Application Note

Angular rate sensor, TAG201 series

R E V I S I O N S

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Application note
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1. Introduction of angular rate sensor (rate gyro, rate sensor or gyroscope)

An angular rate sensor is a sensor which detects rotation rate (°/s or °/h) of moving objects. Integration of rotation rate for a certain period of time yields angle (°), which can be used as attitude angle of the objects. Another use of angular rate sensor is stabilization of the objects, by utilizing rotation rate output as a feedback signal source to maintain stable attitude of the objects. Although there exist encoders and resolvers as similar kinds of angular sensor, an angular rate sensor described here is absolutely different from those angular sensors in that it doesn't require any rotation center axis in setting up (i.e. encoders and resolvers requires rotation center to be set up) and can detect rotation rate at arbitrary point in space.
Note that the term "rate gyro" and "gyroscope (or gyro)" often correspond angular rate sensor.

2. Ordering information including outline, pin assignment info.

This product is categorized and typed by the direction of rate-sensitive axis and sensitivity. First category is a direction of rate-sensitive axis and divided into two subtypes, one is vertical type (Fig.2) and the other is horizontal type (Fig.3). Second category is sensitivity (output voltage per unit angular gate, e.g. °/second, °/hour) and there are 4 subtypes. Both vertical type and horizontal type have 4 sensitivity subtypes, so totally 8 types are standardized in TAG201 product line (Table 2). Although these 8 types are standard line up of TAG201 series, special requirement as described below may be acceptable on your request but may be subject of supplemental charge. Please contact our sales reps.

【Examples of special requirements】
- Inclined detection axis. This may be applied to car navigation systems mounted in dashboard, which is inclined 10~20°. 10°and 20°will be appreciated for relatively easy customize.
- Extended detection range (dynamic range). Up to ±1000°/s may be applicable.
- Faster frequency response. Upto 60Hz may be applicable.

Vertical type : TAG201N0010~TAG201N0040
They are suitable for detection of orthogonal axis (Z axis) of base board (Fig.1)

Horizontal type : TAG201N1010~TAG201N1040
They are suitable for detection of in-plane axis (X,Y axis) of base board (Fig.1)

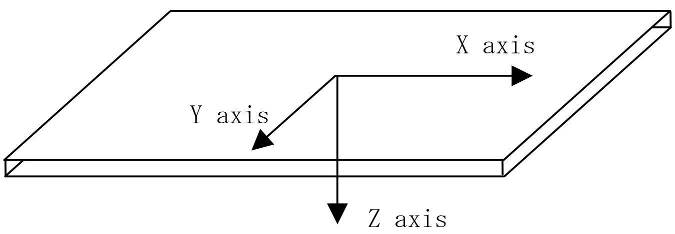

Fig.1 Axis definition of base board

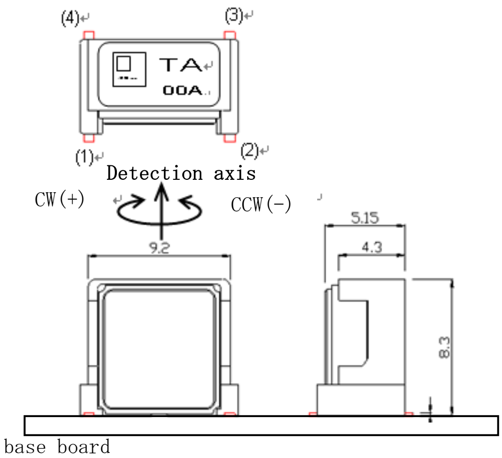

Fig.2 Detection axis of vertical type
TAG201N00**
(**=10,20,30,40)

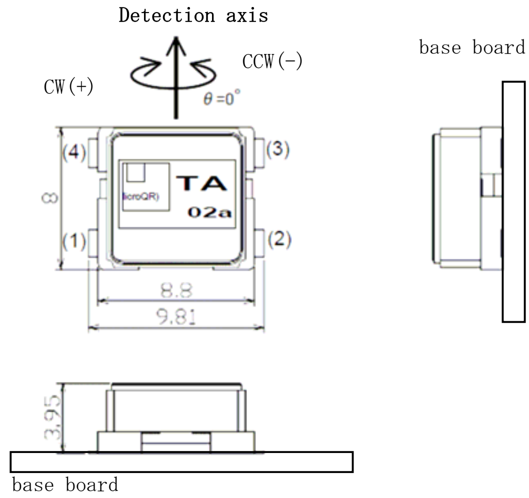

Fig.2 Detection axis of horizontal type
TAG201N10**
(**=10,20,30,40)

Table 1 Pin assignment (common in both vertical type and horizontal type)

No	Pin name	Function
(1)	Vout	Rotation rate output
(2)	Vcc	Power +5V
(3)	TS	Temperature sensor out
(4)	GND	GND

Table 2 Standard line-up of TAG201 series

Type		Direction	Detection range (dynamic range)	Sensitivity
TAG201	N0010	Vertical type (Fig.2)	±60° /s	25mV/° /s
	N0020		±100° /s	20mV/° /s
	N0030		±200° /s	10mV/° /s
	N0040		±300° /s	6mV/° /s
	N1010	Horizontal type (Fig. 3)	±60° /s	25mV/° /s
	N1020		±100° /s	20mV/° /s
	N1030		±200° /s	10mV/° /s
	N1040		±300° /s	6mV/° /s

3. Understanding of technical data sheet with brief explanation of technical terms used in the technical data sheet.

Below is a explanation of type TAG201N0030's data sheet, which is very typical example of TAG201 series.

3.1 Absolute maximum ratings

Absolute maximum ratings are shown in Table 3. Please avoid using TAG201 gyros beyond these conditions.

Table 3 Absolute maximum ratings

No.	Parameter	Rating	Unit	Note
1	Supply voltage	-0.3～+7.0	V	
2	Operating temperature	-40～+85	°C	
3	Storage temperature	-40～+85	°C	
4	Mechanical shock	200	G	X,Y and Z axis x 1time, unpowered

3.2 Operating conditions

Operating conditions are shown in Table 3.

Table 4 Operating conditions

No.	Parameter	Specification			Unit	Conditions
		MIN	TYP	MAX		
1	Supply voltage range	4.75	5	5.25	V DC	
2	Measurement range	-200		200	deg/sec	
3	Frequency response	-7		-2	dB	f=30Hz
4	Start up time			0.7	second	25°C ± 2°C

Supply voltage : Supply voltage must be conditioned in range shown in item 1.

Measurement range : Range of detectable angular rate of this angular rate sensor.

Frequency response : Responsibility to angular rapid rate change. Here sensitivity attenuation level at angular rate change of 30Hz is shown in unit dB. -7dB and -2dB equal to 0.45 and 0.8 time sensitivity attenuation respectively.

Start up time : This parameter indicates waiting time to have reliable angular rate after power ON.

3.3 Electrical characteristics(Table 5)

These parameters indicates specification of consumption current and output voltage of this product, which include some functional parameters such as sensitivity, linearity and noise.

表５ Electrical characteristics

No	Item	Specification			Unit	Condition
		MIN	TYP	MAX		
1	Supply current			6	mA	
2	Maximum output voltage	Vcc - 0.3			V	
3	Minimum output voltage			0.3	V	
4	Nominal bias	2.4	2.5	2.6	V	
		2.35	2.5	2.65	V	Ta= -40~+85°C
5	Bias drift after power on	-15		15	mV	0.7sec.~15min. after power on
6	Scale factor	9.5	10.0	10.5	mV/deg/sec	
		9.0	10.0	11.0	mV/deg/sec	Ta= -40~+85°C
7	Scale factor symmetry	-0.5		0.5	%	
8	Linearity	-0.5		0.5	%Fs	
9	Cross axis sensitivity	-5		5	%	Ta= -40~+85°C
10	Output noise			5	mVpp/5s	Ta= -40~+85°C
11	Ratiometric error for bias	-20	0	20	%	0.7sec.~ after power on Vcc:4.75V~5.25V
12	Ratiometric error for scale factor	-20	0	20	%	0.7sec.~ after power on Vcc:4.75V~5.25V

2,3 Maximum output voltage, Minimum output voltage
These value indicates output voltage range. If supply voltage is＋5.0V, the device outputs voltage from 0.3 to 4.7V, which corresponds ±220°/s input rate range.

4 Nominal bias : This indicates output voltage under static condition (zero angular rate).

5 Bias drift after power on : This indicates nominal bias change during 0.7sec~15min after power on. Item 4 and 5 are critical factor as an error source, which is explained in section * in detail.

6 Scale factor : Coefficient value to change output voltage into angular rate.

（Output voltage）÷（Scale factor） = Angular rate
mV mV/°/s °/s

7 Scale factor symmetry : This value indicates scale factor difference between CW and CCW rotation.

8 Linearity : This value indicates error between input angular rate and measured (calculated) angular rate. ±0.5%of dynamic range（±200°/s＝400°/s）is to be 2°/s. So measured (calculated) angular rates are within (true angular rate)±2°/s.

9 Cross axis sensitivity : This value indicates sensitivity to axis perpendicular to input axis.

10 Output noise : This value indicates output voltage perturbation in peak-to-peak during 5 sec. operation. Detailed noise definition will be shown in section 5.

11 Ratiometric error for bias : Ratio of nominal bias change when supply voltage is change.

12 Ratiometric error for scale factor : Ratio of scale factor change when supply voltage is change.

3.4 Electrical characteristics (Variation with temperature) (Table 6)

Temperature dependence of nominal bias, output voltage and scale factor are summarized in table 6.

Table 6 Electrical characteristics (Variation with temperature)

No.	Item	Specification			Unit	Condition
		MIN	TYP	MAX		
13	Bias variation with temperature（Max-Min）	-3.5		3.5	deg/sec	Ta= -40~+85°C
14	Bias variation with temperature	-6		6	mV/2.5°C	Ta=0～60°C
		-13.5		13.5	mV/7.5°C	Ta= -40~+85°C
15	Scale factor variation with temperature	-3.0		3.0	%	Ta= -40~+85°C

13 Bias variation with temperature（Max-Min） : This value indicated nominal bias change in -40~+85℃ temperature range. Values are calibrated to deg/sec unit.

14 Bias variation with temperature : Nominal bias change during indicated temperature change (2.5°C and 7.5°C).

15 Scale factor variation with temperature : Ratio of scale factor change against 25°C during temperature change (-40~+85°C).

4. Connecting external devices.

4.1 Using sensor output directly

This is a standard usage of this angular rate sensor. Recommended connecting circuit is shown in Fig.4. Note that

- Vcc(pin No.2) is connected to power supply through protection resistance(R1) and bypass capacitor (C1). Recommended value for R1 and C1 is shown in Fig.4.
- Vout(pin No.1) is connected to external device through bypass capacitor (C2) and load resistance (R2). Recommended value for R2 and C2 is shown in Fig.4. If you use A/D converter as an external device, please refer to section 4.3.

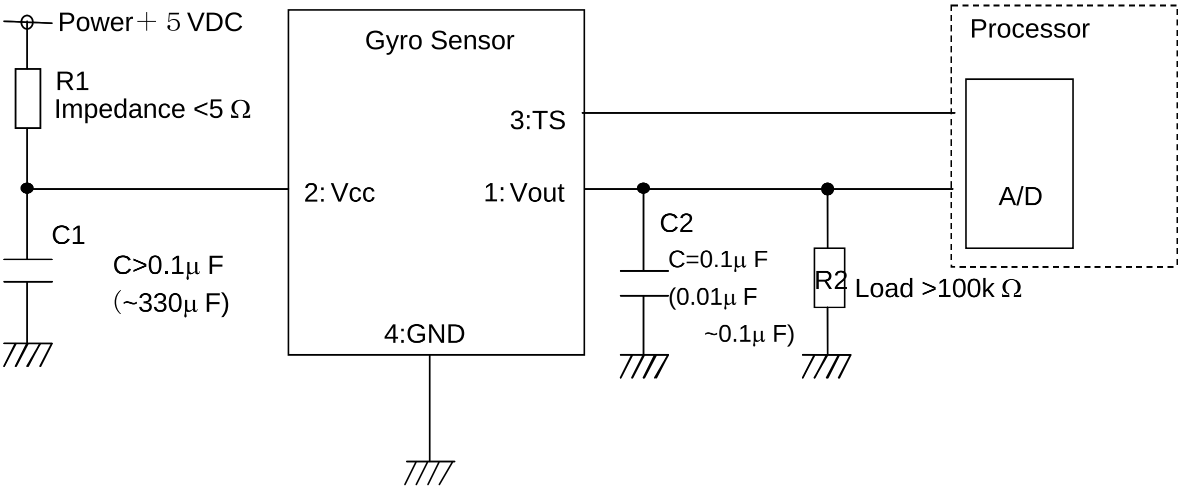

Fig.4 Standard usage of the angular rate sensor

4.2 Amplification and low pass filtering of the output

If you want to measure low rotation rate in high sensitivity, or you want to filter high frequency noise refer to configuration shown in Fig.5. This circuit has function of amplifying sensor out put 10 times and 6Hz 1 order low pass filter.

And this circuit has function of buffering sensor out put and improve resistance to load impedance change. If you use A/D converter as an external device, please refer to section 4.3.

This circuit is recommended under condition shown below.

- Increased sensitivity is necessary.
- Avoiding high frequency noise.
- In case load impedance varies.

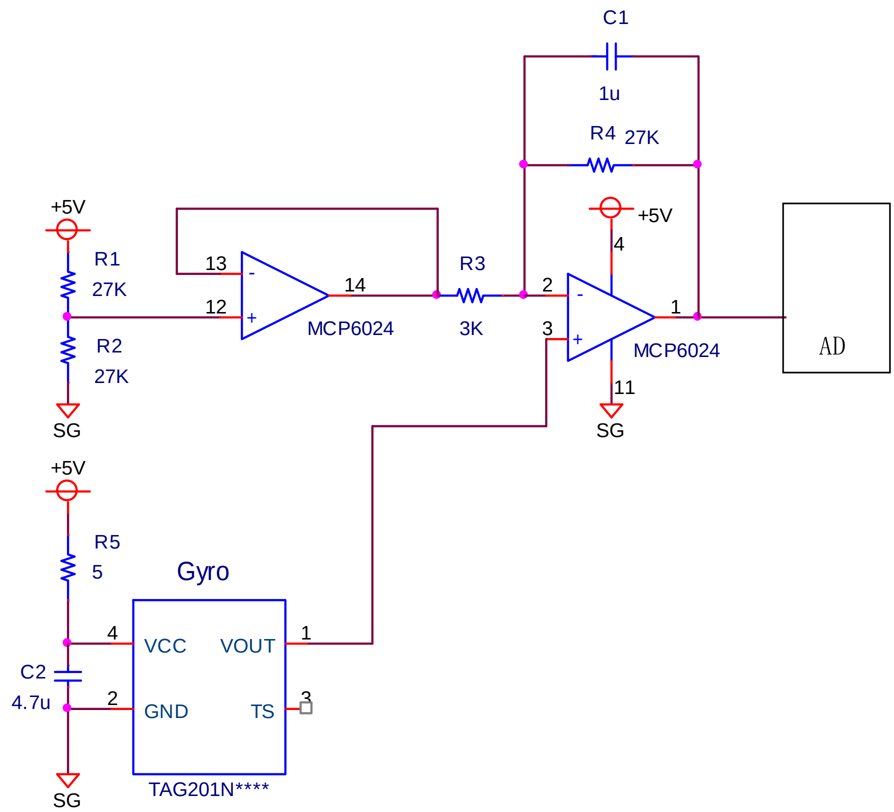

Fig.5 Amplification and low-pass filtering circuit for the angular rate sensor

4.3 Tips for A/D converting

If you use the angular rate sensor under digitized condition, you have to convert the sensor output to digital data by A/D converter.

Table 7 shows estimated 1LSB resolution of typical +5V input A/D converter of various bit (10 to 16bit). If you require fine resolution, using angular rate sensor with

high sensitivity combined with high bit A/D converter. Sensitivity amplification using Fig.5 configuration is also be a solution for having high sensitive angular rate output.

By increasing sampling rate, you can increase effective resolution with low bit A/D converter about 2 times better resolution by 10 times increase in sampling rate. This is related to “bias instability” explained in section 5(1).

Table 7 BIT of A/D converter and resolution (°/s)

		10bit	12bit	14bit	16bit
N0010	25mV/°/s	0.195	0.049	0.012	0.003
N0020	20mV/°/s	0.244	0.061	0.015	0.004
N0030	10mV/°/s	0.488	0.122	0.030	0.008
N0040	6mV/°/s	0.813	0.203	0.050	0.013

5. Definition of terms presenting bias and noise

Bias and noise are important factors of angular rate sensor accuracy. These factors represents DC error and AC error components multiplied superimposed to ordinary zero stable output when the angular rate sensor is put stable condition. In recent years, many terms representing these value have emerged and making the definition confusing.

Allan variance is recently introduced to analyze the angular sensor rate noise totally. But the term used in allan variance analysis and traditional term of angular rate sensor bias and noise resemble, and this cause confusion in our understanding of angular rate sensor noise.

Now let us define parameters below here. Note that the words “Zero point error”, “Bias and “Offset” are generally used as synonym.

（１）Bias instability(Bias stability)
（２）Bias repeatability
（３）Angular random walk
（４）Bias drift (Rate ramp)

Here let us introduce Allan variance

This analytical method is developed for evaluating frequency stability of oscillator. Equation (1) is the definition of Allan variance. As shown in the equation, sectioning the obtained data to a certain period of time (from short period to long period) and calculating average of the data in each data cluster and obtain variance of among averaged values. And plot cluster time vs. allan variance like Fig.6.

Applying allan variance to angular rate sensor bias data we mainly obtain three parameters 1)angular random walk, 2)bias instability and 3)bias drift, all of which represent bias property of the senor. Below is a brief explanation of the method to read these three parameters from the allan variance plot (See Fig.7).

$$AVAR(\tau) = \frac{1}{2(n-1)} \sum_{i} \left[y(\tau)_{i+1} - y(\tau)_{i} \right]^2 \qquad (1)$$

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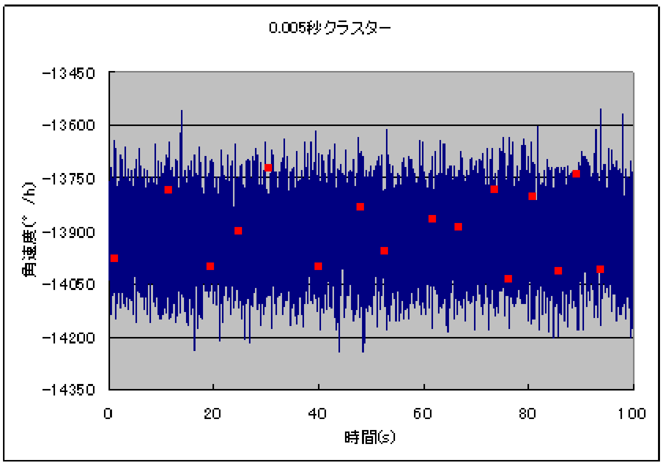
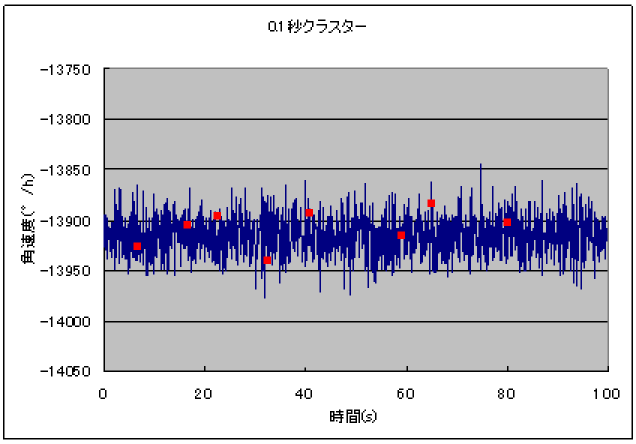
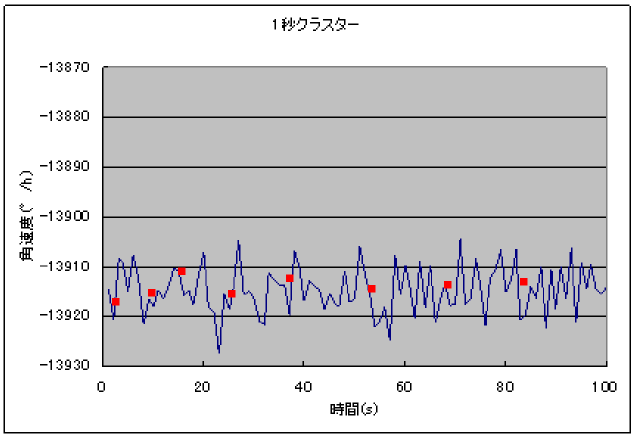


(a) Original (200Hz sampling rate =0.005sec cluster time)



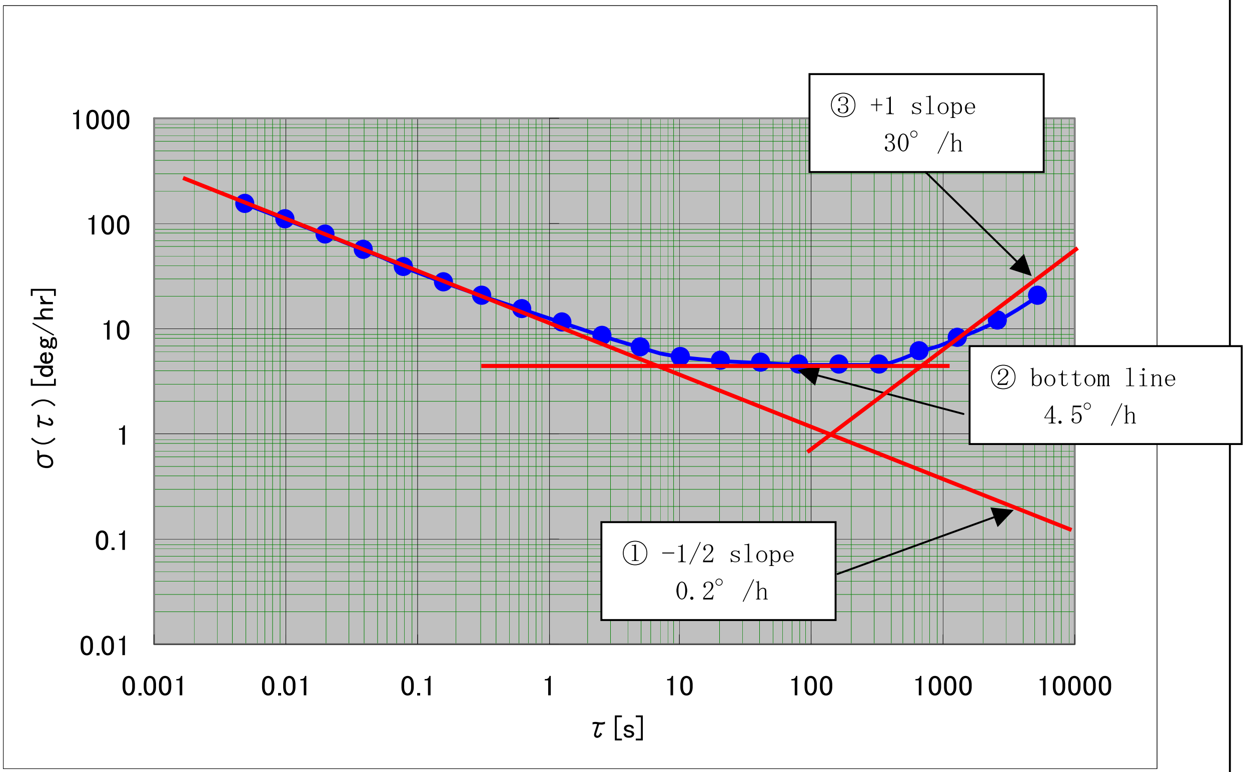
(b) 0.1sec cluster (10Hz)



(c) 1sec cluster (1Hz)

As can be seen, longer cluster time yields less variation between consecutive data

Fig.6 Example of allan variance plot



① Angular random walk

Fitting the line with -1/2 slope to plot of short cluster time(in this case 0.005~1sec). Along this fitting line to cluster time 3600sec and read value of σ(τ) at 3600sec. This value represents angular random walk in unit °/√Hr. In this case 0.2°/√Hr.

② Bias instability

Read the σ(τ) value at the inflection point of the plot. And divide the value by coefficient 0.664. In this case σ(τ) at the inflection point is 4.5°/h, divided by 0.664 yields 6.7°/h bias instability.

③ Bias drift (Rate ramp)

Fitting the line with +1 slope to plot of longer cluster time(300sec and up). Along this fitting line to cluster time √2 hour (5091sec) and read value of σ(τ) at 5091sec.

This value represents a Bias drift (or rate ramp) in unit °/Hr/Hr

In this case bias drift (or rate ramp) is 30°/Hr/Hr

Fig.7 Example of reading allan variance plot（Typical of TAG201）

（1）Bias instability(Bias stability)

This value is calculated from allan variance data as described in Fig.7. This value is defined to be minimum angular rate which can be measured by the angular rate sensor after proper compensation is made to the sensor out put (bias canceling, averaging and so on).

Not that this parameter is often confused with the parameter shown in (2). This parameter has smaller value than bias repeatability value of (2).

Bias instability of this angular rate sensor is 10°/h(at 10 sec cluster time). This means by averaging sensor output for 10sec, angular rate of 10°/h is minimum angular rate which could barely be measured by the sensor.

（2）Bias repeatability

This parameter represents the variation of nominal bias at the sensor between power on times.

This value also addressed as on-off bias stability, but the definition is absolutely different from the Bias instability (or Bias stability) of (1).

This parameter affects the angular integral calculated from the angular rate sensor.

Bias repeatability of this angular rate sensor is ±0.1°/s. This means error of Angular integral of this angular rate sensor will be 0.1° in 1sec (360° in 1 hour)

（3） Angular random walk

Among the AC noise superimposed to the sensor output, this parameter represents so-called white noise.

Integrating the sensor output with this noise yields randomly varied angular data. So this kind of noise is called Angular random walk.

Angular random walk of this angular rate sensor is calculated to be 0.2°/√H From allan variance plot.

（4）Bias drift (or rate ramp)

This parameter represents long term variation of the angular rate sensor out put.

6. Typical usage of angular rate sensor

（1）Calculating angle from sensor output

This angular rate sensor outputs voltage proportional to input angular rate. The unit of angular rate is °/s so multiplying time to angular rate yields angle. This rate sensor can measure angle of objects in free space (without rotation center axis).

Note that the output contains error components, it is necessary to remove error by proper methods. DC bias components can be removed by substituting the bias as a pre-set (set to ROM etc.) value. In this case bias repeatability will be a determinant of total error. If bias repeatability be a problem, it will be a solution to renew bias value consecutively during the measurement (ex. detecting or making stable time period during the measurement).

Angular random walk (or white noise) will be a variation of angle on relatively short period of time. If you need an angular stability in short period of time, select low noise sensor (ex FOGs) instead of this kind of vibratory angular rate sensor.

（2）Using angular rate output directly

This include stabilization of the moving objects and azimuth measurement (by earth rate). Note that this angular rate sensor is not suitable for azimuth measurement because bias instability of this angular rate sensor is 10°/h and earth rate, whose rotation rate is 15°/h, is too small to be detected by this sensor.

7. Other notes

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