

MRU

Motion Reference Unit - 5th generation





KONGSBERG

MRU 5th generation Motion Reference Unit

User Manual

MRU-D-210/1.0

30.05 2012 © Kongsberg Seatex AS

Document history

Document number: MRU-D-210 / Revision 1.0		
Rev. 1.0	30.05 2012	First issue of this manual

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Comments

To assist us in making improvements to the product and to this manual, we welcome comments and constructive criticism.

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Table of contents

Glossary	5
1 INTRODUCTION	7
1.1 About the reader	7
1.2 Notations used in this manual	7
1.3 Product restrictions	8
1.3.1 Restrictions in export	8
1.3.2 Restrictions in guarantee	8
1.3.3 Restrictions in use	8
1.4 Disposal	9
1.5 Equipment handling	9
2 PRODUCT DESCRIPTION	11
2.1 Purpose and application	11
2.1.1 MRU 5+ function	13
2.1.2 MRU 5 function	13
2.1.3 MRU E function	13
2.1.4 MRU H function	14
2.1.5 MRU 3 function	14
2.1.6 MRU 2 function	14
2.1.7 MRU D function	15
2.2 System components	15
2.3 Construction	15
2.4 Internal sensors	16
2.5 Sensor calibration procedure	17
2.5.1 MRU calibration certificate	17
3 TECHNICAL DESCRIPTION	19
3.1 Six degrees of freedom motion	20
3.2 Gravity erection of orientation	21
3.3 Frames for measurements of motion entities	23
3.3.1 Definition of frames and variables	24
3.4 Trimming of the MRU axis directions	26
3.5 Rotation angle output	26
3.6 Angular rate and acceleration output	27
3.7 Velocity and position output	28
3.8 Heave estimation	28
3.8.1 Selection of heave filter mode	29
3.8.2 Heave measurements with mean value dependent on vessel tilt	32
3.8.3 Delayed heave output	33
3.9 Internal processing and I/O delays	33

4	OPERATING INSTRUCTIONS	35
4.1	Start procedure.....	35
4.2	Operation	35
4.3	Stop procedure.....	36
5	MAINTENANCE	37
5.1	Periodic maintenance.....	37
5.1.1	Software upgrades.....	37
5.1.2	Recalibration	37
5.2	Repairs and modifications	38
5.2.1	Repair of the MRU.....	38
5.2.2	Installation of spare MRU.....	38
5.2.3	Repair of the MRU junction box	39
5.3	Troubleshooting.....	39
5.3.1	MRU status: Abnormal	39
5.3.2	Reduced roll or pitch performance	40
5.3.3	Echo sounder depth error.....	40
5.3.4	Reduced heave performance	40
6	REFERENCES.....	42
A	ARRIVAL CHECK AND TEST	43
A.1	Equipment needed for the test	43
A.2	Startup procedure.....	43
A.3	The MRU test	44
B	CORIOLIS FORCE GYROS	45

Glossary

Abbreviations

AHRS	Attitude and Heading Reference System
AP	Aft Perpendicular. The vertical intersection of the design waterline at the stern, alternatively the center line of the rudder stock.
BL	Base Line. Is the same as the keel for a vessel with horizontal keel line.
CG	Centre of Gravity. The mass centre of a vessel. This is normally the location with least linear acceleration, and hence the best location for measurements of roll and pitch.
CGND	Communication ground.
CL	Centre line. Is the longitudinal axis along the centre of the ship.
CRP	Common Reference Point.
GA	General Arrangement drawing.
GGND	The MRU ground.
GNSS	Global navigation satellite system
GUI	Graphical user interface
HPR	Hydroacoustic Positioning Reference system.
IMU	Inertial Measurement Unit
INS	Intertial Navigation System.
LGND	Logic ground
MEMS	Micro-Electro-Mechanical-Structure.
MP	Monitoring Point
MRC	MRU configuration software. Runs on a PC under Microsoft Windows.
MRU	Motion Reference Unit. A MRU consists of gyros and accelerometers.
NMEA	National Marine Electronics Association. NMEA 0183 is a standard for interchange of information between navigation equipment.
PGND	Power ground
PPS	Pulse per second
RMS	Root mean square
UDP	User Datagram Protocol

UTC	Universal Time Coordinated. This is the official time in the world and has replaced GMT (Greenwich Mean Time) as the official time.
WEEE	Waste electrical and electronic equipment

Definitions

Alignment	Is the process of adjusting the current internal navigation frame in the instrument to the true external frame.
Attitude	The orientation relative to the vertical axis of a vehicle. Heading is not included. If heading is included, the word "orientation" is used for the vehicle.
Heave	The vertical dynamic motion of a vehicle and defined positive down. Heave position and velocity are dynamic motion variables calculated for a selected average heave period.
Origin	The zero point in the coordinate system. The origin location can be configured by the user. Typical origin locations are CRP in a survey report, CG, MRU or the intersection point between AP, BL and CL.
P-axis	This axis is fixed in the vehicle and points in the starboard direction horizontally when the roll angle is zero. Positive rotation about this axis is bow of the vehicle up.
Pitch	A rotation about the pitch axis is positive when the bow moves up. Normally, pitch means the dynamic pitch angle motions.
R-axis	This axis is fixed in the vehicle and points in the forward direction horizontally when the pitch angle is zero. Positive rotation about this axis is starboard side of the vehicle down.
Roll	A rotation about the roll axis is positive when starboard side of the vehicle moves down. Normally, roll means the dynamic roll angle motion.
Starboard	When looking in the bow direction of a vehicle, this is the right hand side of the vehicle.
Y-axis	Yaw axis. This axis is fixed in the vehicle (b-frame), and points in the downward direction when the vehicle is aligned horizontally. Positive rotation about this axis is turning the bow of the vehicle to starboard.
Yaw	A rotation about the vertical axis is positive when turning Eastward (Clockwise) when the vehicle cruises in North direction. Normally, yaw means the dynamic yaw motion.

1 Introduction

1.1 About the reader

This user manual is intended as a reference manual for the personnel installing and using the MRU. It contains necessary information to understand the MRU technology and to operate and maintain the MRU.

1.2 Notations used in this manual

The following notations are used in this manual:

Bold text is used for all menu names. A series of menu selections is indicated by **File**→**New**

Italics is used for manual names and for information that needs your attention.

Note

A note is used to draw attention to special features or behaviour of the equipment.

Caution

Caution is used to make the user aware of procedures and operational practice which, if not followed, may result in degraded performance or damage to the equipment.

WARNING

Warning is used when it is necessary to warn personnel that risk of injury or death exists if care is not exercised.

1.3 Product restrictions

1.3.1 Restrictions in export

Export of the MRU 5+, 5, E, H and 2 models to other countries than EU countries or Argentina, Australia, Canada, Iceland, Japan, New Zealand, Switzerland, South-Korea, Turkey, Ukraine and USA, requires an export license.

Note

Notice to importer: The MRU product specified in this document has been shipped from Norway in accordance with The Ministry of Foreign Affairs' Official Notification on Export Control and US EAR. The MRU may be subject to restrictions if re-exported from your country.

1.3.2 Restrictions in guarantee

Changes or modifications to the product not explicitly approved by Kongsberg Seatex AS will void the guarantee.

The liability of Kongsberg Seatex AS is limited to repair of this system only under the given terms and conditions stated in the sales documents. Consequential damages such as customer's loss of profit or damage to other systems traceable back to this system's malfunctions, are excluded. The warranty does not cover malfunctions of the system resulting from the following conditions:

- The MRU is not shipped in the original transport box.
- The MRU has been exposed to extreme shock and vibrations.
- The MRU housing has been opened by the customer in an attempt to carry out repair work.
- Over-voltage or incorrect power connection.

1.3.3 Restrictions in use

MRU 5+, MRU 5

The MRU function is based on an inertial sensor to operate. It is designed for use on board marine surface operated vehicles with linear acceleration less than $\pm 30 \text{ m/s}^2$ ($\pm 3g$) and an angular rate range less than $\pm 150^\circ/\text{s}$.

Only relative dynamic heave position is calculated.

The MRU 5+ product shall be used in maritime survey and navigation applications only. No military and nuclear end-users or uses.

MRU E, MRU H, MRU 2

The MRU function is based on an inertial sensor to operate. It is designed for use on board marine surface operated vehicles with linear acceleration less than $\pm 30 \text{ m/s}^2$ ($\pm 3g$) and an angular rate range less than $\pm 100^\circ/\text{s}$.

For MRU E and H only relative dynamic heave position is calculated.

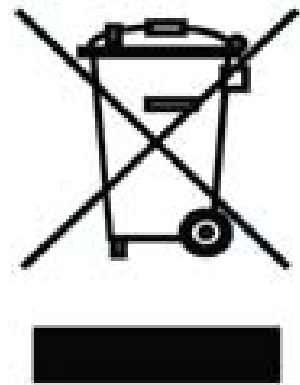
MRU D, MRU 3

The MRU function is based on an inertial sensor to operate. It is designed for use on board marine surface operated vehicles with linear acceleration less than $\pm 50 \text{ m/s}^2$ ($\pm 5g$) and an angular rate range less than $\pm 100^\circ/\text{s}$.

For MRU 3 only relative dynamic heave position is calculated.

1.4 Disposal

All electrical and electronic components have to be disposed of separately from the municipal waste stream via designated collection facilities appointed by the government or local authorities. The correct disposal and separate collection of your old appliance will help prevent potential negative consequences for the environment and human health. It is a precondition for reuse and recycling of used electrical and electronic equipment. For more detailed information about disposal of your old appliance, please contact your local authorities or waste disposal service.



The equipment may be returned to Kongsberg Seatex AS if there is no local WEEE collection. The equipment is marked with this pictogram.

1.5 Equipment handling

Observe the following when handling the equipment:

- All units must be handled with care.
- The case containing the unit must be kept dry at all times and must be sheltered from the weather.
- It must not be subjected to shocks, excessive vibration or other rough handling.
- The equipment must be preserved and stored in such a way that it does not constitute any danger to health, environment or personal injury.
- The unit must, whenever possible, be stored and transported in its original transportation box.
- The box must not be used for any purpose for which it was not intended.

- The storage area's mean temperature must not be lower than – 25 °C and not warmer than + 70 °C.
- Once unpacked, the equipment must be kept in a dry, non-condensing atmosphere, free from corrosive agents and isolated from sources of vibration.

Note

After the installation please save the transportation container. To maintain warranty validity, the MRU must be shipped in this container for service or repair.

2 Product description

This manual describes the 5th generation MRU products. This generation motion sensing products is both mechanically and electrically compatible with the previous MRU generations. The 5th generation MRU products are identified by serial numbers above 20000, titanium coloured housing and Ethernet communication.

2.1 Purpose and application

The MRU products are inertial attitude reference systems with dynamic linear motion measurement capability included. They are primarily intended for medium accuracy measurements of motion in marine applications where long lifetime and no regular maintenance are important. The MRU products are not equivalent to high performance gyro platform or laser gyro based devices, but can compete with medium range “strap-down” rate gyro based Attitude and Heading Reference Systems (AHRS).

The MRU products are supplied in a range of models from MRU D to MRU 5+, which is the top performance model. The capabilities of the various models are:

	Roll/pitch	Heave (real-time)	Heave period [s]	Acceleration [m/s²]
MRU 5+	0.01°	5 cm	25	0.001
MRU 5	0.02°	5 cm	25	0.01
MRU E	0.05°	5 cm	25	0.01
MRU H	0.05°	5 cm	25	0.01
MRU 3	0.08°	5 cm	18	0.02
MRU 2	0.1°			0.01
MRU D	0.35°			0.05

The different MRU products vary in performance and price to meet the customer’s need. The table shows the various performances.

Overview of capabilities of MRU models							
Capability	MRU 5+	MRU 5	MRU E	MRU H	MRU 3	MRU 2	MRU D
<i>Primary sensors:</i>							
Accelerometers	3	3	3	3	3	2	2
Angular rate sensors	3	3	3	3	3	2	2
<i>Functions:</i>							
Full "strap down" function	Yes	Yes	Yes	Yes	Yes	No	No
Free mounting orientation	Yes	Yes	Yes	Yes	No	No	No
Lever arm corrections	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sensor temperature comp. & linearisation & orthogonalisation	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Built-in self testing	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Outputs:</i>							
Roll and pitch angles	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yaw angle, dynamic only	Yes	Yes	Yes	Yes	Yes	No	No
Heave measurements	Yes	Yes	Yes	Yes	Yes	No	No
Surge and sway measurements	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Inputs:</i>							
Speed log	Yes	Yes	Yes	Yes	Yes	No	No
External heading	Yes	Yes	Yes	Yes	Yes	No	No
1PPS	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Interfaces:</i>							
Ethernet communication	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Digital RS-232/422 compatible	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Analog output from junction box	Yes	Yes	Yes	Yes	Yes	Yes	Yes

2.1.1 MRU 5+ function

The MRU 5+ is the highest capability MRU model. It outputs roll, pitch, yaw and relative (dynamic) heave, surge and sway motion. Acceleration and velocity of the linear motions, as well as angular acceleration and velocity, are also output from the unit. This MRU provides no absolute north information and the measurement drifts slowly in yaw, except when external heading is input to the unit.

The MRU 5+ includes high-end Kongsberg Seatex AS developed MEMS based gyro design. This gyro is called MRG (MRU Rate Gyro). It combines very low noise, excellent bias stability and outstanding gain accuracy.

The product is developed specially for hydrographic surveys and other high precision applications. The MRU 5+ is suitable as an IMU in integrated GNSS/inertial systems, as a backup sensor for position and heading determinations during dropout of GNSS signals.

2.1.2 MRU 5 function

The MRU 5 is constructed in the same way as the MRU 5+, but includes less accurate MRU Rate Gyros (MRG) and accelerometers.

It outputs roll, pitch and yaw angles and corresponding angular rate vectors fixed to the vehicle frame. The unit outputs relative (dynamic) heave, surge, sway positions, velocities and accelerations in adjustable frames. This MRU provides no absolute north information and the measurement drifts slowly in yaw, except when external heading is input to the unit.

Typical applications are roll, pitch and heave compensation of multi-beam echo sounders on ROVs and ships for seabed mapping, heave compensation of offshore cranes, hydroacoustic positioning systems and dynamic motion monitoring of roll, pitch angles and linear accelerations on offshore structures.

2.1.3 MRU E function

The MRU E is constructed in the same way as the MRU 5, but includes less accurate MEMS rate gyros.

This MRU provides no absolute north information and the measurement drifts slowly in yaw, except when external heading is input to the MRU E.

The MRU E is produced to operate at ambient temperatures from -25 to +70° C and to be installed on open decks, inside cabinets or on bulkheads. Typical applications for the MRU E is direct mounting of the unit under the helideck center to measure 3-axes linear accelerations together with roll, pitch and heave. The MRU E is typically used in a Helideck Monitoring System where the helideck is located separately from the accommodation and the hull. No additional enclosure or cabinet is required.

The MRU E outputs roll, pitch and heave together with linear acceleration in 3-axes.

2.1.4 MRU H function

The MRU H is constructed in the same way as the MRU 5, but includes less accurate MEMS rate gyros.

This MRU provides no absolute north information and the measurement drifts slowly in yaw, except when external heading is input to the MRU H.

The MRU H is specially designed for motion measurements in marine applications requiring highly accurate heave measurements in environments with extreme horizontal accelerations. The MRU H is an ideal sensor for roll, pitch and heave compensation of offshore cranes and echo sounders. The MRU H can also be used on typical ship motions monitoring applications such as helideck motion monitoring, hydroacoustic positioning systems, as well as hull stress monitoring.

The MRU H outputs roll, pitch and yaw angles and corresponding angular rate vectors fixed to the vehicle frame. The unit outputs relative (dynamic) heave position, velocity and acceleration in adjustable frames.

2.1.5 MRU 3 function

The MRU 3 is constructed in the same way as the MRU H, but includes less accurate angular rate gyros and accelerometers. The limitation compared to an MRU H is that the MRU 3 can only be mounted in one fixed direction relative to the ship and that is with the connector pointing up or down.

The cost-effective MRU 3 model is specially designed for use in marine applications like real-time heave compensation of single beam echo sounders and offshore cranes. The unit incorporates 3-axis MEMS sensors for both linear acceleration and angular rate. The MRU unit provides no absolute north information and the measurement drifts slowly in yaw, except when external heading is input to the MRU 3.

The MRU 3 outputs roll, pitch and yaw angles and corresponding angular rate vectors fixed to the vehicle frame. The unit outputs relative (dynamic) heave position, velocity and acceleration in adjustable frames.

2.1.6 MRU 2 function

The MRU 2 is specially designed for use in marine applications that require both static and dynamic roll and pitch measurements. The unit incorporates 2-axis sensors for linear acceleration and angular rate. The limitation compared to an MRU H, which has 3-axis angular rate and acceleration measurements, is the fact that the MRU 2 is not capable of measuring heave and can only be mounted in one fixed direction relative to the ship.

The MRU 2 achieves high reliability by using sensors with no rotational or mechanical wear-out parts.

Typical applications for an MRU 2 are roll and pitch measurements in offshore riser monitoring systems, dynamic positioning systems, telecommunication antenna compensation systems and motion damping systems on high speed crafts.

The MRU 2 outputs roll and pitch angles and corresponding angular rate vectors fixed to the vehicle frame. The unit outputs surge and sway accelerations.

2.1.7 MRU D function

The MRU D is constructed in the same way as the MRU 2.

This cost-effective MRU model is specially designed for use in marine applications and is the ideal sensor for roll and pitch measurements on board ships. The unit incorporates 2-axis MEMS sensors for both linear acceleration and angular rate.

This unit has to be mounted in a fixed direction relative to the ship and that is with the connector pointing up or down. The MRU D is best suited for applications with limited range in roll and pitch. If unlimited mounting orientation and/or unlimited mounting range is required, we recommend one of the MRU models with sensors in all three axis.

Typical applications for this MRU D model are roll and pitch measurements in dynamic positioning systems, GNSS antenna compensation and motion damping systems on high speed crafts.

The MRU D outputs roll and pitch angles and corresponding angular rate vectors fixed to the vehicle frame. The unit outputs surge and sway accelerations.

2.2 System components

The MRU models are supplied with the following standard parts:

- The MRU motion sensor.
- Three-metre Ethernet configuration cable for connection to a PC.
- Power supply 24 V for Ethernet configuration cable.
- USB memory stick including the MRU configuration software MRC+, manuals, configuration and calibration file.
- Transportation box.

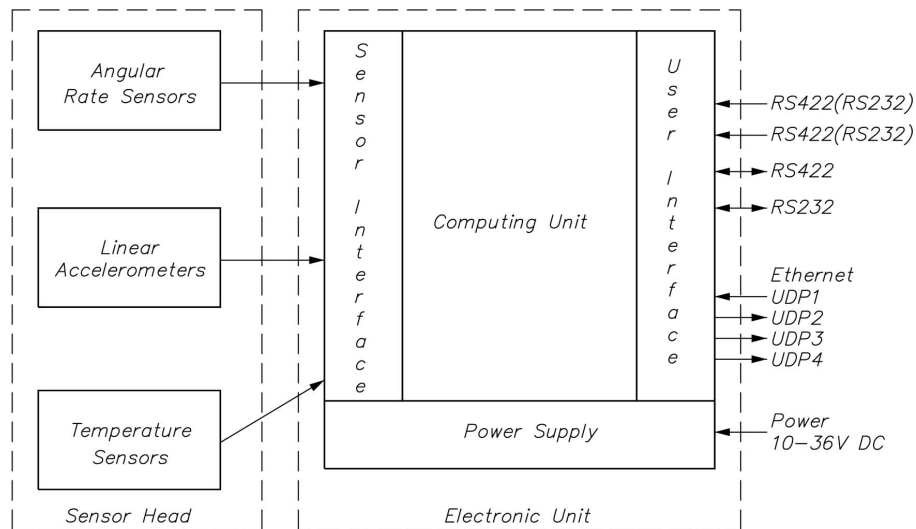
In addition comes a mounting bracket, a junction box and cables according to the customer's requirements.



2.3 Construction

All the 5th generation MRU models are constructed in the same way, but differ in the number and quality of the inertial sensors inside. The high level functions of the MRU are illustrated. All functions are located inside the MRU housing, including power supply and all signal processing.

Figure 1 MRU functional modules



The interior of the MRU is divided into sub-assemblies consisting of an electronic and a sensor part. The housing cylinder should, however, not be removed by anyone else than Kongsberg Seatex AS.

The signal processing inside the MRU is in real time with very accurate timing requirements and high-speed operation. The important tasks are always performed independent of external user requests. The processing software, configuration settings and calibration constants are downloaded to the MRU from a PC via the Ethernet interface. The software and other data are stored on Flash and remain resident while the MRU is not powered. A user can download new configuration or new versions of the MRU software by the MRC+ configuration software.

2.4 Internal sensors

The MRU has two sensor clusters that measure the following physical vector quantities: angular rate and linear acceleration. The sensor readings are scaled, linearised, orthogonalised and temperature compensated before they are passed on to the more advanced signal processing inside the MRU. The sensor axes are accurately aligned to the axes marked on the top lid of the MRU by the orthogonalisation procedure.

For a more detailed description of the angular rate sensors used in the MRU, see *Coriolis force gyros* on page 45.

2.5 Sensor calibration procedure

An advanced, time efficient and error-safe procedure for calibration of the internal sensors is one of the key properties to achieve the quality of the MRU product. Calibration, orthogonalisation, linearisation and temperature compensation are carried out for each physical sensor inside each MRU.

For calibration of the angular rate sensors and the accelerometers a 2-axis Acutronic rate table system with temperature chamber is used. The calibration process is fully automated with the capacity of calibrating and testing several MRUs simultaneously. Due to the temperature chamber on the rate table, temperature gradients can be kept at a minimum during calibration. The accuracy of this Acutronic system is better than 1 arc s (0.0003°) and provides a very accurate reference during calibration and testing. The calibration of the angular rate sensors is performed at different rates and temperatures. The accelerometers in the MRU are calibrated by setting the rate table at certain angles relative to the vertical and repeating the procedure for different temperatures. From these data the sensor calibration parameters are computed using a least square error fit procedure.

The parameters from the calibration process for each MRU can be found in the ASCII file with the name `mruNNNNN.par` on the USB memory stick accompanying each MRU delivery. Here NNNNN is the serial number of the MRU.

2.5.1 MRU calibration certificate

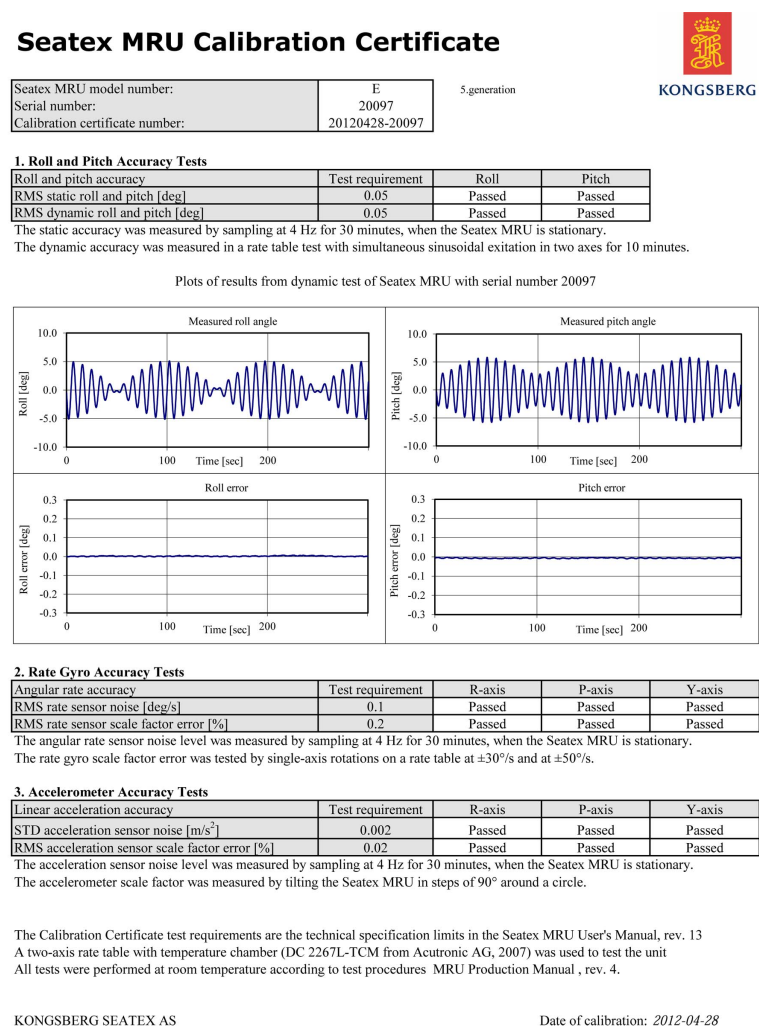
After calibration, static and dynamic tests are performed on each MRU for final performance verification. These tests are carried out using the Acutronic rate table system and are performed immediately after sensor calibration. The results from these tests are presented in the MRU Calibration Certificate delivered with each unit.

In order to provide the customers with data showing the quality of each MRU compared with its technical specifications, the following tests are carried out:

- Dynamic roll and pitch test that combines two sine functions with different frequencies for a 10-minute recording period. The results are presented in RMS values and plots of both the measurements and the errors are shown on the certificate.
- Static noise level test for the roll, pitch and yaw angles and angular rate along with the accelerometers. The results are presented in RMS values for a 30-minute recording period.
- Rate gyro scale factor test by rotating each sensor axis in the rate table at $\pm 10^\circ/\text{s}$ and $\pm 30^\circ/\text{s}$. The measured scale factor error is presented in RMS values.
- The accelerometer scale factor is tested by tilting the MRU in steps of 30 degrees around a circle. The measured scale factor error is presented in RMS values.

All the above tests are performed at room temperature. The Calibration Certificate contains data of each measurement along with the test requirements and an approval column (passed/failed). The test requirements are according to the technical specifications given in the *MRU Installation Manual*, see *References* on page 42.

Figure 2 MRU calibration certificate



3 Technical description

This chapter covers basic properties of inertial motion measurement and explains the design principles of the 5th generation MRU models and how they are functioning. It also defines the basic principles required to understand the function of motion measurement devices.

It is important to understand its internal functions to fully exploit the possibilities of the MRU. This section should be read before the MRU is used in a new application. The MRU should not be used in applications for which it is not designed.

The MRU operates much like a "strap down" inertial navigation system. It is an inertial navigational system without use of gimbals or a mechanical platform. All sensors are "strapped" to the housing of the unit or to the vehicle where the MRU is mounted. The MRU algorithms are tailored to obtain optimum performance from the MRU's internal sensors in marine applications dominated by ocean wave induced roll, pitch and heave motion. It is important to obtain as much information as possible from the angular rate sensors, and to provide fast data response for use in critical real time applications of the MRU.

The algorithms take into account the fact that the placement of the ship's centre of gravity, the MRU location and the measurement location on a ship, are usually different (lever arm compensation). An "intuitive" description on how the MRU works, can be summarised as:

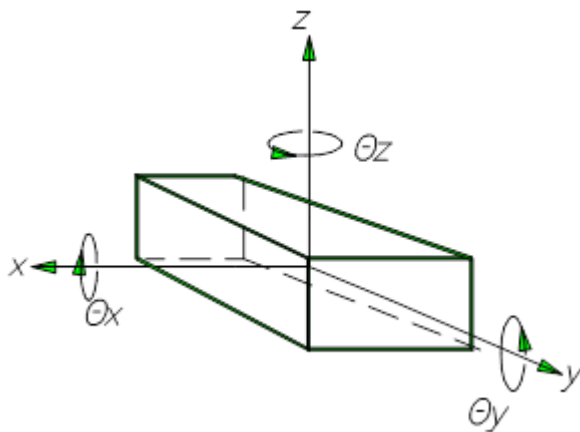
- The angular rate sensors determine the short term orientation of the MRU, expressed as roll, pitch and yaw angles or body angular velocity. Internally, the orientation information is kept in a rotation matrix (a 3 x 3 matrix). This computation is executed at fast cyclic rates and gives instant orientation response to the user.
- A small feedback from the horizontal acceleration of the vehicle's centre of gravity (CG) and the earth rate, compensates for the angular rate sensor errors. Compensation for centripetal acceleration by speed log input is also performed, if available. In a time frame of 3 to 10 minutes, the horizontal frame in the MRU will slowly be adjusted so that the observed horizontal accelerations of the CG are averaged to zero.
- Linear motions are computed by limited double integration of the acceleration. The limited integration means that the ideal 40 dB/decade frequency response of a double integration is broken at a lower cutoff frequency. The cutoff frequency is set from the average motion period (T_0), which has to be configured by the user.

3.1 Six degrees of freedom motion

A free moving body or vehicle has six independent degrees of freedom which may be quantified as:

- Linear translations in three perpendicular axes directions (x, y, z below)
- Rotation about three perpendicular axes (shown below as Θ_x , Θ_y , Θ_z)

Figure 3 Rigid body motion



To obtain full knowledge concerning the state of this body or vehicle, the velocities of the six entities above need to be known. Totally, twelve independent variables are needed to describe the full state of a moving rigid body at a given moment. The derivatives of the velocities are accelerations, and the differentiated angular velocities are angular accelerations. These six accelerations provide information about the forces acting on the vehicle and can additionally be of value to the customer's system.

Inertial motion measurement can similarly be divided into the following tasks:

- Inertial orientation measurements
- Inertial linear translation measurements

Inertial orientation measurement requires a gyro-like device which physically measures angular acceleration, angular velocity or angular displacements. Some sensors physically measure angular rate, and integrate the rate over time to compute the angular displacement in the sensor interface. This allows an angular rate sensor to perform like an angular displacement sensor.

The inertial linear translation measurement requires acceleration measurement. There exists no inertial sensor that directly measures the physical linear velocity. Consequently, the linear acceleration is integrated over time twice to obtain the translations. This places high requirements on the accelerometers. Also, the orientation measurement must be very accurate to alleviate the unavoidable g-component of the acceleration.

Inertial measurement of linear translations are only useful if the orientation of the body or vehicle is known (for example if the motion is mechanically constrained in some way), or the orientation is measured. In most cases, orientation measurement cannot be avoided, even if only the linear acceleration, velocity and translation are measured.

Variables output from the MRU and similar systems

The theoretical maximum number of variables available from an inertial measurement system is 18. This includes the six accelerations (3 linear, 3 rotational) resulting from the forces acting on the body. The other 12 are six velocities (3 linear, 3 rotational) and six displacements (3 linear, 3 rotational).

Most inertial systems can only output some of these variables because the units are dedicated to a specific application. The MRU can output all 18 variables mentioned above, with some limitations:

- Only dynamic (short-term) changes in velocities and positions can be measured.
- Only dynamic changes in heading (or rotation about a true vertical axis) can be measured, unless an absolute heading source (magnetic or north seeking compass) is available.
- The angular accelerations are obtained by numeric differentiation of the angular rates. There are no separate sensors which measure angular acceleration.

The 18 basic output variables can be represented in several ways which are more or less equivalent. The user can, in principle, compute all the desired variables from these basic 18 variables.

3.2 Gravity erection of orientation

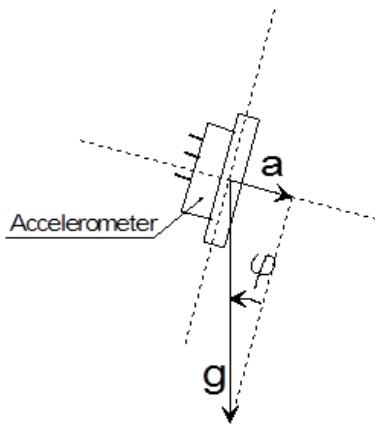
The Motion Reference Units use gravity to locate the vertical direction. The gravity and the orientation of the system referred to earth down, is measured by linear accelerometers. The MRU estimates the gravity at the location it is used (latitude dependent). When the gravity (g) is known, the measured acceleration from the accelerometer (a) is used to calculate the orientation of the accelerometer according to earth down, as illustrated. The orientation angle of the accelerometer according to g , is directly given as:

- $\delta\phi = \arcsin(a/g)$

where,

- **a**: measured acceleration by the accelerometer
- **g**: the gravity

Figure 4 Orientation measurements by use of accelerometer

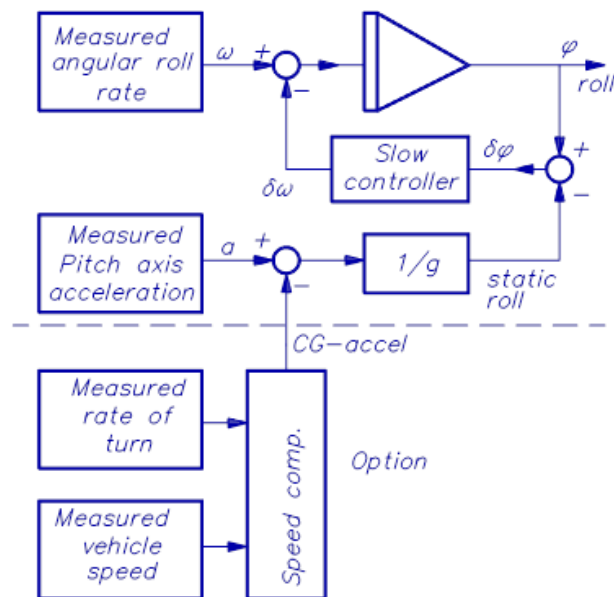


An important feature for such systems is to minimise the sensitivity to the horizontal accelerations of the ship or vehicle. This is a contradiction because the last accelerations cannot be separated from the g -vector by an accelerometer. A pure, classical inclinometer directly measures the total acceleration direction. This results in large inclination errors when horizontal accelerations are present.

The ideal situation is to use a Motion Reference Unit that averages the g -vector over an extremely long period of time in order to obtain an accurate reading of the vertical direction. A ship or a vessel will only accelerate for a limited time (except if cruising in circles). The sensitivity to short term horizontal accelerations is restricted by averaging the gravity over time. The angular erection to the vertical is calculated in the MRU in a complicated way, since the calculation is carried out for 3 axes in parallel. The erection is performed through software in the MRU. The principle for a simplified 1-axes MRU like device is illustrated. The function is:

- Angular rate is integrated to roll angle.
- Inclination is measured by the use of an accelerometer sensitive in the side direction of the ship.
- The roll angle is slowly adjusted from the difference between inclinometer output and integrated roll rate.

Figure 5 Single axis rate gyro based device



A very small feedback in the controller results in low acceleration sensitivity, but errors in the angular rate sensors will contribute largely to the error in the roll angle output ϕ . The better the quality of the angular rate sensor and the better the errors in the angular rate sensors are estimated, the better the total performance of the system will be. In a device like the MRU, advanced error models are used in order to reduce the errors as much as possible.

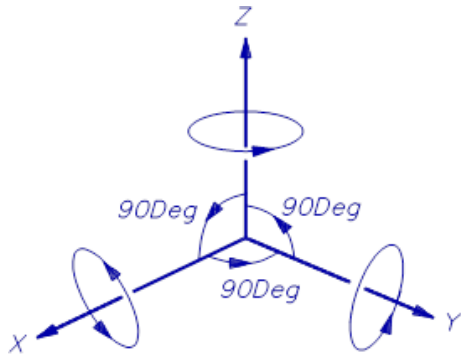
Single axis rate gyro based device on page 23 shows how the speed log subtracts an adjustment on the side acceleration of the ship to compensate for acceleration set up by the rate of turning at a high speed.

3.3 Frames for measurements of motion entities

It is necessary to operate with a unified coordinate frame in order to avoid confusion in the definitions of the outputs from the MRU. Many different definitions are used in industry. The following basic rules apply:

- Frames are orthogonal, which means that there are 90-degree angles between the axes. Frames have a name.
- The frames are always right-hand oriented, as illustrated. The succession of axes are X, Y and Z. Translations, velocities and accelerations are positive in the direction of the axis.
- Turning is defined as positive around a given axis, when the rotation is clockwise seen from the origin along a given axis. Rotation X means rotation around the axis X in the frame.

Figure 6 Right oriented frame



3.3.1 Definition of frames and variables

Commonly used frames in the MRU are:

- **g**: Geographic frame, with axes N, E and D at a given location.
- **h**: Heading frame, with axes F, S, D.
- **b**: Body frame, with axes R, P, Y. This frame is fixed to the vehicle or ship with its origin in the ship's centre of gravity, CG.
- **s**: Sensor frame, with axes x, y, z. This frame is defined by the MRU itself (the axes marked on the housing of the MRU). The s and b-frame are identical if the MRU mounting angles set in the software configuration are zero.

Geographic Frame or g-frame

This frame is called the g-frame. The g-frame has its origin at the current geographic location and is fixed to the earth surface. The frame is chosen with the following successive axes directions:

- **N**: Geographic north
- **E**: Geographic east
- **D**: Down

Heading Frame or h-frame

This frame is called the h-frame. The h-frame is the same as the g-frame rotated the heading angle around the D-axis. This frame has its origin in the ship's centre of gravity, CG. The frame is chosen with the following successive axes directions:

- **F**: Forward
- **S**: Starboard
- **D**: Down

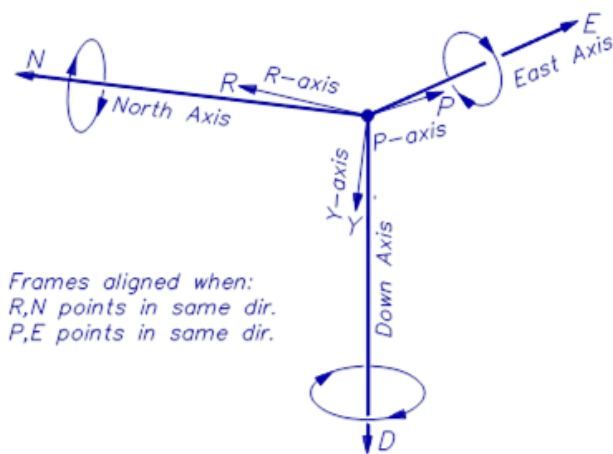
The F and S are always in the horizontal plane. The axis directions F and S are the axes for surge and sway motion as defined here.

Body Frame or b-frame

This frame is called the b-frame. This frame is fixed to the vehicle or ship with its origin in the ship's centre of gravity, CG. The definition of the axes directions is as follows:

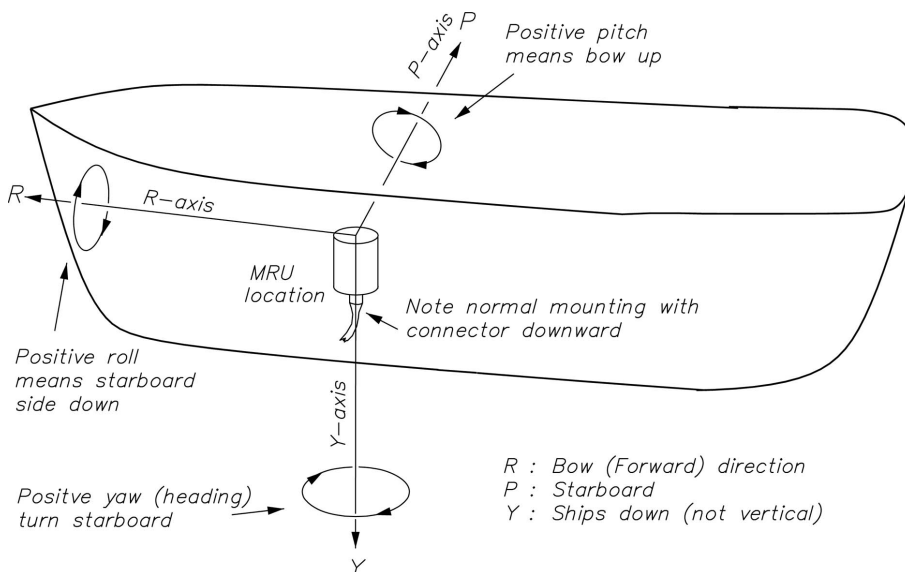
- **R:** R-axis, points in the bow direction of a ship and horizontally when pitch angle is zero.
- **P:** P-axis, points in the starboard direction of a ship and horizontally when roll angle is zero.
- **Y:** Y-axis, points down in the direction of gravity when roll and pitch are zero.

Figure 7 Geographic frame and body frame



Down is defined by the local gravity (normal to the ideal earth geoid).

Figure 8 B-frame definition

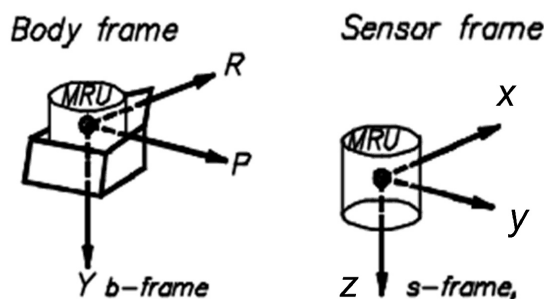


Sensor Frame or s-frame

This frame is called the s-frame. This frame is defined by the MRU itself (the axes marked on the housing of the MRU). The physical sensor frame origin at the centre of the MRU top. The s and b-frames are identical if the MRU mounting angles set in the software configuration are zero. The definition of the axes directions is as follows:

- **x**: x-axis as marked on the MRU
- **y**: y-axis as marked on the MRU
- **z**: z-axis as marked on the MRU

Figure 9 Frames fixed to ship/vessel



3.4 Trimming of the MRU axis directions

The axis directions of the MRU are set to be aligned with the axis directions marked on the MRU housing (x, y, z) during the calibration procedure. When the MRU is installed in the vehicle, it is important that the MRU axes are trimmed and aligned to the vehicle axis or the axis of the system for which it is supposed to compensate the vehicle motions. These offset angles between the MRU and the vehicle axes are referred to as **mounting angles** and need to be sent to the MRU from the configuration software, MRC+, see the *Installation Manual* in *References* on page 42 for instructions. These mounting angles define the b-frame relative to the s-frame.

This means that accurate axis directional trimming is not performed mechanically, but by computer software. The precision reference is on the top lid (connector facing down). Index holes for Dowel pins in the top lid help the customer to align the MRU properly.

3.5 Rotation angle output

There are numerous ways to define the orientation between the g-frame and the b-frame. We will denote the roll, pitch and yaw angles (Φ , Ψ , θ), which are actual outputs from the MRU. It is important to note that these angles are not directly related to the R, P and Y-axis. The used definitions for roll, pitch and yaw angles (named Φ , Ψ , θ) are given by the following turning operation between the frames g and b:

- a Start with the two frames g and b aligned.
- b Rotate the b-frame an angle Ψ about the common Y and D-axis. This angle is defined as the heading of the vehicle.
- c Rotate the b-frame an angle θ about the new P-axis of the b-frame.
- d Rotate the b-frame an angle Φ about the new R-axis of the b-frame

These definitions of rotation angles correspond to the standard definition of roll/pitch/yaw angles for ships. The definitions are a set of so-called Euler angles.

Note

The angles are measured from the start position to the final position in each step above. Positive angular directions are clockwise rotations around the actual turning axis, when looking from the origin to the end of the axis.

Roll and yaw — angles are not defined for pitch angles of $\pm\pi/2$ (so-called singular configurations). This is because the roll angle and the yaw angle in this case both describe a rotation about the same vertical axis. Ships do not reach this configuration of 90-degree pitch in normal operations.

3.6 Angular rate and acceleration output

Raw data from the gyro and accelerometer sensors in the s-frame are rotated to the b-frame and properly scaled into b-frame angular rate and acceleration respectively. The angular rate is filtered with a second order low-pass filter with a cutoff frequency at 10 Hz to reduce high frequency noise. The angular rate can be output from the MRU in the b-frame or optionally in the g-frame. Positive angular directions are clockwise rotations around the actual turning axis, when looking from the origin to the end of the axis.

The accelerometers in the MRU measure both the accelerations of the vessel and the gravity field. In order to obtain the acceleration of the vessel, an estimate of the gravity vector must be subtracted. This acceleration is commonly referred to as the specific force acceleration, but it can also be referred to as the linear acceleration as it represents the acceleration that contributes to linear motion of the vessel. In the MRU both the specific force acceleration and the actual measured acceleration can be output. The linear (specific force) acceleration is compensated both for gravity and lever arm effects, and can be output both filtered and unfiltered in all frames (b, h or g). The filtered accelerations are filtered with a second order low-pass filter with a cutoff frequency at 3 Hz. The linear acceleration variables are part of the linear motion variables, which have variable id's from 200, see the variable list in the *Installation Manual*. The measured b-frame acceleration in the MRU point including gravity is filtered with a second order low-pass filter with cutoff frequency at 3 Hz, and is available as variable id 11, 12 and 13.

3.7 Velocity and position output

The vertical position is referred to as heave and the horizontal position along the forward and starboard axes is referred to as surge and sway respectively. The relative linear position computation is based on a double integration of the linear acceleration over time. However, it is necessary to use a high-pass filter to keep unavoidable errors under control. Only changes within a short time frame can be estimated since the MRU has no static information (no position measurements). Hence, the MRU can not be used for any direct navigation purposes, but it can be used to obtain dynamic velocity and position estimates about a zero level. A ship or vessel will have short term motions dominated by ocean waves when it is at sea. The average heave level for a ship or vessel is zero and the heave measurements will always be output relative to this zero level. Velocity and position output from the MRU is compensated for lever arm effects and can be output in four different locations (MRU, CG, MP1 and MP2) .

A fundamental property to be aware of is that it is much easier to remove the g-influence in the vertical component than in the horizontal component of the acceleration vector. Due to this property, the performance is far better in the heave direction than in the surge and sway directions. A small error in roll/pitch angle $\delta\phi$ results in the following horizontal acceleration error:

- $a_{\text{err}} = g \cdot \delta\phi$

For the vertical direction the same influence is approximately:

- $a_{\text{err}} = 0.5 \cdot \delta\phi^2$

where,

- $\delta\phi$ is the roll/pitch error in radians and a_{err} is the acceleration error in m/s^2

3.8 Heave estimation

Estimation of heave is a double integration of acceleration over time. However, slowly varying errors and measurement noise make it necessary to apply a high-pass filter on the acceleration measurements. The optimal cutoff frequency for this filter is in general dependent on the average heave period T_0 . In order to achieve optimal performance, the user can set the average period T_0 in the range 1 to 25 seconds. If a too long period is selected, the velocity and position outputs will have a slowly varying error. If a too short period is chosen, the estimated heave will have a phase error for long period motions.

In the software two different types of filter structures are implemented for real-time measurements of linear motion. The filter mode *General purpose* is implemented to achieve optimal amplitude performance, whereas the *Hydrographic survey* filter is optimized to also provide good phase performance. Hence, the *Hydrographic survey* filter should be used when the filter is to be output correctly in time. If the average wave period is unknown, or the average wave period is time varying, the *Automatic* filter mode can be chosen. The *Automatic* filter mode estimates the average heave period T_0 and automatically sets the filter period in real time during operation. The *Automatic* filter mode uses the *Hydrographic survey* filter structure.

It is problematic to measure linear motions with long periods, like periods of 20 seconds or more. Therefore, a newly developed delayed heave algorithm called PFreeHeave® is implemented in the MRU. This algorithm uses both past and future measurements to output an accurate and phase-free heave from the MRU 5. The delayed heave signal has an advantage in long swell conditions and for applications that can use a heave signal which is delayed some minutes. Due to very low error, this filter is the most appropriate for applications where a heave signal which is delayed some minutes, can be used. The PFreeHeave algorithm is further described in *Delayed heave output* on page 33.

The accuracy of position and velocity estimates is far better in the heave direction than in the surge and sway (horizontal) directions. The reason for the difference between the channels is the influence of roll/pitch error generated gravity components, being a first order effect in the horizontal channel and a second order effect in the vertical channel. Due to this, the filter mode *General purpose* is the only mode available for surge and sway measurements.

3.8.1 Selection of heave filter mode

The following selections are available in the configuration in order to achieve the optimal heave performance:

- **Heave filter mode.** Selection between different filter structures.
- **Period.** The average heave period for the vessel, T_0 .
- **Damping.** The heave damping factor ε to be used in the filter.

The heave filter damping and average period should be chosen in order to obtain the best possible correspondence between the estimated heave motion and the real heave motion. These parameters can be set to a constant value or the automatic adaptive filter may be selected in case of varying sea states. The following should be considered when selecting the different heave filter modes and parameters:

Heave filter mode:

- **Automatic.** To be selected when the vessel is operating in various sea states or when the average heave period is unknown.
- **General purpose.** Is selected when optimal heave amplitude is to be measured and the heave phase is of no importance. This mode is typically selected when the system is to be used for measuring the heave height and period on oceanographic buoys.
- **Hydrographic survey.** To be selected when the heave phase and amplitude have to be output correctly in real time. This mode is typically selected when the heave output signal from the system is to be used for heave compensation of echo sounders, hydro acoustic positioning systems and offshore crane systems.

Period:

- An expected average heave period has to be set to the heave filter unless the automatic mode is chosen.

- The settling time for the heave measurements from power-on or after a turn will be about 10 times the selected period, T_0 . By selecting an unnecessary high heave period, the settling time will be longer than optimal. For vessels performing surveys with frequent turns, the period should be set as low as possible to minimise the heave settling time after turns.

The selection of heave filter period is a trade-off between low heave error over a wide range of heave periods and the settling time after an occurrence introducing a step response in the heave filter. For an MRU without external input we recommend the following selections:

- The selection $T_0 = 5$ or lower is recommended for sea-states with short period waves, and for vessels performing surveys with a lot of turning on rivers or within harbours. The settling time in heave will be about 50 seconds.
- The selection $T_0 = 10$ is the default setting for the hydrographic survey mode and covers most surveys, unless there are long period heave motions.
- The selection $T_0 = 20$ is recommended only for vessels operating in oceans with deep waters or vessels that frequently operate with following sea. The use of a long average wave period will result in increased low frequency error in the estimated heave, and should not be used unless long wave periods in the sea-state is evident.

The figure *Relative heave error as function of wave period* on page 30 illustrates the relative heave residual in percentage of amplitude for the "Hydrographic survey" filter with damping 0.7 and various average heave periods of 5, 10, 15 and 20 seconds.

The figure *Heave step response with corresponding settling time* on page 31 illustrates the heave step response with corresponding settling time for the "Hydrographic survey" filter with damping 0.7 and various average heave periods of 5, 10, 15 and 20 seconds.

Figure 10 Relative heave error as function of wave period

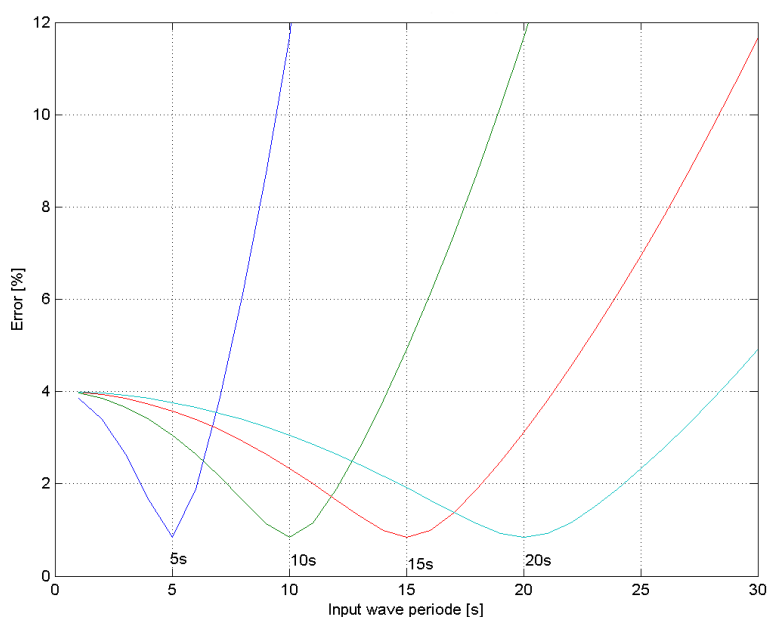
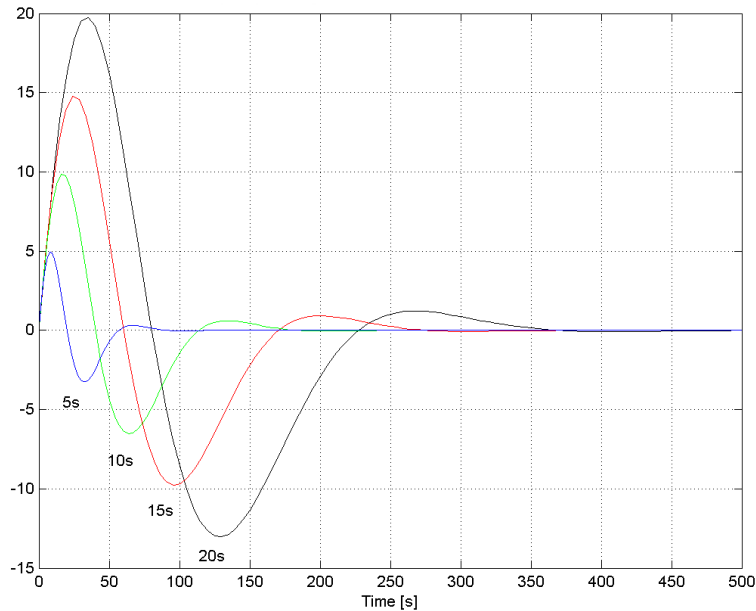


Figure 11 Heave step response with corresponding settling time



Note

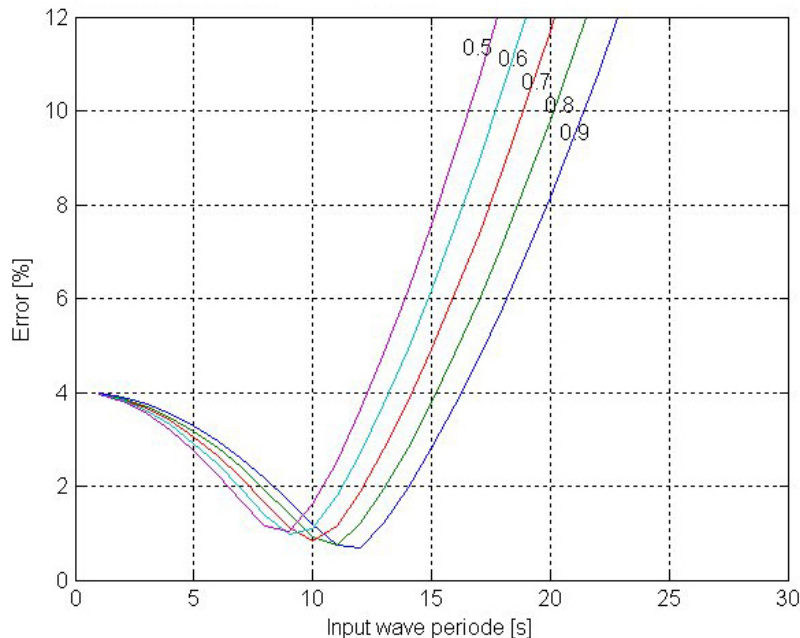
The MRU can be set up to output an estimate of the heave period (variable 129). This to assist in selecting the correct T_0 value. To check the performance of the heave filter it is possible to compare the delayed heave output with the real-time heave output. Another alternative is to select Automatic mode on the heave filter.

Damping:

- The heave damping factor shall usually be set to 0.7.

The figure *Relative heave error as function of damping— average heave period 10 s* on page 32 illustrates the relative heave residual as a percentage of the amplitude for the "Hydrographic survey" filter with average heave period set to 10 seconds with various damping factors of 0.5, 0.6, 0.7, 0.8 and 0.9.

Figure 12 Relative heave error as function of damping— average heave period 10 s



3.8.2 Heave measurements with mean value dependent on vessel tilt

In the MRU it is possible to output two different estimates of lever arm compensated position and velocity for a monitoring point. One estimate which is obtained by lever arm compensation of the position estimated in CG, and one estimate which is obtained by lever arm compensation of the position estimate in the MRU location.

The variables which are lever arm compensated from CG, are referred to by the prefix LA, e.g. variable LA_PosMp1_D which is lever arm compensated position in monitoring point MP1 in the down axis (heave). In general, a lever arm compensated position has a mean value that depends on the position of the MP and the vessel trim and list at any time. Note that for the position estimated by lever arm compensation from CG, this offset is not removed. Hence, these variables are useful especially in applications where the distance between the MP and the sea level is to be determined, like in some offshore crane operations or in echo sounder installation with depth changes due to change in vessel trim and list.

Lever arm compensated velocity and position can also be obtained by lever arm compensation from the MRU location, e.g. PosMp1_D and VelMp1_D. A high-pass filtering of the lever arm compensated position is applied to ensure a zero mean value.

3.8.3 Delayed heave output

The newly developed PFreeHeave® algorithm uses both past and future measurements to output an accurate and phase-free heave from the MRU. The delayed heave signal has an advantage in long swell conditions and for applications that can utilise a heave signal which is delayed some minutes, e.g. seabed mapping applications. The delayed heave signal can be output on serial line or Ethernet (UDP/IP) together with the real-time heave signal. The delay is exactly 132 seconds.

To take advantage of this functionality, the MRU user can post-process echo sounder recordings together with the motion sensor recordings. This can be performed in post-processing software delivered from QPS, CARIS, EIVA, HYPACK, Kongsberg Maritime and others. These software packages are able to read the PFreeHeave output format. See the *MRU Installation Manual* in *References* on page 42 for details on the PFreeHeave output format.

3.9 Internal processing and I/O delays

The total time delay for the output data seen from the user is a sum of a number of delay sources. The size of the contribution from each delay source is determined by the configuration of the MRU. It also strongly depends on the baud rate and if polled or cyclic I/O is used.

Below there is a summary of the timing delays found when measuring the time by the use of an oscilloscope connected to software triggered hardware outputs. The basic timing of each operation was measured. The actual time delays given by the configuration setting must be included to find the total time delay. The timing will probably vary slightly depending on the release number of the software. Be aware of the difference between cyclic and polled output of data. The sample interval will always be an integer time of the internal computation period within the unit (5 ms) when cyclic output data are used. The output data will then be synchronous with the internal life of the MRU. With polled output data the sample interval is set by the user (host system), and it is then decoupled from the internal life of the MRU.

Summary of time delays inside the MRU

- 1 Sensor interface delay given by averaging over the last measurement sample : $t_a = 2.5 \text{ ms}$
- 2 Main processing time. Varies with varying processing time : $t_b = <1 \text{ ms}$
- 3 Digital line request response time (only present with polled output) : $t_c = 2.5 \pm 2.5 \text{ ms}$
- 4 Transmission delay on digital line b is the baud rate, n is number of variables : $t_f = (n + 1) * 40000/b \text{ ms}$
- 5 Polling message transmission delay_b is the baud rate, only valid with software polling : $t_g = 50000/b \text{ ms}$

Summary of time delays given by application

This is the time from the physical event until data are available as a complete message received by the user (host system).

By cyclic digital output: $t = t_a + t_b$

By polled hardware output: $t = t_a + t_b + t_e + t_f$

By polled software output: $t = t_a + t_b + t_e + t_f + t_g$

Note

The angular rate (var. no. 1, 2 and 3) and some acceleration linear variables (var. no. 11, 12, 13, 203, 204, 205, 241, 242, 243, 253, 254, 255, 303, 304, 305, 353, 354, and 355) are low-pass filtered and therefore include an additional group delay. The group delay depends on the cutoff frequency in the low-pass filter. The cutoff frequency in the low-pass filter for angular rate is set to 10 Hz. The group delay for angular rate is then maximum 30 ms. The cutoff frequency in the low-pass filter for acceleration is set to 3 Hz. The group delay for linear acceleration is then maximum 95 ms. Unfiltered linear accelerations can alternatively be output without this group delay.

Example 1 Time delay calculation

Digital cyclic output of data, four variables at 19200 baud. Then:

- $t_a = 2.5 \text{ ms}$, $t_b = 1 \text{ ms}$, $t_f = (4 + 1) * 40000/19200 = 10.4 \text{ ms}$

Delay on output signals from the MRU: $\text{delay}_1 = t_a + t_b = 3.5 \text{ ms}$

Delay on output signals when received by host system: $\text{delay}_2 = t_a + t_b + t_f = 13.9 \text{ ms}$

4 Operating instructions

4.1 Start procedure

The following start procedures shall be used when the MRU is installed according to the procedures described in the *MRU Installation Manual*, see *References* on page 42.

How to start the MRU

- 1 Turn power on. The MRU starts automatically when the unit receives power and will be in operation as long as power is received.
- 2 The MRU needs some time before full accuracy is achieved. The maximum erection time is 15 minutes. During this period the MRU runs an internal self check procedure for sensors and electronic boards and performs an initial alignment.
- 3 When the MRU has obtained full accuracy, the status message from the MRU will change from "reduced accuracy" to "normal" on the communication lines.
- 4 Preferably leave the MRU with power on since there are no wear-out parts.

Once the MRU is installed, there is no need for manual intervention during operation.

4.2 Operation

Normally the MRU outputs signals on the serial line and/or Ethernet without any involvement from the user.

When using the MRU for real-time heave measurements, it is important to tune the heave parameters (heave period and damping) to the vessel size and motion characteristics for the actual weather conditions. Since the configuration parameter **Heave filter mode** only enters the default values of the heave period and damping according to the selected mode, these values have to be tuned for the actual vessel and weather conditions in order to achieve optimum heave performance.

Therefore, before a survey and/or during operation, check the heave performance of the MRU and tune the heave parameters until the best heave performance is achieved. An alternative is to select **Automatic** and let the MRU estimate the heave filter parameters during operation.

4.3 Stop procedure

How to stop the MRU

- 1 Disconnect the power to stop the MRU. The unit will shut down by itself in a controlled way.

If the power to the MRU is interrupted, the MRU will stop automatically in a controlled way and the configuration downloaded into the unit will be kept while unpowered.

5 Maintenance

The MRU is not designed for service in the field except for installation of new software versions and change of user configuration. An opening of the housing will result in damage or degradation of the unit and void the warranty. The MRU is filled with nitrogen to ensure correct thermal conductivity and to avoid condensation of water vapour inside the MRU housing at low temperatures.

An MRU in need of service has to be shipped in the original transportation box to Kongsberg Seatex AS. You will find the address on page two of this manual.

Note

When returning the MRU for service, only the MRU itself has to be returned. The mounting bracket shall not be returned, but stay onboard.

5.1 Periodic maintenance

The periodic maintenance of the MRU consists of software upgrades and recalibration.

5.1.1 Software upgrades

Kongsberg Seatex AS will offer regular software upgrades for the MRU with improvements and new functionalities. It is up to the user to decide whether he will upgrade his MRU with the new software. The new software is downloaded to the MRU by following the setup procedure described in the Release Note for the actual software. These upgrades can be carried out without opening the MRU housing by connecting a PC to the MRU and downloading the new software through the MRC configuration program.

5.1.2 Recalibration

The need for recalibration depends on the MRU model and the application in which it is used. In general the following is recommended:

- For the MRU 2 and H models a recalibration is recommended every fourth year.
- For the MRU E and D models a recalibration is recommended every third year.
- For the MRU 5+, 5 and 3 models a recalibration is recommended every second year.

The above mentioned recommendations are valid for applications where it is required that the MRU measurements are within their specifications.

A recalibration is recommended due to changes in the characteristics of the internal sensors over time and is therefore necessary in order to achieve the specified performance. Exactly when a recalibration is required, will depend on the use of the unit. The MRU has to be returned to Kongsberg Seatex AS for recalibration.

To reduce the need for recalibration, try to install the unit in an environment with constant and low temperatures.

5.2 Repairs and modifications

Repairs of the MRU products consists of replacement of damaged cables, replacement of the MRU, the MRU junction box or other MRU additional equipment.

5.2.1 Repair of the MRU

All repairs and modifications of the MRU, except for installation of new software versions and user configuration, have to be carried out by Kongsberg Seatex AS.

Caution

Opening the MRU housing will result in permanent damage and the user should under no circumstances make any attempt to do so.

5.2.2 Installation of spare MRU

If a spare unit is available while your unit is in for repair, use the following procedure to download your configuration to the spare unit:

How to download configuration to spare unit

- 1 Connect a PC to the MRU to be repaired as described in *Arrival check and test* on page 43.
- 2 When contact is established with the MRU by the MRC+ software, select **Configuration** menu → **Save** to save the configuration to file. The configuration in the MRU will then be saved on a file on the PC.
- 3 When the configuration file is saved on your hard disk, exit the MRC+ software.
If it is not possible to establish contact with the MRU and a backup copy of the used MRU configuration is not available, the spare MRU has to be configured from start according to the configuration instructions in the *MRU Installation Manual*, see *References* on page 42.
- 4 Disconnect the MRU to be repaired from the configuration cable and connect the spare unit to this cable.
- 5 Enter the MRC+ software and click the **Connect** button in the **Sensor** menu to establish communication with the spare MRU.

- 6 When contact is established, select **Configuration** menu →**Open** to read your saved configuration from a file on the PC.
- 7 Select **Configuration** menu →**Send to <MRU>** to send your configuration to the spare MRU.
- 8 Exit the MRC+ software.
- 9 Disconnect the spare MRU from the configuration cable and mount the unit into the mounting bracket. Ensure that the MRU is mounted in the correct orientation.

5.2.3 Repair of the MRU junction box

How to repair the MRU junction box

- 1 Check that the fuse within the box is not blown and replace it if it is. The fuse used is of type T2A 250 V with size 5 x 20 mm.
- 2 Check if any of the cable wires have loosened from the terminals.
- 3 Check the LEDs in the unit:
 - a MRU PWR light diode should shine green indicating that the MRU receives power.
- 4 If the LED light diodes indicate that the junction box is still not working, the box has to be returned to Kongsberg Seatex AS for repair.

5.3 Troubleshooting

The best tool for troubleshooting of the MRU is the MRC configuration software. If trouble occurs, always connect a PC to the MRU by the test cable and power up the unit. The equipment needed and how to start MRC+ is described in detail in *Arrival check and test* on page 43, in this manual.

The aim of this section is to identify the problem so that the appropriate actions can be taken.

5.3.1 MRU status: Abnormal

If the MRC+ software responds with the MRU status **Abnormal** in red characters in the MRC+ top bar, no data will be transmitted from the MRU. When this status appears on the screen, this is most likely due to problems during startup.

5.3.1.1 Problems during startup

If *Abnormal* mode appears in the MRC+ after startup, try to restart the MRU. Unless there are some serious problems with the MRU, the unit will now enter *Normal* mode after the restart. If the unit still does not function properly, please contact your nearest Kongsberg Seatex office.

5.3.2 Reduced roll or pitch performance

Sometimes the system may experience reduced roll or pitch performance.

What to check if roll or pitch performance is reduced

- 1 The MRU x-arrow is not properly aligned with the ship's longitudinal axis. A misalignment of only one degree will reduce the performance when exposed to heavy motions due to cross-coupled roll and pitch measurements. If not already done, ensure that the MRU yaw offset according to the ship's longitudinal axis is accurately measured and entered into the MRU configuration.
- 2 It has been several years since the MRU was last calibrated. Contact Kongsberg Seatex AS to check whether the MRU needs recalibration.

5.3.3 Echo sounder depth error

Sometimes the system may experience depth errors in the outer beams on a multi-beam echo sounder.

What to check if depth errors occur

- 1 The oscillations in the depth of the outer beams are correlated with the pitch angle of the vessel. Check the mounting angle around the z-axis. The MRU x-axis has to be parallel with the ship's longitudinal axis as long as the echo sounder transducer head is aligned with the ship axes.
- 2 The oscillations in the depth of the outer beams are correlated with the roll angle of the vessel. Check the lever arm vector (the components along the x, y and z-axes) from the MRU to the ship's centre of gravity (CG), and especially the vertical component (z). Please note that it is the co-ordinates from the MRU to the CG which should be entered and that positive vertical direction is downwards. If the location of the CG is below the location of the MRU, the vertical component (z) must be positive. Use the 2D "vessel window" to check that the MRU is on the expected location according to the ship's centre of gravity.
- 3 There is incorrect synchronisation of the MRU and the multi-beam data (timing error). Check that the measurements from the two data sources are handled correctly and that a timing error has not occurred. A 1PPS input to the MRU should be considered used. Post-processing of the MRU and the multi-beam data can be used to analyse whether incorrect synchronisation is the reason for the depth errors.

5.3.4 Reduced heave performance

The system the MRU is connected to experiences reduced performance in heave or depth errors in the centre beam of an echo sounder.

What to check if reduced performance in heave or depth errors occur in an echo sounder

- 1 There are oscillations in heave or the depth of the centre beams. Check that the correct Heave filter mode and Heave period are selected in the sub-folder **Sensors** → **MRU** → **Heave config** in the **MRU Configuration**.

- 2 The vertical vector component from the MRU to the monitoring point is defined positive down. If the location of the transducer head is below the location of the MRU, the vertical component will be positive and vice versa. Use the 2D "vessel window" to check that the MRU is on the expected location according to the entered monitoring point (MP).

6 References

Reference documents

- *MRU Installation Manual*, Kongsberg Seatex AS

Appendix A

Arrival check and test

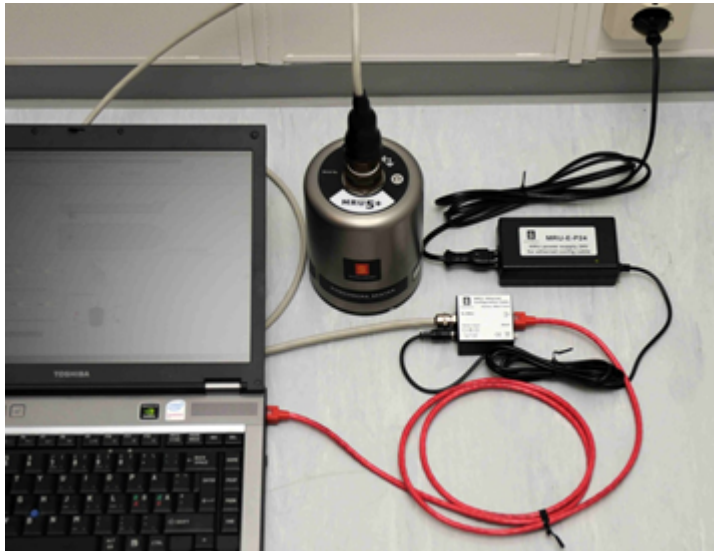
We recommend that a simple test of the MRU is performed when receiving the unit. The test procedure can also be used as a setup for troubleshooting the unit. The test is carried out by connecting the MRU to a PC by the test cable and power supply supplied by Kongsberg Seatex AS.

A.1 Equipment needed for the test

- The MRU-E-P24 power supply delivered with the MRU or similar.
- The MRU-T-015 Ethernet configuration cable.
- The MRU-E-CE1 peer-to-peer Ethernet cable of type crossed (yellow colour) or similar.
- A PC that runs under Microsoft Windows XP, Vista or 7 with a free Ethernet port. Not delivered together with the MRU.
- A stable table on which to place the MRU.

A.2 Startup procedure

- 1 Place the MRU on a stable table with the connector end of the housing pointing up.
- 2 Install the MRC+ configuration software as described in the *MRU Installation Manual*, see *References* on page 42, if not already done.
- 3 Connect the MRU to the PC and power as shown in the illustration.



- 4 Start up the MRU from the MRC+ software by following the procedure described in the *MRU Installation Manual*, see *References* on page 42.

A.3 The MRU test

- 1 When the MRC+ software is started and the connection to the MRU is established, select the **Configuration** tab if not already done.
- 2 Enter the folder **Sensors**→ **MRU** →**Geometry** and input the Mounting angles 180.0, 0.0, 0.0 in the roll, pitch and yaw field. (The default mounting of the MRU is with the MRU connector pointing down 0.0, 0.0, 0.0).
- 3 Enter the folder **Communication Interface** →**Input/Output** and click on Port #2 on the interface list. Select port number 7551 under **I/O Properties**. Select the **MRU Normal** protocol, set Interval to 100 ms and Token to 78. In the **Source** column input the variable no. 63 for roll measurements on the first channel and 64 for pitch on the second.
- 4 In the **Configuration** menu select **Send to MRU** in order to transfer the edited configuration to the MRU.
- 5 Select the **Data Presentation** tab and select the check box in front of each of the four variables number. This to ensure that these variables are shown graphically on the screen. Click on the **Start** button to display the MRU data graphically (MRU in *Normal* mode and the curves on the graphs are green). Check that the roll and pitch measurements have stabilised within 10 minutes from startup of the MRU. Check the outputs of roll and pitch changes by moving the unit gently.
- 6 If the MRU is functioning according to the description above, the unit is found acceptable.

Appendix B

Coriolis force gyros

All MRU models measure the angular rate vector initially without the use of moving parts (gyros) by use of Coriolis force based vibratory angular rate sensors. These rate sensors use linear vibratory motion instead of rotary motion, and have low power consumption and no wear-out parts.

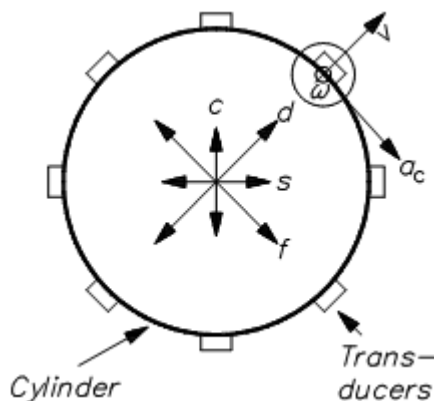
The accuracy of the angular rate sensors is very important for the accuracy of the MRU. If the gyroscopes are accurate, only small and slow feedback from the accelerometers is needed to determine the vertical direction at all times. This ensures low sway and surge acceleration sensitivity in the vertical direction.

The characteristics of the Coriolis force based angular rate sensors are as follows:

- Very low environmental sensitivity to acceleration and vibration given by high frequent oscillation (14 kHz), and a symmetric design that cancels external vibrations. This means that mechanical vibrations in the sensor have only limited impact on the MRU rate sensors.
- Both the scale factor (gain) and the offset (zero) of the sensors are stabilised by a symmetric and simple mechanical design of the oscillatory mechanical system. Electrical drift is cancelled in the basic analog design.
- High linearity, which results in small average drift errors during oscillating rate loads (as on a ship's roll axis).
- Small high frequency noise level.

The design of the Coriolis gyro is based on the use of a vibrating cylinder or ring.

Figure 13 Coriolis force rate gyro function



- **d** Drive axis direction
- **f** Feedback, measurement of drive axis
- **s** Sensing axis
- **c** Compensation axis
- ω Rotation rate in an axis normal to the paper plane
- **v** Linear velocity set up by driven oscillation
- a_c The Coriolis acceleration

The sensor is implemented as a force feedback system. The d-axis is used for excitation, and the f-axis is used to measure the drive amplitude to control the excitation. A measurement feedback loop controls an excitation along the c-axis. This excitation cancels the vibration set up along axis s given by the Coriolis acceleration a_c , which we want to measure. The drive signal to the c-axis is thus the final output from the rate sensor.

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