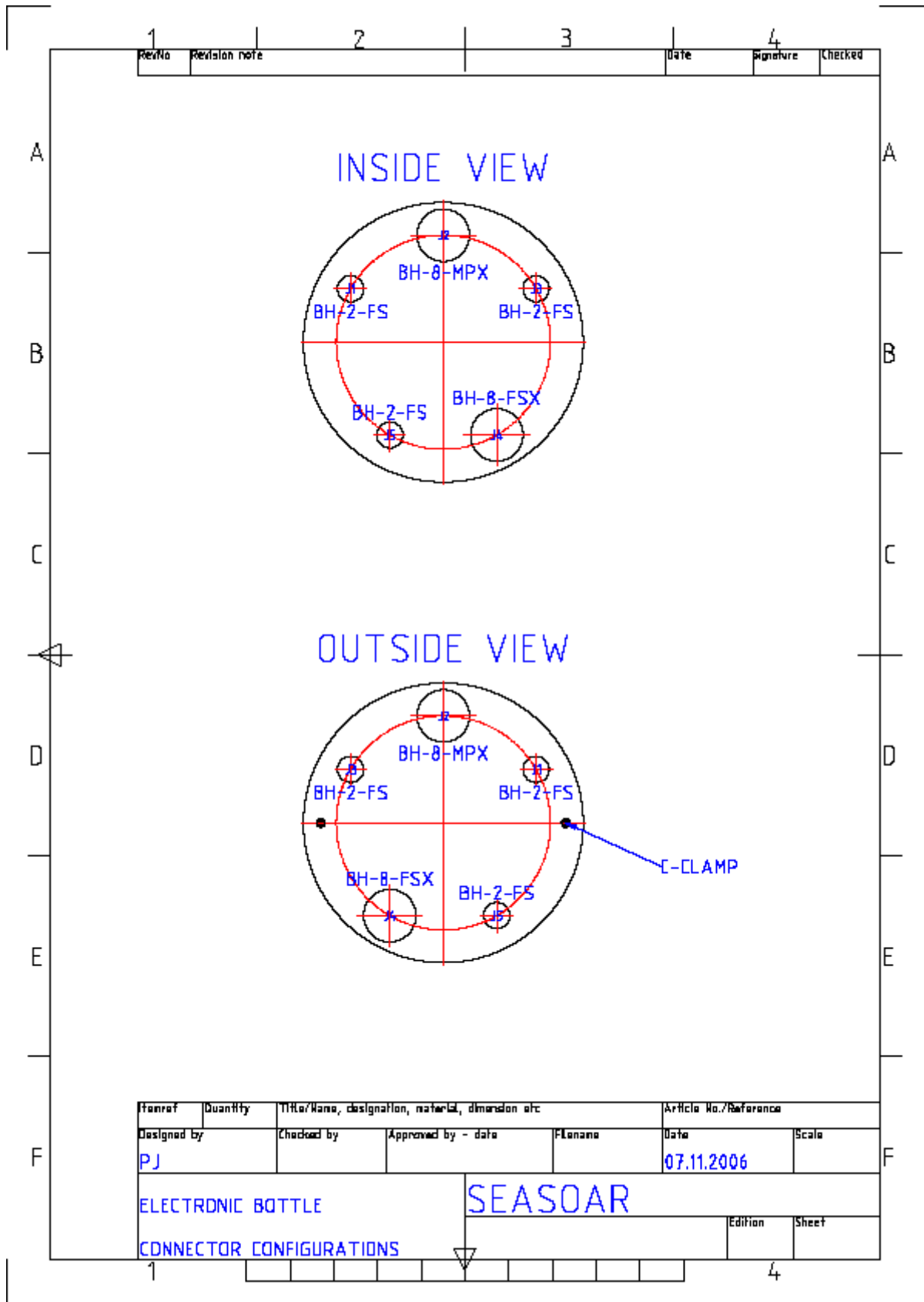


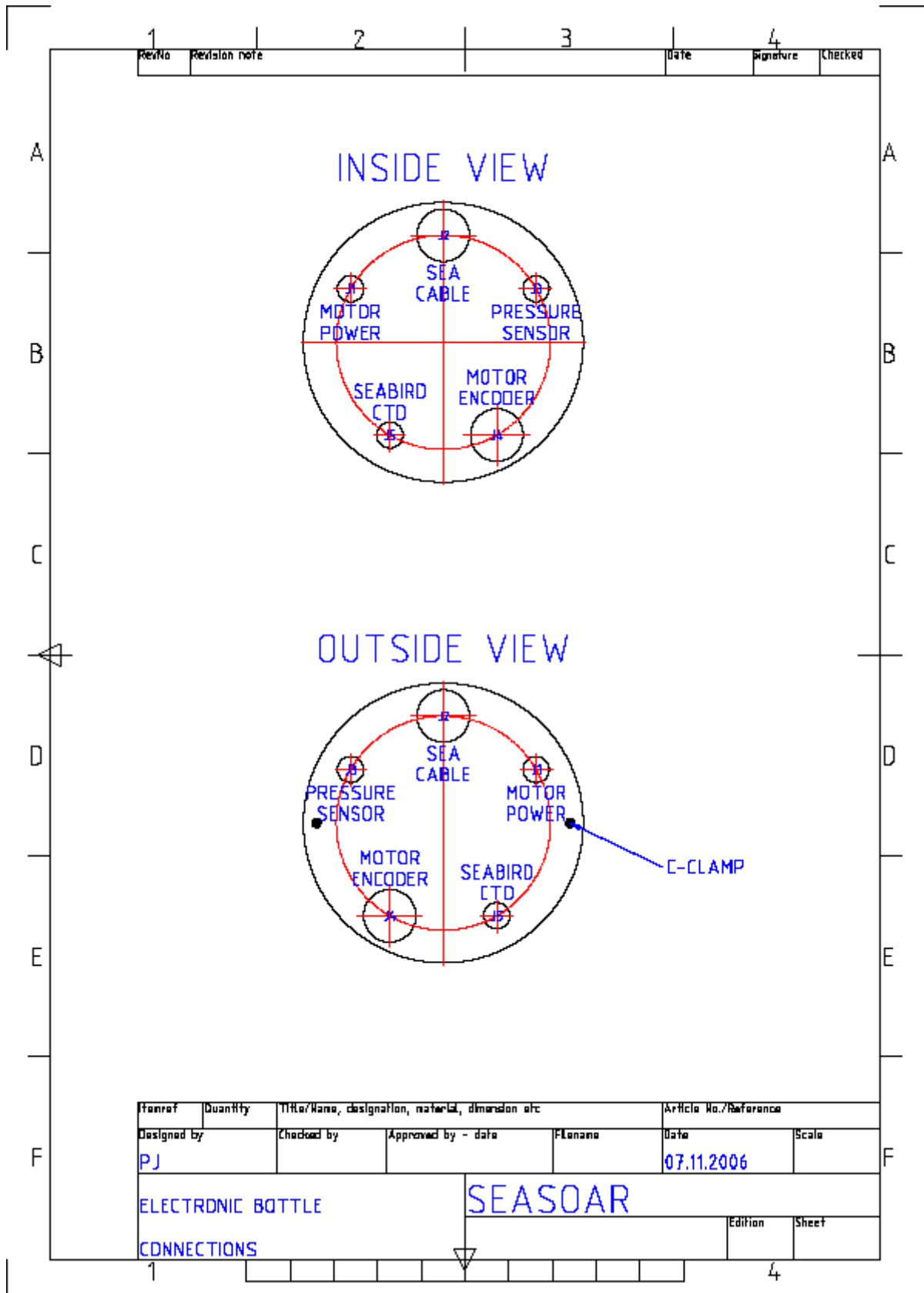




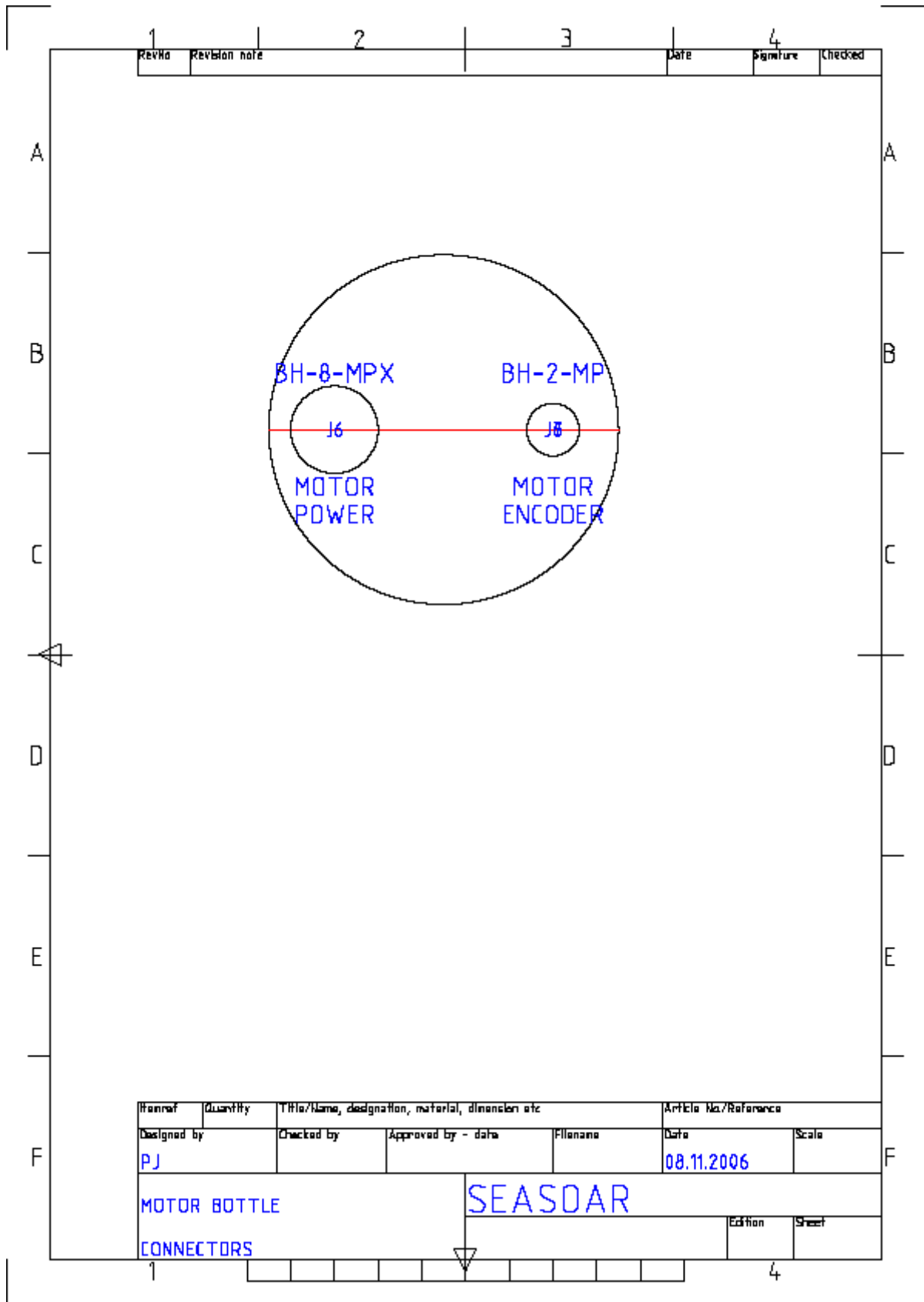














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