

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Semiconductor devices – Micro-electromechanical devices –
Part 20: Gyroscopes**

**Dispositifs à semiconducteurs – Dispositifs microélectromécaniques –
Partie 20: Gyroscopes**



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2014 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in 14 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

More than 55 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC

Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Catalogue IEC - webstore.iec.ch/catalogue

Application autonome pour consulter tous les renseignements bibliographiques sur les Normes internationales, Spécifications techniques, Rapports techniques et autres documents de l'IEC. Disponible pour PC, Mac OS, tablettes Android et iPad.

Recherche de publications IEC - www.iec.ch/searchpub

La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,...). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et aussi une fois par mois par email.

Electropedia - www.electropedia.org

Le premier dictionnaire en ligne de termes électroniques et électriques. Il contient plus de 30 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans 14 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary

Plus de 55 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: csc@iec.ch.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Semiconductor devices – Micro-electromechanical devices –
Part 20: Gyroscopes**

**Dispositifs à semiconducteurs – Dispositifs microélectromécaniques –
Partie 20: Gyroscopes**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX

XA

ICS 31.080.99

ISBN 978-2-8322-1667-5

**Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

CONTENTS

FOREWORD.....	4
1 Scope.....	6
2 Normative references	6
3 Terms and definitions	6
4 Essential ratings and characteristics.....	6
4.1 Categorization of gyro.....	6
4.2 Absolute maximum ratings	7
4.3 Normal operating rating	8
4.4 Characteristics.....	8
5 Measuring methods	10
5.1 Scale factor	10
5.1.1 Purpose.....	10
5.1.2 Measuring circuit (circuit diagram).....	10
5.1.3 Measuring principle	12
5.1.4 Measurement procedures	21
5.1.5 Specified conditions.....	23
5.2 Cross axis sensitivity	24
5.2.1 Purpose.....	24
5.2.2 Measuring circuit (circuit diagram).....	24
5.2.3 Principle of measurement	25
5.2.4 Precautions to be observed during the measurements of the angular rate applied	27
5.2.5 Measurement procedures	27
5.2.6 Specified conditions.....	27
5.3 Bias	28
5.3.1 Purpose.....	28
5.3.2 Measuring circuit	28
5.3.3 Principle of measurement	30
5.3.4 Measurement procedures	35
5.3.5 Specified conditions.....	37
5.4 Output noise	38
5.4.1 Purpose.....	38
5.4.2 Measuring circuit	38
5.4.3 Principle of measurement	39
5.4.4 Precautions during measurement.....	40
5.4.5 Measurement procedures	40
5.4.6 Specified conditions.....	43
5.5 Frequency band	43
5.5.1 Purpose.....	43
5.5.2 Measuring circuit	43
5.5.3 Principle of measurement	45
5.5.4 Precautions during measurement.....	47
5.5.5 Measurement procedure	47
5.5.6 Specified conditions.....	49
5.6 Resolution	49
5.6.1 Purpose.....	49

5.6.2	Measuring circuit	49
5.6.3	Principle of measurement	49
5.6.4	Measurement procedures	50
5.6.5	Specified conditions.....	51
Annex A (informative)	Accuracy of measured value of gyro characteristics	52
A.1	General.....	52
A.2	Angle and angular rate.....	52
A.3	Example of angular deviation occurring after calibration.....	52
Bibliography		53
Figure 1	– Example of measuring circuit	11
Figure 2	– Example of wiring configuration.....	12
Figure 3	– Example of measurement data when the angular rate is applied	13
Figure 4	– Example of scale factor data at each temperature	15
Figure 5	– Example of relationship between scale factor and scale factor temperature coefficient at each temperature	16
Figure 6	– Example of measurement of ratiometric error for the scale factor	17
Figure 7	– Example measurement of scale factor stability	19
Figure 8	– Example of measurement of scale factor symmetry	20
Figure 9	– Measuring circuit for cross axis sensitivity.....	25
Figure 10	– Principle of measurement for cross axis sensitivity.....	26
Figure 11	– Measuring circuit 1 for bias	29
Figure 12	– Measuring circuit 2 for bias	30
Figure 13	– Example measurement of ratiometric error for bias	32
Figure 14	– Bias temperature sensitivity and bias hysteresis.....	34
Figure 15	– Bias linear acceleration sensitivity.....	35
Figure 16	– Output noise measuring system	39
Figure 17	– Example of wiring configuration for output noise.....	39
Figure 18	– Frequency power spectrums.....	40
Figure 19	– Angular random walk.....	41
Figure 20	– Bias instability and Allan variance curve.....	42
Figure 21	– Measuring circuit for frequency response	44
Figure 22	– Example of wiring configuration for frequency response	45
Figure 23	– Frequency response characteristics	46
Figure 24	– Gain peak response characteristics.....	46
Figure 25	– Calibration of frequency response	48
Table 1	– Categories of gyro	7
Table 2	– Absolute maximum ratings	7
Table 3	– Normal operating ratings	8
Table 4	– Characteristics	9
Table 5	– Specified condition for measurement of scale factor	23
Table 6	– Specified conditions for the measurement of bias	37
Table 7	– Specified condition for the measurement of frequency band	49
Table 8	– Specified condition for the measurement of resolution.....	51

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**SEMICONDUCTOR DEVICES –
MICRO-ELECTROMECHANICAL DEVICES –****Part 20: Gyroscopes****FOREWORD**

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 62047-20 has been prepared by subcommittee 47F: Micro-electromechanical systems, of IEC 47: Semiconductor devices.

The text of this standard is based on the following documents:

FDIS	Report on voting
47F/188/FDIS	47F/191/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62047 series, published under the general title *Semiconductor devices – Micro-electromechanical devices*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 20: Gyroscopes

1 Scope

This part of IEC 62047 specifies terms and definitions, ratings and characteristics, and measuring methods of gyroscopes.

Gyroscopes are primarily used for consumer, general industries and aerospace applications. MEMS and semiconductor lasers are widely used for device technology of gyroscopes.

Hereafter, gyroscope is referred to as gyro.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

None

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

rotating table rate table

rotating tool on which a gyro is loaded during measurement

3.2

earth rate

angular rate generated in inertial space due to the rotation of the earth

Note 1 to entry: When the angular rate in inertial space is defined as stellar day 23 hours, 56 minutes, a reference of 4,098 903 691 seconds is obtained as specified by the International Earth Rotation and Reference Systems Service (IERS) and therefore, the angular rate of Earth in inertial space is approximately 15,04 °/h. For details of the definition, refer to the IERS website (<http://www.iers.org>).

3.3

scale factor

ratio of gyro output voltage or output digital signal versus the rotating angular rate being applied, described in unit: V/(°/s) or bit/(°/s)

4 Essential ratings and characteristics

4.1 Categorization of gyro

Table 1 shows uses of gyro categorized by application fields.

Table 1 – Categories of gyro

Category	Contents
1	primarily for consumer use where variations of bias are not specified
2	primarily for industrial use where designing with appropriate range of values of variations of bias
3	primarily for aerospace use where designing with detectable function of the earth rate

4.2 Absolute maximum ratings

Table 2 describes absolute maximum ratings of gyro.

The following items listed in the table shall be described in the specification, unless otherwise stated in the relevant procurement specifications. Stresses over these limits can be one of the causes of permanent damage to the devices.

Table 2 – Absolute maximum ratings

Item no	Absolute maximum ratings	Category			Specification			Unit	Remarks
		1	2	3	min	typ	max		
4.2.1	Storage temperature range	x	x	x	x		x	°C	
4.2.2	Operating temperature range	x	x	x	x		x	°C	
4.2.3	Storage humidity range							%	Moisture absorption management level (for example, see levels specified in Table 5-1 "Moisture Sensitivity Levels" of page 7 in IPC/JEDEC J-STD-020C, [1] ¹) for reflow soldering shall be specified. Those descriptions shall not be provided to devices applied with no reflow soldering process and/or hermetic seal packaging process.
4.2.4	Mechanical shock in operating state	x	x	x			x	m/s ²	Maximum limiting value of mechanical shock which does not cause permanent damage to devices under an appropriate operating state. Acceleration, times and wave forms shall be specified.
4.2.5	Mechanical shock in non operating state	x	x	x			x	m/s ²	Maximum limiting value of mechanical shock which does not cause permanent damage to devices under an appropriate non-operating state. Acceleration, times and wave forms shall be specified.
4.2.6	Mechanical vibration in operating state	x	x	x			x	m/s ²	Maximum limiting value of mechanical vibration acceleration and frequency which does not cause permanent damage to devices under an appropriate operating state.
4.2.7	Mechanical vibration in non operating state	x	x	x			x	m/s ²	Maximum limiting value of mechanical vibration acceleration and frequency which does not cause permanent damage to devices under an appropriate non-operating state.
4.2.8	Angular rate limit	x	x	x			x	°/s	Maximum limiting value of angular rate which does not cause permanent damage to devices under an appropriate operating state.

¹ Numbers in square brackets refer to the Bibliography.

Item no	Absolute maximum ratings	Category			Specification			Unit	Remarks
		1	2	3	min	typ	max		
4.2.9	Angular acceleration limit	x	x	x			x	°/s ²	Maximum limiting value of angular acceleration which does not cause permanent damage to devices under an appropriate operating state.
4.2.10	Maximum supply voltage	x	x	x			x	V	Maximum limiting value of supply voltage which does not cause permanent damage to devices.
4.2.11	Maximum supply current						x	A	Maximum limiting value of supply current which does not cause permanent damage to devices. This limiting value shall be specified only for a kind of constant current driving devices.
NOTE x: mandatory, blank: optional									

4.3 Normal operating rating

Table 3 describes normal operating ratings of gyro.

The following items should be described in the specification, unless otherwise stated in the relevant procurement specifications. These conditions are recommended to keep specified characteristics in stable state during operations of applying devices.

Table 3 – Normal operating ratings

Item no.	Normal operating ratings	Category			Specification			Unit	Remarks
		1	2	3	min	typ	max		
4.3.1	Guarantee operating temperature range	x	x	x	x		x	°C	Recommended ranges of appropriate indexes of environmental conditions (such as conditions of electromagnetic environments, air pressure) specified as a specified minimum value to maximum value.
4.3.2	Guarantee operating humidity range	x	x	x			x	%	
4.3.3	Supply voltage range	x	x	x	x	x	x	V	
4.3.4	Current consumption	x	x	x			x	A	
4.3.5	Start up current			x			x	A	
4.3.6	Power supply ripple requirement			x			x	Vpp	
4.3.7	Other environmental condition				x		x		
4.3.8	Overload recovering time			x			x	s	
NOTE x: mandatory, blank: optional									

4.4 Characteristics

Table 4 describes characteristics of gyro.

Table 4 – Characteristics

Item no	Characteristics	Category			Specification			Unit	Remarks
		1	2	3	min	typ	max		
4.4.1	Measurement range	x	x	x			x	°/s	Angular rate measuring range for guarantee of performance
4.4.2	Nominal scale factor	x	x	x		x		V/(°/s) or bit/(°/s)	Nominal scale factor is also called as standard sensitivity.
4.4.3	Initial scale factor variation		x	x	x		x	%	Minimum and maximum value of variation from standard sensitivity at a specified temperature
4.4.4	Scale factor variation with temperature or Temperature coefficient of scale factor		x	x	x		x	%	Minimum and maximum value of standard sensitivity under a specified variation in temperature
4.4.5	Ratiometric error for scale factor			x			x	%	Maximum value of error of sensitivity applying voltage fluctuation caused by operating instability of applying electric power supply
4.4.6	Linearity						x	%	
4.4.7	Scale factor stability	n		x		x			A typical value of stability of sensitivity under a specified definite input voltage value
4.4.8	Scale factor symmetry	n		x		x			A typical value of asymmetry of sensitivity defined as a ratio of the sensitivity applying plus value of a specified input voltage to minus value of a specified input voltage, see 5.1.3.8.
4.4.9	Cross axis sensitivity			x			x	%	Maximum value of sensitivity of cross axis (see 5.2.3 Principle of measurement).
4.4.10	Nominal bias	x	x	x		x		V or bit	Typical value of bias voltage or bit value under an appropriate applying input voltage value
4.4.11	Initial bias variation			x	x		x	°/s	Minimum and maximum value of bias under a specified temperature
4.4.12	Bias variation with temperature or Temperature coefficient of bias			x	x		x	°/s	Minimum and maximum value of standard bias under a specified variation in temperature
4.4.13	Ratiometric error for bias			x			x	V	Maximum value of error of bias applying voltage fluctuation caused by operating instability of applying electric power supply. No description is required for digital output case.
4.4.14	Bias repeatability (switch on to switch off)			x	x		x	°/s	Minimum value and maximum value of bias fluctuation of each period during a switching on state to a switching off state
4.4.15	Bias hysteresis			x			x	°/s	Maximum value of hysteresis of bias under a specified variation in temperature
4.4.16	Linear g sensitivity			x			x		Maximum value of changed bias value under operating conditions of a specified constant acceleration value, expressed in comparison with $g(°/s)/g$

Item no	Characteristics	Category			Specification			Unit	Remarks
		1	2	3	min	typ	max		
4.4.17	Bias drift after power on			x			x	°/s	Maximum value of drift of bias during turned on state of applying electric power supply
4.4.18	In-band noise			x			x	°/s	In-band output noise at stable state operation, described with RMS
4.4.19	Broadband noise			x			x	°/s	Broadband output noise at stable state operation, described with RMS
4.4.20	Angular random walk			x			x	°/√h or (°/h)/√Hz	Output variation of gyroscope due to noise, described with RMS
4.4.21	Bias instability			x			x	°/s	Described with RMS
4.4.22	Start up time			x			x	s	Time required for the gyro output to reach the specified output after power on
4.4.23	Frequency band	x	x	x	x			Hz	Frequency response characteristics
4.4.24	Gain peak						x	dB	Maximum value of gain of frequency characteristics under a specified frequency. Describe with a specified value of the frequency (Hz).
4.4.25	Resolution			x	x			°/s	Detectable minimum change in the input angular rate
NOTE x: mandatory, blank: optional, n: unnecessary									

5 Measuring methods

5.1 Scale factor

5.1.1 Purpose

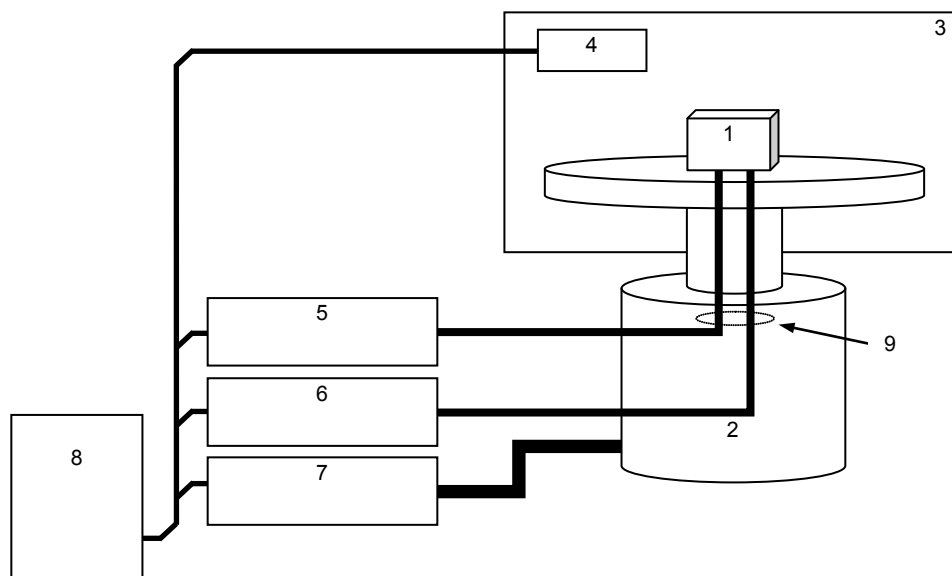
To specify measuring method relating to scale factor in gyro.

5.1.2 Measuring circuit (circuit diagram)

Figure 1 shows an example of composition of the sensitivity measuring circuit and Figure 2 shows an example of wiring configuration. The measuring circuit is composed of the gyro to be measured and the devices listed below. Components to apply in the measuring circuit shall satisfy the points described below.

- Temperature controlled chamber: This should be capable of maintaining the gyro at a specified ambient temperature. Furthermore, the temperature control range should be wider than the operating temperature range of gyro.
- Temperature sensor: This should be capable of measuring the temperature in the temperature controlled chamber. A temperature sensor provided in advance in the temperature controlled chamber can be used.
- Power supply for gyro: This should be capable of supplying the voltage and current required by gyro. The fluctuating range for ripple voltage on the output should meet the gyro requirements in the supplying state.
- Data acquisition system: Measuring device or measuring system adjusted to the output configuration of gyro. For example, a digital multimeter or data logger is used if gyro output is analogue voltage.

- Rotating table control device: Control device which controls the input angular rate given to the rating table. This table is given an angular rate of rotation that is not less than the detection range of gyro, and that is capable of accommodating changes in the angular rate corresponding to the minimum resolution. See Annex A for measurement accuracy of the rotating table.
- Measuring system controller: An overall system for automatic control of the power supply, gyro, data acquisition system and rotating table control device. This is not required for manual operation.
- Slip ring: It should be noted that the slip ring can be a source of noise generation.

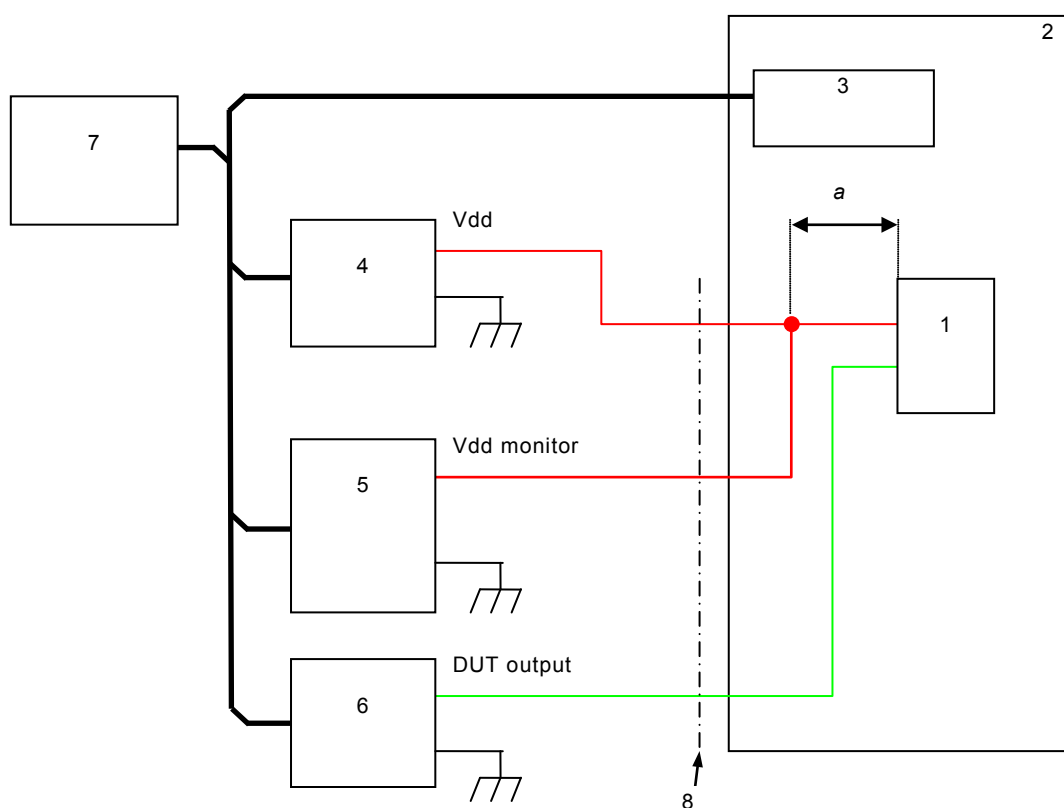


IEC 2054/14

Key

- | | |
|---|---|
| 1 | DUT, a piece of gyro |
| 2 | rate table |
| 3 | temperature controlled chamber, to keep a specified temperature value of DUT |
| 4 | temperature sensor, to monitor environmental temperature in a chamber |
| 5 | power supply to operate DUT |
| 6 | data logger, to obtain data during the measurement |
| 7 | controller for rate table, to set up a specified rotating condition of the rate table |
| 8 | control system, to control the measuring circuit during the measurement |
| 9 | slip ring |

Figure 1 – Example of measuring circuit



IEC 2055/14

Key

- 1 DUT, a piece of gyro
- 2 temperature controlled chamber, to keep a specified temperature value of DUT
- 3 thermometer, to monitor environmental temperature in a chamber
- 4 power supply, to supply electric power to operate DUT
- 5 monitor for power supply
- 6 data logger, to obtain data during the measurement
- 7 control system
- 8 slip ring position (when slip ring used)
- a length from power supply feedback position to gyro supply terminal position (the length of wiring should preferably be as short as possible)
- Vdd voltage of power supply
- Vdd Monitor
- DUT output output of DUT (gyro)

Figure 2 – Example of wiring configuration

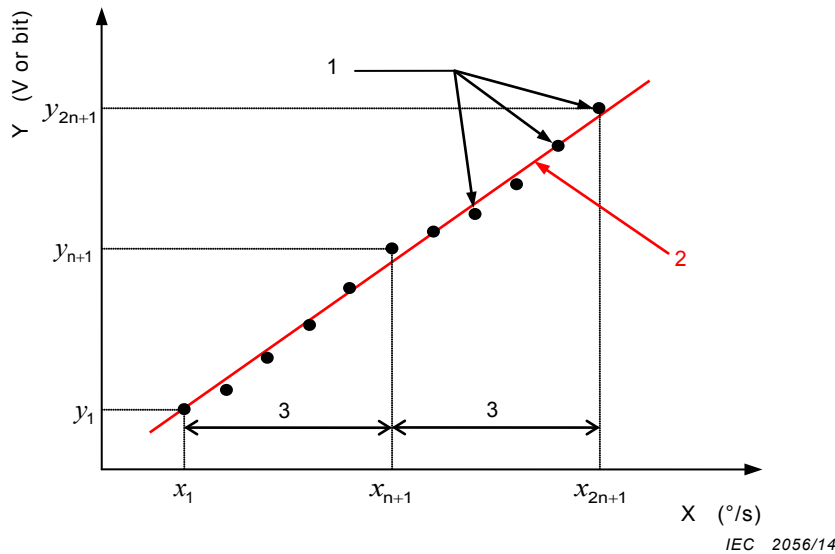
5.1.3 Measuring principle

5.1.3.1 Scale factor

In the measuring circuit shown in Figure 1, while gyro is under conditions of a specified measuring temperature T_{BASE} (specified temperature provided as a medium value between a specified minimum operating temperature and maximum operating temperature, see Figure 4) and a specified supply voltage V_{BASE} , rotating angular rate of $x_1, x_2, \dots, x_{2n+1}$, which divides lower and higher half detection range of gyro into n -distribution such as $x_1, x_2, \dots, x_n$ (preferably $n \geq 5$) are applied, and corresponding output values of signal of $y_1, y_2, \dots, y_{2n+1}$ measured in unit of $V/(\text{°/s})$ or $\text{bit}/(\text{°/s})$ of this detection input angular rate.

Furthermore, although the manufacturer can specify the value of n , it can be changed as necessary based on specifications agreed between a manufacturer and its user.

Figure 3 shows an example of the measurement data. Abbreviated symbols of CCW and CW in the figure show the left rotation (counter clockwise) and right rotation (clockwise), respectively. (In Figure 3, it is equally divided by $n = 5$ and a total of 11 points of data are shown including the stationary state). A scale factor is obtained by calculations from these points. However, since acquired data are not on a straight line as represented by Figure 3, a straight line on which the sum of squares becomes minimum is obtained by calculation (this straight line is referred to hereafter as the best fit line).



Key

- 1 points of measurement data at the applied angular rate value
- 2 best fit line
- 3 divided in specified intervals of " n "
- X x-axis, input angular rate in unit of $^{\circ}/s$
- x_1 CCW maximum detection
- x_{n+1} stationary state
- x_{2n+1} CW maximum detection input angular rate
- Y y-axis, gyro output signal in unit of V or bit
- y_1 CCW side maximum output value
- y_{n+1} output value at stationary state
- y_{2n+1} CW side maximum output value

Figure 3 – Example of measurement data when the angular rate is applied

Here, the gyro output value at each measuring point is represented by " y_i " and the angular rate to be input to gyro is represented by " x_i ". Constants of the best fit line " $y = a_{BASE} \times x + b_{BASE}$ " are then obtained as follows:

$$a_{BASE} = \frac{(2n+1) \sum_{i=1}^{2n+1} x_i y_i - \sum_{i=1}^{2n+1} x_i \sum_{i=1}^{2n+1} y_i}{(2n+1) \sum_{i=1}^{2n+1} x_i^2 - \left(\sum_{i=1}^{2n+1} x_i \right)^2} \quad (1)$$

$$b_{\text{BASE}} = \frac{\sum_{i=1}^{2n+1} x_i^2 \sum_{i=1}^{2n+1} y_i - \sum_{i=1}^{2n+1} x_i y_i \sum_{i=1}^{2n+1} x_i}{(2n+1) \sum_{i=1}^{2n+1} x_i^2 - \left(\sum_{i=1}^{2n+1} x_i \right)^2} \quad (2)$$

Inclination “ a_{BASE} ” of the best fit line on this occasion is the scale factor under the conditions of reference measurement temperature “ T_{BASE} ” and reference supply voltage “ V_{BASE} ”.

5.1.3.2 Initial scale factor variation

This shows the amount of variation between the scale factor “ a_{BASE} ” and the nominal scale factor (standard value of scale factor) “ a_{TYP} ” of its gyro under the conditions of reference measurement temperature “ T_{BASE} ” and reference supply voltage “ V_{BASE} ” of gyro.

Here, initial scale factor variation “ $S_{\text{F,VAR,BASE}}$ ” is obtained as follows:

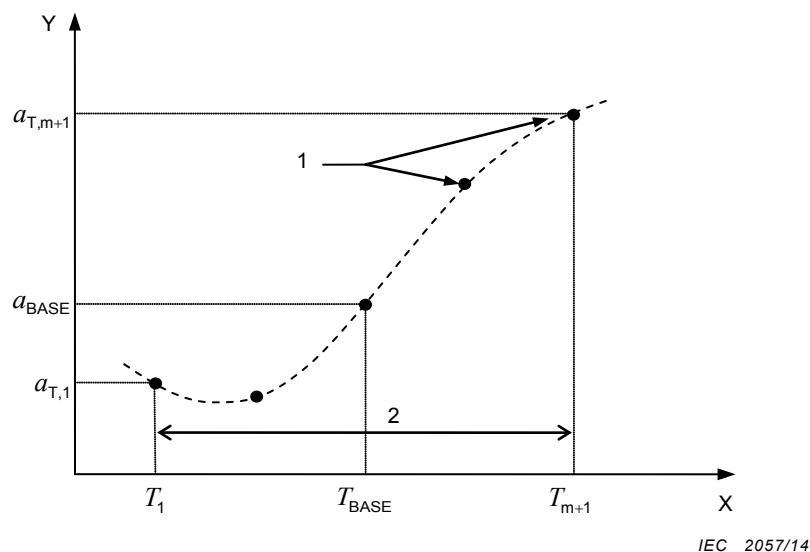
$$S_{\text{F,VAR,BASE}} = \frac{a_{\text{BASE}} - a_{\text{TYP}}}{a_{\text{TYP}}} \quad (3)$$

5.1.3.3 Scale factor variation with temperature

When the operating temperature range of gyro into m -distribution of $T_1, T_2, \dots, T_{m+1}$ (preferably $m \geq 4$) under the condition of reference supply voltage “ V_{BASE} ” of gyro, and the scale factor obtained at each temperature values of “ $T_1, T_2, \dots, T_{m+1}$ ” is expressed by “ $a_{T1}, a_{T2}, \dots, a_{Tm+1}$ ”, respectively, the amount of variation between these values and “ a_{BASE} ” represents the temperature error at that temperature.

Furthermore, although the manufacturer can specify the value of m , it can be changed as necessary based on specifications agreed between a manufacturer and its user.

Figure 4 shows an example of scale factor data. (In Figure 4, it is equally divided by $m = 4$ and one with $m = 3$ is considered to be the reference measurement temperature).

**Key**

1	scale factor value at each temperature
2	divided in m -segments
X	x-axis: gyro environment temperature
T_1	lower operating temperature
T_{BASE}	reference measurement temperature
T_{m+1}	maximum operating temperature
Y	y-axis: gyro scale factor value
$a_{T,1}$	scale factor value at minimum operating temperature
a_{BASE}	scale factor value at reference measurement temperature
$a_{T,m+1}$	scale factor value at maximum operating temperature

Figure 4 – Example of scale factor data at each temperature

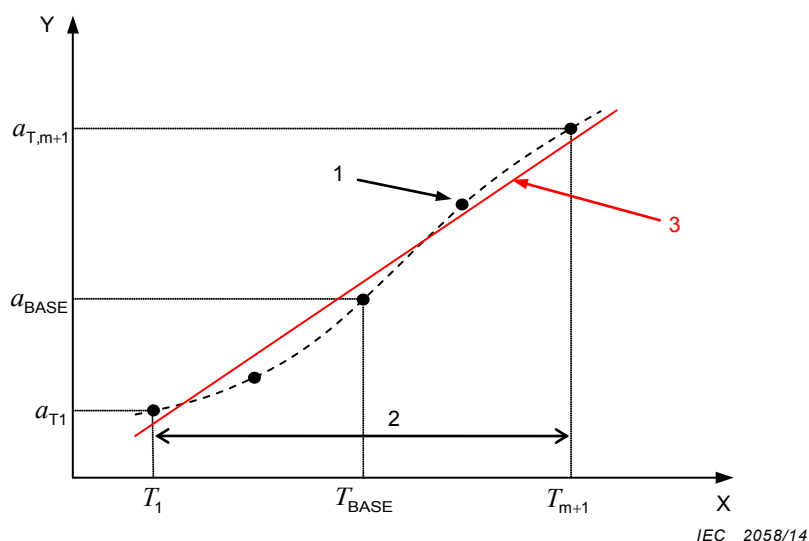
Here, when the scale factor at temperature " T_i " is represented by " $a_{T,i}$ ", the scale factor variation with temperature " S_{F,VAR,T_i} " is obtained as follows:

$$S_{F,VAR,T_i} = \frac{a_{T,i} - a_{BASE}}{a_{BASE}} \quad (4)$$

The above calculation is carried out for each of the temperatures " $T_1, T_2, \dots, T_{m+1}$ " and the value " S_{F,VAR,T_i} " obtained is the scale factor variation with temperature value at that temperature " T_i ".

5.1.3.4 Temperature coefficient for scale factor

The amount of inclination of temperature change for scale factor variation with temperature under the condition of reference supply voltage " V_{BASE} " of gyro becomes the temperature coefficient for the scale factor. Figure 5 shows an example.



Key

- 1 scale factor value at each temperature
- 2 divided in m -segments
- 3 best fit line (Temperature coefficient = $T_{c,SF}$)
- X x-axis: gyro environment temperature
- T_1 minimum operating temperature
- T_{BASE} reference measurement temperature
- T_{m+1} maximum operating temperature
- Y y-axis: gyro scale factor value
- $a_{T,1}$ scale factor value at minimum operating temperature
- a_{BASE} scale factor value at reference measurement temperature
- $a_{T,m+1}$ scale factor value at maximum operating temperature

Figure 5 – Example of relationship between scale factor and scale factor temperature coefficient at each temperature

For " $a_{T,1}, a_{T,2}, \dots, a_{T,m+1}$ " obtained by the method shown in 5.1.3.3, the straight line, best fit line " $y = T_{c,SF} \times x + c$ " on which the sum of squares becomes minimum is obtained.

$$T_{c,SF} = \frac{(m+1) \sum_{i=1}^{m+1} T_i a_{Ti} - \sum_{i=1}^{m+1} T_i \sum_{i=1}^{m+1} a_{Ti}}{(m+1) \sum_{i=1}^{m+1} T_i^2 - \left(\sum_{i=1}^{m+1} T_i \right)^2} \quad (5)$$

$$c = \frac{\sum_{i=1}^{m+1} T_i^2 \sum_{i=1}^{m+1} a_{Ti} - \sum_{i=1}^{m+1} T_i a_{Ti} \sum_{i=1}^{m+1} T_i}{(m+1) \sum_{i=1}^{m+1} T_i^2 - \left(\sum_{i=1}^{m+1} T_i \right)^2} \quad (6)$$

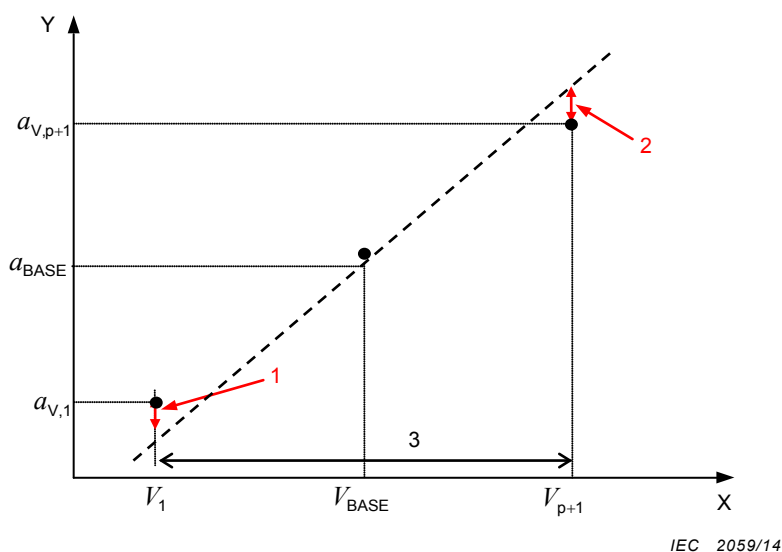
Inclination $T_{c,SF}$ of the best fit line on this occasion is the temperature coefficient for the scale factor.

5.1.3.5 Ratiometric error for scale factor

When the operating power voltage range of gyro is divided in p -distribution (preferably $p \geq 2$) under the condition of reference measurement temperature “ T_{BASE} ” of gyro, the scale factor at each power voltage “ $V_1, V_2, \dots, V_{p+1}$ ” becomes “ $a_{V,1}, a_{V,2}, \dots, a_{V,p+1}$ ” respectively.

Here, although the manufacturer can specify the value of p , it can be changed as necessary based on discussions between the user and manufacturer.

Figure 6 shows an example of ratiometric error for scale factor data. (In Figure 6, it is equally divided by $p = 2$ and one with $p = 2$ is considered to be the reference supply voltage).



Key

- 1 ratiometric error amount (R_{error,V_1})
- 2 ratiometric error amount ($R_{\text{error},V_{p+1}}$)
- 3 divided in p -segments
- X x-axis: gyro operating voltage
- V_1 operating voltage lower limit
- V_{BASE} reference supply voltage
- V_{p+1} operating voltage upper limit
- Y y-axis: gyro scale factor value
- $a_{V,1}$ scale factor value at operating voltage lower limit
- a_{BASE} scale factor value at reference supply voltage
- $a_{V,p+1}$ scale factor value at operating voltage upper limit

Figure 6 – Example of measurement of ratiometric error for the scale factor

In this case, ratiometric error for the scale factor “ R_{error,V_i} ” is obtained as follows:

$$R_{\text{error},V_i} = \frac{\left| a_{V_i} - (a_{\text{BASE}}) \times \left(\frac{V_i}{V_{\text{BASE}}} \right) \right|}{a_{\text{BASE}}} \quad (7)$$

The above-shown calculation is carried out for each of voltages “ $V_1, V_2, \dots, V_{p+1}$ ” and the value “ R_{error,V_i} ” obtained is the ratiometric error for the scale factor value at the voltage “ V_i ”.

5.1.3.6 Linearity

This is a value showing the amount of variation between the measured output data and the values on the best fit line under the conditions of reference measurement temperature “ T_{BASE} ” and reference supply voltage “ V_{BASE} ” of gyro in accordance with 5.1.3.1.

The linearity error “ $L_{\text{error},i}$ ” at a specified angular rate is obtained as shown below, when a certain angular rate “ x_i ” is added and the gyro output value is represented by “ y_i ”, the value is obtained from the best fit line by “ $a_{\text{BASE}} \times x_i + b_{\text{BASE}}$ ” and the gyro detection range is represented by “ F_{ullScale} ”.

$$L_{\text{error},i} = \frac{|y_i - (a_{\text{BASE}} \times x_i + b_{\text{BASE}})|}{F_{\text{ullScale}}} \quad (8)$$

Here, the case of Figure 3 is considered,

$$F_{\text{ullScale}} = y_{\text{MAX,CW}} - y_{\text{MAX,CCW}} = y_{2n+1} - y_1 \quad (9)$$

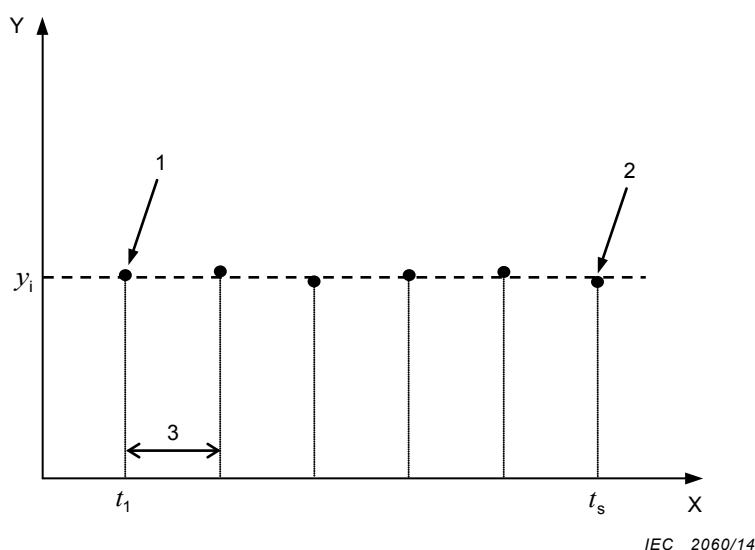
The above-shown calculation is carried out for each of measuring points “ $y_1, y_2, \dots, y_{2n+1}$ ”. “ $L_{\text{error},i}$ ” obtained is the linearity error value at that rotating angular rate y_i .

5.1.3.7 Scale factor stability

This shows the amount of stability while gyro is rotating continuously at a constant angular rate under the condition of reference measurement temperature “ T_{BASE} ” and reference supply voltage “ V_{BASE} ” of gyro. Rotating angular rate “ x_i ” (x_i is the angular rate of either of $x_1, x_2, \dots, x_{q+1}$) is given while the detection range of gyro is divided in q -segments, and output value “ y_i ” (y_i is one output of $y_1, y_2, \dots, y_{q+1}$) is measured continuously with constant sampling time “ r ” during sampling number “ s ”. (Therefore, measuring time is expressed by $r \times s$).

Here, although the manufacturer can specify the values of “ q ”, “ r ” and “ s ”, they can be changed as necessary based on discussions between the user and manufacturer.

Figure 7 shows an example of measurement data for scale factor stability. (Figure 7 is an explanatory drawing showing output stability at input angular rate x_i).

**Key**

- 1 output at start ($y_{i,1}$)
- 2 output at measurement completion ($y_{i,s}$)
- 3 sampling time
- X x-axis: time elapsed
- t_1 measurement start time
- t_s measurement completion time
- Y y-axis: gyro output value
- y_i gyro output value under constant angular rate

Figure 7 – Example measurement of scale factor stability

When groups of data of gyro output values at input angular rate “ x_i ” are represented by “ $y_{i,1}$ ”, “ $y_{i,2}$, $y_{i,3}$, ... , $y_{i,s}$ ”, and the detection range is represented by “ $F_{ullScale}$ ”, stability “ δ_i ” of these values is obtained as follows:

$$\delta_i = \frac{\sqrt{\frac{\sum_{j=1}^s (y_{i,j} - \bar{y}_i)^2}{s}}}{F_{ullScale}} \quad (10)$$

$$\bar{y}_i = \frac{1}{s} \times \sum_{j=1}^s y_{i,j} \quad (11)$$

Here, Figure 3 case is taken into account. Then,

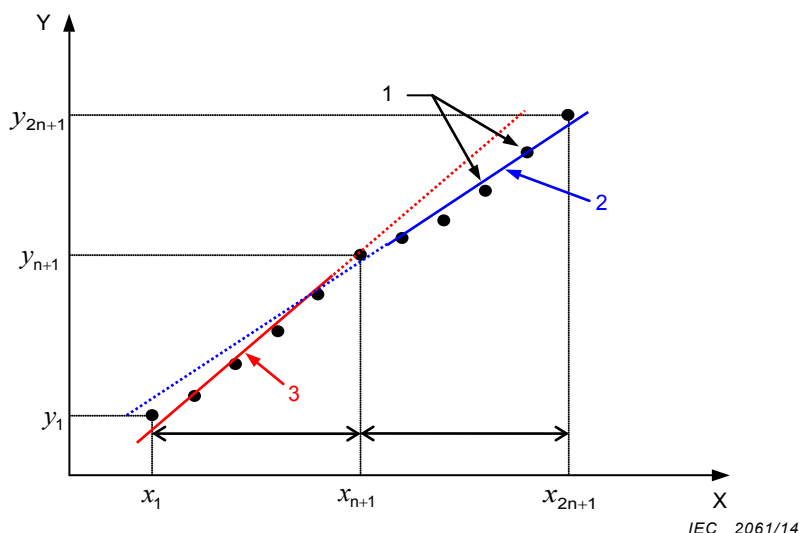
$$F_{ullScale} = y_{MAX,CW} - y_{MAX,CCW} = y_{2n+1} - y_1 \quad (12)$$

is obtained.

The above-shown calculation is carried out for rotating angular rate “ $x_1, x_2, \dots, x_{q+1}$ ” to be set. Value δ_i obtained is the scale factor stability value at that rotating angular rate “ x_i ”. Furthermore, this measurement is not applicable to the stationary state.

5.1.3.8 Scale factor symmetry

This is a value showing the difference in scale factor values obtained when the best fit line is calculated while measured output data are separated into CW (right turning) and CCW (left turning) under the conditions of reference measurement temperature “ T_{BASE} ” and reference supply voltage “ V_{BASE} ” of gyro in accordance with 5.1.3.1.



Key

- 1 group of measurement data when angular rate is applied
- 2 best fit line (CW)
- 3 best fit line (CCW)
- X x-axis: input angular rate
- x_1 CCW maximum detection input angular rate
- x_{n+1} resting state
- x_{2n+1} CW maximum detection input angular rate
- Y y-axis: gyro output signal
- y_1 CCW side maximum output value
- y_{n+1} resting state output value
- y_{2n+1} CW side maximum output value

Figure 8 – Example of measurement of scale factor symmetry

Here, taking Figure 8 case as an example, the best fit line of CW and CCW is represented by “ $y_i = a_{CW} \times x_i + b_{CW}$ ” and “ $y_i = a_{CCW} \times x_i + b_{CCW}$ ”, respectively. They are then obtained as follows:

$$a_{CW} = \frac{n \sum_{i=n+2}^{2n+1} x_i y_i - \sum_{i=n+2}^{2n+1} x_i \sum_{i=n+2}^{2n+1} y_i}{n \sum_{i=n+2}^{2n+1} x_i^2 - \left(\sum_{i=n+2}^{2n+1} x_i \right)^2} \quad (13)$$

$$b_{CW} = \frac{\sum_{i=n+2}^{2n+1} x_i^2 \sum_{i=n+2}^{2n+1} y_i - \sum_{i=n+2}^{2n+1} x_i y_i \sum_{i=n+2}^{2n+1} x_i}{n \sum_{i=n+2}^{2n+1} x_i^2 - \left(\sum_{i=n+2}^{2n+1} x_i \right)^2} \quad (14)$$

$$a_{CCW} = \frac{n \sum_{i=1}^n x_i y_i - \sum_{i=1}^n x_i \sum_{i=1}^n y_i}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \quad (15)$$

$$b_{CCW} = \frac{\sum_{i=1}^n x_i^2 \sum_{i=1}^n y_i - \sum_{i=1}^n x_i y_i \sum_{i=1}^n x_i}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \quad (16)$$

The measurement data “ y_{n+1} ” in stationary state is not used for this calculation.

For scale factor “ a_{CW} ” and “ a_{CCW} ” of CW and CCW thus obtained, symmetry error “ $S_{Y,error}$ ” is calculated by the following equation:

$$S_{Y,error} = \frac{|a_{CW} - a_{CCW}|}{a_{TYP}} \quad (17)$$

5.1.4 Measurement procedures

5.1.4.1 Scale factor

Measurement procedures of scale factor in temperature “ T_i ” and supply voltage “ V_i ” is shown hereunder. For scale factor variation with temperature and ratiometric error for scale factor, measurement is taken while the temperature and voltage are changed according to the procedures same as those shown below, and calculation is made from the result of the measurement.

a) Supply voltage

Voltage “ V_i ” is applied to gyro. Voltage drop due to wirings is also conceivable in this case. Therefore, power supply line and voltage monitoring line are wired separately as shown in Figure 2 and it should be checked if the output value of the voltage monitoring line agrees with the target voltage.

b) Temperature setting

Gyro on the rotating table is exposed to the temperature “ T_i ” to be measured. Gyro on the rotating table should be left in the temperature controlled chamber at the very least till it reaches the set temperature.

c) Voltage readjustment

It is probable that the set power voltage varies slightly due to time elapsed or changes in consumption current at temperature setting mentioned above. Therefore, the voltage should be adjusted again after gyro reached the set temperature.

In this case, it is probable that the voltage cannot be set accurately to the set point (e.g., 4,999 8 V for set voltage of 5,000 0 V) and therefore, the voltage actually supplied should be recorded.

d) Confirmation of output

After confirming that the output of gyro in resting state is stable, rotating angular rate is given as shown in 5.1.3.1 and output on this occasion is measured.

e) Normalization of output

When gyro has the ratiometric characteristics, in order to minimize faint error due to power voltage (e.g., error due to the fact that supply voltage at measurement is 4,999 8 V against set voltage 5,000 0 V), output value actually measured should be normalized considering that the measured output functions in ratiometric fashion along with theoretical value.

Here, output value actually measured is represented by " $y_{\text{RAW},i}$ ", set voltage by " V_{BASE} ", and supply voltage is represented by " V_i ", and output corrected value " y_i " is expressed by the following equation:

$$y_i = y_{\text{RAW},i} \times \frac{V_{\text{BASE}}}{V_i} \quad (18)$$

f) Calculation of each data

Each data is obtained by calculation based on the equations shown in 5.1.3.1. Items other than scale factor stability can be obtained by changing the temperature and voltage.

5.1.4.2 Scale factor stability

Measurement procedures of scale factor stability at temperature " T_i " and supply voltage " V_i " are shown hereunder.

a) Supply voltage

See 5.1.4.1 a).

b) Temperature setting

See 5.1.4.1 b).

c) Voltage readjustment

See 5.1.4.1 c).

d) Confirmation of output

After confirming that the output of gyro in resting state is stable, rotating angular rate is given as shown in 5.1.3.7 and output on this occasion is measured.

e) Normalization of output

When gyro has the ratiometric characteristics, in order to minimize faint error due to power voltage (e.g., error due to the fact that supply voltage at measurement is 4,9998 V against set voltage 5,0000 V), output value actually measured should be normalized considering that the measured output functions in ratiometric fashion along with theoretical value.

Here, output value actually measured is represented by " $y_{\text{RAW},i,j}$ ", set voltage by " V_{BASE} ", and supply voltage is represented by " V_i ", and output corrected value " $y_{i,j}$ " is expressed by the following equation:

$$y_{i,j} = y_{\text{RAW},i,j} \times \frac{V_{\text{BASE}}}{V_i} \quad (19)$$

f) Calculation of each data

Each data is obtained by calculation based on the equations shown in 5.1.3.7.

5.1.5 Specified conditions

Table 5 describes measurement condition parameters which should be determined prior to the measurement.

Table 5 – Specified condition for measurement of scale factor

Item No.	Measuring item	Parameter	Supplemental explanations
5.1.3.1	Scale factor	Reference measurement temperature: T_{BASE} Reference supply voltage: V_{BASE} Measured angular rate: $x_1, x_2, \dots, x_{2n+1}$	Angular rate of " $x_1, x_2, \dots, x_{2n+1}$ " in Figure 3 Therefore, data as many as " $2n+1$ " are necessary for calculation of scale factor.
5.1.3.2	Initial scale factor variation	Reference measurement temperature: T_{BASE} Reference supply voltage: V_{BASE}	
5.1.3.3	Scale factor variation with temperature	Reference supply voltage: V_{BASE} Measurement temperature: $T_1, T_2, \dots, T_{m+1}$	Temperature value of " $T_1, T_2, \dots, T_{m+1}$ " in Figure 4 Data of as many as " $2n+1$ " points are necessary for calculation of scale factor at each temperature. Therefore, for calculation of scale factor variation with temperature, data as many as $(2n+1) \times (m+1)$ are necessary.
5.1.3.4	Temperature coefficient for scale factor	Reference supply voltage: V_{BASE} Measurement temperature: $T_1, T_2, \dots, T_{m+1}$	Same as those of item 5.1.3.3
5.1.3.5	Ratiometric error for scale factor	Reference measurement temperature: T_{BASE} Measurement voltage: $V_1, V_2, \dots, V_{p+1}$	Measurement voltage value of " $V_1, V_2, \dots, V_{p+1}$ " in Figure 6 Data of as many as " $2n+1$ " points are necessary for calculation of scale factor at each temperature. Therefore, for calculation of ratiometric error for scale factor, data as many as $(2n+1) \times (p+1)$ are necessary.
5.1.3.6	Linearity	Reference measurement temperature: T_{BASE} Reference supply voltage: V_{BASE} Measurement angular rate: " $x_1, x_2, \dots, x_{2n+1}$ "	Same as those of item 5.1.3.1
5.1.3.7	Scale factor stability	Reference measurement temperature: T_{BASE} Reference supply voltage: V_{BASE} Measurement angular rate: " $x_1, x_2, \dots, x_{q+1}$ " Sampling frequency: r Number of times of sampling: s	For measurement conditions of sampling frequency and number of times of sampling and for stability calculation at each angular rate of " $x_1, x_2, \dots, x_{q+1}$ " to be measured, data of " s " points are necessary. Therefore, data as many as $s \times (q+1)$ are necessary for calculation of scale factor stability.

Item No.	Measuring item	Parameter	Supplemental explanations
5.1.3.8	Scale factor symmetry	Reference measurement temperature: T_{BASE} Reference supply voltage: V_{BASE} Measurement angular rate: " $x_1, x_2, \dots, x_{2n+1}$ " (However, x_{n+1} "rest point" is excluded).	Angular rate value of " $x_1, x_2, \dots, x_{2n+1}$ " in Figure 8 (however, x_{n+1} "rest point" is excluded). Therefore, data as many as "2n" are necessary for calculation of scale factor symmetry.

5.2 Cross axis sensitivity

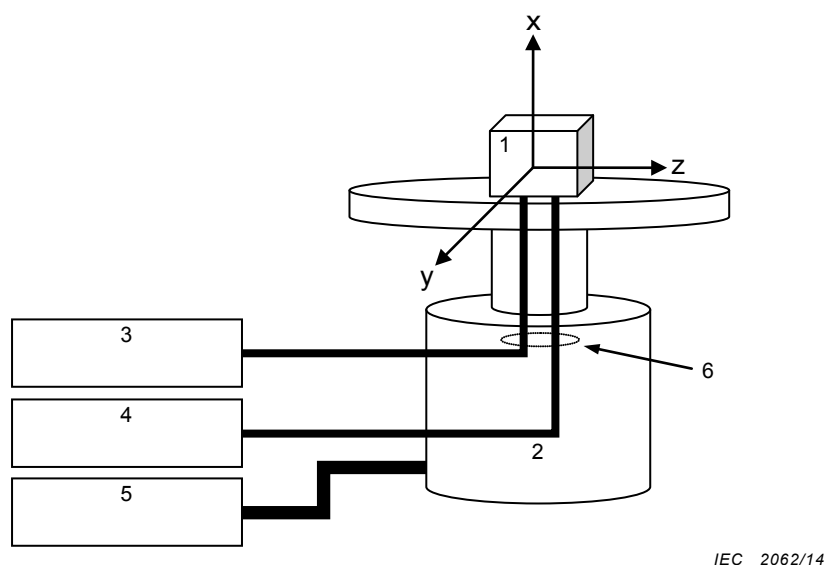
5.2.1 Purpose

To specify the measuring method related to cross axis sensitivity in gyro.

5.2.2 Measuring circuit (circuit diagram)

Figure 9 shows a measuring circuit for cross axis sensitivity. The measuring circuit is composed of the gyro to be measured, power supply, rotating table, data logger system, and wiring. Components to apply in the measuring circuit shall satisfy the points described below.

- Power supply shall be able to supply a specified voltage and electric current required by the gyro (DUT) and the fluctuating range for ripple voltage on the output, etc. should meet the gyro requirements in the supplying state.
- Rate table part of rotating system shall have capabilities to apply a specified rotating angular rate for the gyro, and should be able to vary input angular rate of the gyro within an appropriate range that is equivalent to a specified minimum resolution value of the angular rate. Moreover, in case of measurement of cross axis sensitivity, specified value of angular rate should apply to the gyro continuously. So supply of a specified electric power and detection of electric output signal should be provided appropriately through slip ring(s). Slip ring(s) should be used with any influence of the noise to detection.
- Controller shall be able to control specified ranges of input angular rate of the gyro by controlling rotation of the rotating table.
- Data logger system shall be a kind of measuring tool or measuring system adjusted to the output mode of gyro. For example, a digital multimeter or data logger is used if the gyro output is voltage (analogue).
- Wiring shall be connected by cables for electrical connection of the power supply, gyro, and data logger system. Pass of the measurement wiring shall be performed as an appropriate pass to minimize influence generated by inside of the measuring system and interfering noises from outside of the system.

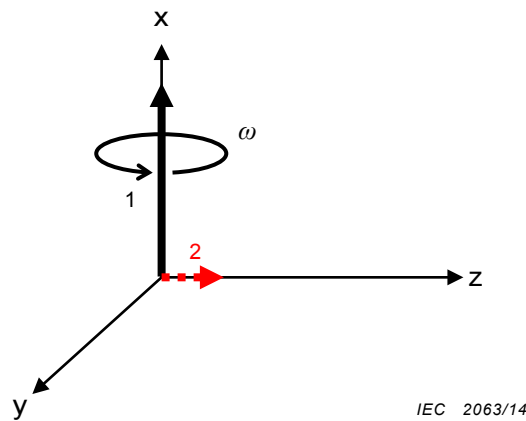
**Key**

- 1 DUT (gyro)
- 2 rate table
- 3 power supply for DUT (gyro)
- 4 data logger
- 5 rate table controller
- 6 slip ring position (when slip ring used)
- x x-axis: DUT (gyro) non detection axis
- y y-axis: DUT (gyro) non detection axis
- z z-axis: DUT (gyro) detection axis

Figure 9 – Measuring circuit for cross axis sensitivity**5.2.3 Principle of measurement**

The definition of cross axis sensitivity is as follows:

Figure 10 shows the case when angular rate ω is applied around the x-axis and cross axis sensitivity is defined to be the gyro output angular rate divided by the applied angular rate.



Key

- | | |
|---|--|
| 1 | applied angular rate (gyro non-detection axis) |
| 2 | gyro output angular rate |
| x | x-axis: DUT(gyro) non detection axis |
| y | y-axis: DUT (gyro) non detection axis |
| z | z-axis: DUT (gyro) detection axis |

Figure 10 – Principle of measurement for cross axis sensitivity

Considering the definitions described above, the basic principle of measurement is provided as follows:

In here, to provide a simplified principle of measurement for cross axis sensitivity, an example of principle of measurement of one axis sensitivity of the gyro involving its input axis is provided as follows.

The reference axis of the three orthogonal axes defined by a mechanistic chassis or gyro case, is set as the reference axis of the gyro, and the angular rate is applied to each of the axes which should be defined as non-detection axes, then, to measure the gyro output.

For example, as shown in Figure 9 and Figure 10, gyro having an input axis in the z-direction of the chassis is mounted to the rotating table, then the angular rate is applied around the x-axis to measure the gyro output $O_{ut,x}$.

Similarly, the angular rate is applied around the y-axis to measure the gyro output, $O_{ut,y}$ and the cross axis sensitivity is calculated according to the following equation.

$$\omega_x = (O_{ut,x} \times S_F) \quad (20)$$

$$\omega_y = (O_{ut,y} \times S_F) \quad (21)$$

$$K_x = \omega_x / \omega \quad (22)$$

$$K_y = \omega_y / \omega \quad (23)$$

where

- | | |
|------------|--|
| ω_x | angular rate output when angular rate is applied to x-axis |
| ω_y | angular rate output when angular rate is applied to y-axis |
| $O_{ut,x}$ | measurement data when angular rate is applied to x-axis |

$O_{ut,y}$	measurement data when angular rate is applied to y-axis
S_F	scale factor
K_x	cross axis sensitivity when angular rate is applied to x-axis
K_y	cross axis sensitivity when angular rate is applied to y-axis
ω	applied angular rate

The cross axis sensitivity can be determined by the measurements shown above.

5.2.4 Precautions to be observed during the measurements of the angular rate applied

- The axial runout of the rotating table, orthogonal accuracy of the gyro mounting fixture and accuracy of the gyro mounting plane shall be sufficiently smaller ($\leq 0,1, \dots, 0,2$) than the cross axis sensitivity to be measured;
- In general, applied angular rate shall not exceed the absolute maximum rating of gyro;
- To assure more accurate measurement of cross axis sensitivity and/or, for better understanding, the following considerations should be taken into account prior to measure; for example, if the angular rate output stability of gyro is $0,5 \text{ }^\circ/\text{s}$ and measurement range is $200 \text{ }^\circ/\text{s}$, it can be determined that the output is generated by cross axis sensitivity when the measured output is greater than double ($1 \text{ }^\circ/\text{s}$) of the gyro stability. In this case, therefore, a significant measurement of cross axis sensitivity is possible as “ $1 \text{ }^\circ/\text{s}$ output measurement when $200 \text{ }^\circ/\text{s}$ is applied”. (Around $1/200 = 0,5 \text{ } \%$ is obtained when converted to cross axis sensitivity).
- When this cross axis sensitivity is used for the correction or compensation of the measurement, it is recommended that polarity and other relevant factors be adjusted by agreement between the manufacturer and user.

5.2.5 Measurement procedures

Measurement procedures for cross axis sensitivity of gyro are shown below. These are applicable similarly to measurement procedures of gyro having the plurality of the input axes.

- a) Mount the gyro to the rotating table to apply the angular rate to the non-detection axis: orthogonal to the input axis.
- b) Supply a specified value of voltage to DUT (gyro) by applying an appropriate electrical power source, then turn on the DUT to a specified turning on state.
- c) Apply the angular rate around the non-detection axis set described in the procedure step a).
- d) Measure the gyro output while the angular rate is applied.
- e) Switch off the electric power supply not to supply any voltage, and mount the gyro to the rotating table so that the angular rate can be applied to the other non-detection axis: orthogonal to both the axis set described in the procedure step a) and the input axis.
- f) Supply a specified value of voltage to DUT (gyro) by applying an appropriate electrical power source, then turn on the DUT to a specified turning on state and apply the angular rate around the non-detection axis set described in the procedure step e).
- g) Measure the gyro output while the angular rate is applied. Then, switch off the gyro and the measurement system.
- h) By using the results of the procedure steps d) and g), obtain the cross axis sensitivity according to the method specified in the principle of measurement.

5.2.6 Specified conditions

- Angular rate value applied to the DUT;
- Operating temperature value under measurement procedures;
- Voltage value applied to the DUT.

5.3 Bias

5.3.1 Purpose

To specify measuring methods for each item in gyro related to bias.

5.3.2 Measuring circuit

5.3.2.1 General

Figures 11 and 12 show measuring circuits 1 and 2 respectively along with the composition of the measuring device. Measuring circuit 2 is used for measurements of bias linear acceleration sensitivity shown in 5.3.3.8, and measuring circuit 1 is used for measurements of other bias related items.

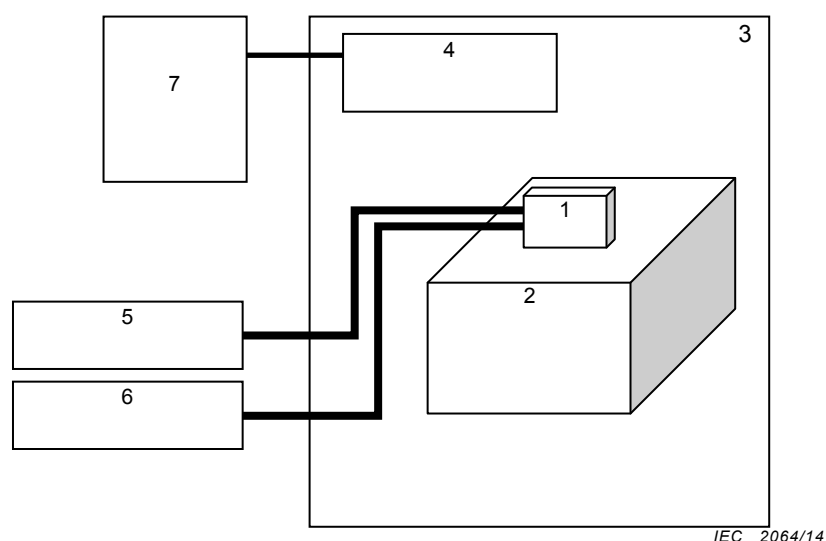
5.3.2.2 Measuring circuit 1

Figure 11 shows measuring circuit 1 for bias that consists of the gyro to be measured, power supply, fixed table, data acquisition system, and temperature controlled chamber (including temperature sensor). Components to apply in the measuring circuit shall satisfy the points described below.

- Fixed table: A device capable of securely fixing the gyro, installed under conditions free of external factors such as vibration, and is capable of directing the input axis of the gyro in a specified direction. Construction to allow for input angular rate is not required.

NOTE Provision for input axis direction is to subtract the amount of Earth rotation angular rate at bias measurement. This is not required when the Earth rotation angular rate: $4,178 \times 10^{-3}$ °/s can be neglected.

- Power supply: Voltage, electric current and noise characteristics of applied power supply have to satisfy appropriate capabilities of those to be able to apply to gyro.
- Data logger system: A measuring device selected according to output specifications (analogue, digital) of the gyro and which is capable of satisfying the accuracy requirements for bias measurement. When the gyro is based on analogue output (analogue voltage or analogue current), a voltmeter or ampere meter should be used and the measuring range and resolution should meet the specifications of the test piece. Similarly, for digital output, the measuring range (number of bits) should be sufficient to meet the specifications of the gyro. The measuring range should be more than double and the resolution should be less than 1/10.
- Temperature controlled chamber: The temperature controlled chamber should be capable of controlling ambient temperature of the test piece provided on the fixed table and of producing the ambient temperature. The ambient temperature can be measured using a temperature sensor different from the one used for functions of the temperature controlled chamber.

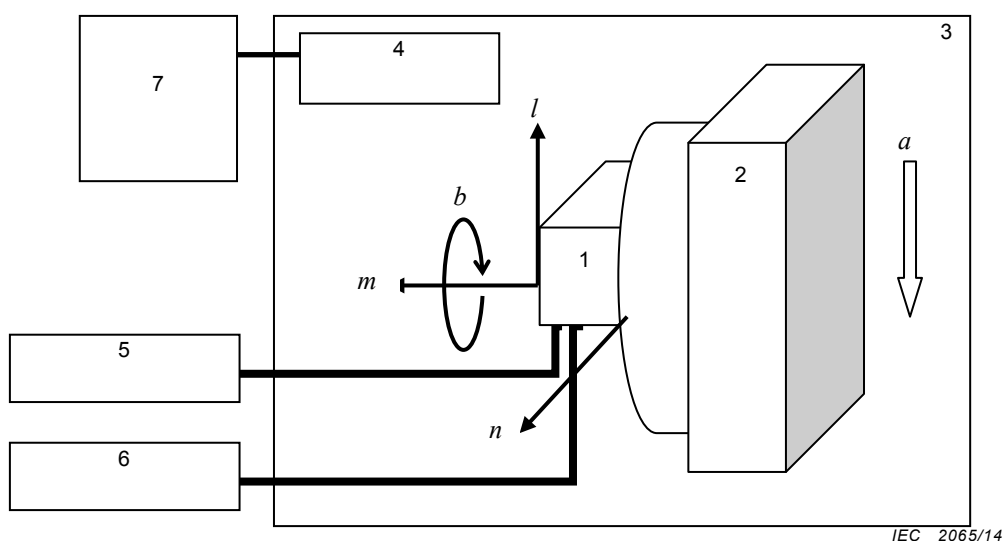
**Key**

- 1 DUT, a piece of gyro
- 2 fixed table
- 3 temperature controlled chamber, to keep a specified temperature value of DUT
- 4 temperature sensor, to monitor environmental temperature in a chamber
- 5 power supply, to supply electric power to operate DUT
- 6 data logger
- 7 controller for the temperature of chamber

Figure 11 – Measuring circuit 1 for bias**5.3.2.3 Measuring circuit 2**

Figure 12 shows measuring circuit 2 for bias. The following parts comprising the measurement circuit have to be set up to the following specified conditions. The same parts comprising circuit 1 have to be set up under the same specified conditions in circuit 2 also.

Fixed table: A device capable of securely fixing the gyro, installed under conditions free of external factors such as vibration, and is capable of directing the input axis of the gyro in a specified direction (two directions; that of the acceleration of gravity and orthogonal to the acceleration of gravity), and is capable of rotating the axis orthogonal to the direction of acceleration and capable of being fixed with a specified angular of interval.



Key

- 1 DUT, a piece of gyro
- 2 rotatable fixed table
- 3 temperature controlled chamber, to keep a specified temperature value of the DUT
- 4 temperature sensor, to monitor environmental temperature in a chamber
- 5 power supply, to supply electric power to operate the DUT
- 6 data logger
- 7 controller, to control the temperature of chamber
- a* direction of acceleration of gravity
- b* amount of acceleration of gravity exerted to detection axis by rotation is changed
- l* perpendicular setting: z-axis, gyro detection axis
vertical setting: y-axis, non-detection axis
- m* perpendicular setting: x-axis, gyro non-detection axis
vertical setting: z-axis, detection axis
- n* perpendicular setting: y-axis, non-detection axis
vertical setting: x-axis, non-detection axis

Figure 12 – Measuring circuit 2 for bias

5.3.3 Principle of measurement

5.3.3.1 Nominal bias

Nominal bias value is obtained based on the following measurement procedures of gyro output and Calculation formula (24).

Gyro output is measured under conditions where the ambient temperature is constant (specified temperature) and the input angular rate is zero or known (presence of Earth rotation input angular rate).

After specified electric power is supplied to gyro and a specified time has elapsed, the known input angular rate (Earth rotation angular rate) is subtracted from the overall average within the specified time (specified data length) of the gyro output.

$$N_{\text{bias}} = O_{\text{ut,ave}} - E_{\text{arthrotation}} (^{\circ}/\text{s})$$

Where

N_{bias} Nominal bias
 $O_{\text{ut,ave}}$ Output average value of gyro
 $E_{\text{arthrotation}}$ Earth rotation angular rate component

The Earth rotation angular rate component is calculated from the direction of the input axis.

For vertical input axis: $E_{\text{arthrotation}}: 4,178 \times 10^{-3} \times \cos \lambda$

λ : Latitude of point of measurement

For horizontal input axis: $E_{\text{arthrotation}}: 4,178 \times 10^{-3} \times \sin \lambda \times \cos \varphi$

φ : Input axis direction (Northward is 0 °)

5.3.3.2 Initial bias variation

Initial bias variation is obtained based on the following measurement procedures of gyro output and Calculation formula (25).

Variation from nominal bias value of gyro output under the environments where the ambient temperature is constant (specified temperature) and the input angular rate is zero or known, is obtained.

After specified electric power is supplied to gyro and a specified time has elapsed, the output obtained by subtracting the known input angular rate (Earth rotation angular rate) from overall average within the specified time (specified data length) of the gyro output is defined as O_{ut} . When the nominal bias is expressed by $O_{\text{ut,typ}}$, the initial bias variation is obtained as follows:

$$\text{Initial bias variation: } O_{\text{ut}} - O_{\text{ut,typ}} \text{ (°/s)} \quad (25)$$

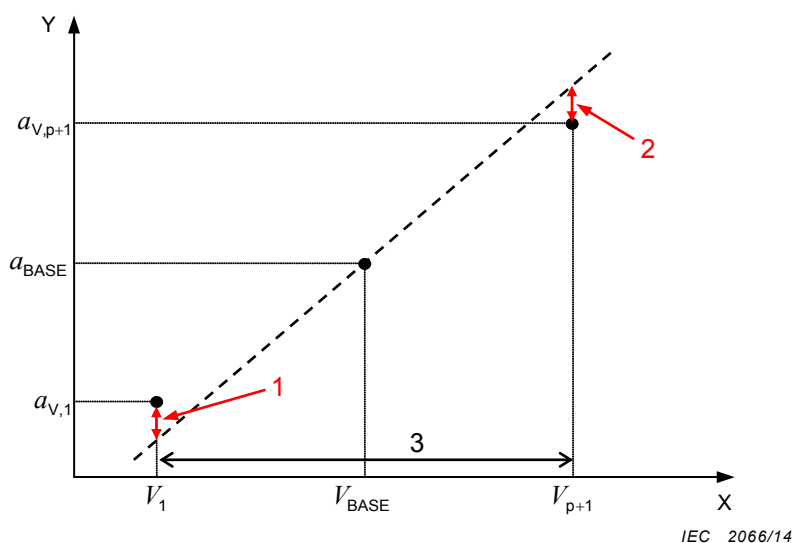
5.3.3.3 Ratiometric error for bias

Ratiometric error for bias is obtained based on following measurement values of key parameters of gyro described in Figure 13 and Calculation formula (26).

When an operating power voltage range where the gyro is functioning is divided into p -segments (preferably $p \geq 2$) under the reference measurement temperature $[T_{\text{BASE}}]$ of gyro, bias in each power voltage " $V_1, V_2, \dots V_{p+1}$ " becomes " $a_{V,1}, a_{V,2}, \dots a_{V,p+1}$ ", respectively.

Here, although the manufacturer can specify the value of " p ", it can be changed as necessary based on discussions between the user and manufacturer.

Figure 13 shows an example of ratiometric error for bias data. (In Figure 13, it is equally divided by $p = 2$, and $p = 2$ is considered to be the reference supply voltage).



Key

- 1 ratiometric error amount (R_{error,V_1})
- 2 ratiometric error amount ($R_{\text{error},V_{p+1}}$)
- 3 p -segments
- X x-axis, gyro operating voltage
- V_1 operating voltage lower limit
- V_{BASE} reference supply voltage
- V_{p+1} operating voltage upper limit
- Y gyro bias value
- $a_{V,1}$ bias value at operating voltage lower limit
- a_{BASE} bias value at reference supply voltage
- $a_{V,p+1}$ bias value at operating voltage upper limit

Figure 13 – Example measurement of ratiometric error for bias

In this case, ratiometric error for bias “ R_{error,V_i} ” is obtained as follows:

$$R_{\text{error},V_i} = \frac{\left| a_{V_i} - (a_{\text{BASE}}) \times \left(\frac{V_i}{V_{\text{BASE}}} \right) \right|}{a_{\text{BASE}}} \quad (26)$$

The above calculation is carried out for each voltage “ $V_1, V_2, \dots, V_{p+1}$ ” and “ R_{error,V_i} ” thus obtained is ratiometric error for bias at voltage “ V_i ”.

5.3.3.4 Bias repeatability

Bias repeatability is obtained based on the measurement value changes of the gyro output described in the following paragraphs of 5.3.3.4.

This shows changes (scattering) in bias values of the gyro output by activating and deactivating the power supply under conditions where the ambient temperature is constant (specified temperature) and the input angular rate is zero or known.

Bias is measured for the specified number of times, and its maximum and minimum values ($\pm$ °/s) are obtained to be used as bias repeatability.