Eddy-Current Rotor Position Sensor

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Abstract :
An Eddy-Current Rotor Position Sensor was developed for traction motors of HEV, EV. It serves – similar to a Resolver – to determine the angular position of the rotor in synchronous motors.It is compact and light weight, even at large rotor size and is proved to be insensitive to magnetic distortion. The arc shaped sensor module offers layout flexibility and allows easy installation and service. There is a good robustness to mechanical tolerance. The unique features of this technology can be very advantageous in applications with corresponding requirements. This article introduces the operating principle, simulation results and layout configurations and shows examples for applications.

EDDY CURRENT ROTOR POSITION SENSOR

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Contents

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1. Introduction
2. RPS (Rotor Position Sensor) Technology
   - Operating principle
   - Simulation model
   - Configuration and application
3. Features and Characteristics
   - Signal processing
   - Specifications
4. Summary

2

Purpose of this presentation

Introduction of RPS technology in Japan

RPS was developed in Europe, thus it is not known enough in Japan. Our products with this technology are now being introduced in the markets of Europe, America and Asia.

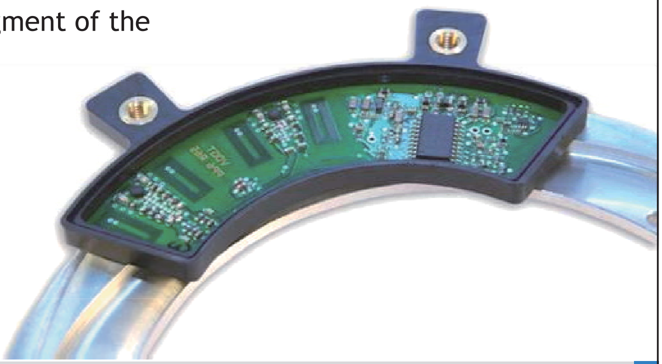
Feedback

We intend to contribute the global HEV/EV industry with this technology, reflecting feedback from customers and those who have interest in our technology.

Outline of RPS technology

Eddy Current Position Sensor

- Modulation of eddy current: *Variable Inductance*
- High operating frequency utilizing planar coils
- Integrated signal processing, 5V DC power supply
- Demodulated, analog sin/cos output signals
- Arc shaped sensor modules sensing a segment of the target rotor



Outline of RPS technology

Key advantages of RPS:

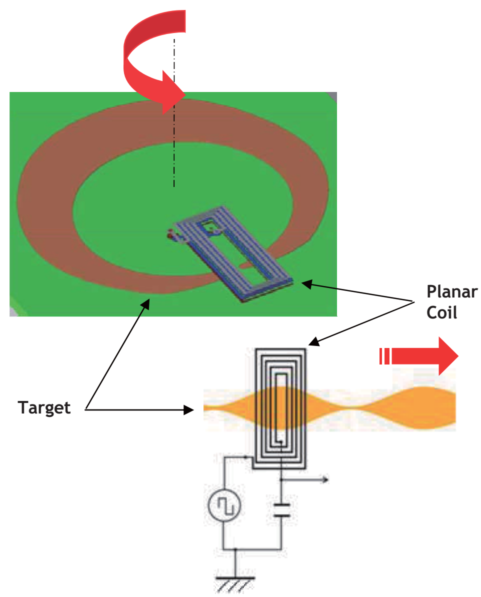
- Compact size & light weight
- Adaptable to various motor concepts
- Easy assembly & service
- Good robustness to mechanical tolerance
- Insensitive to magnetic distortion

 5

Functional Principle

Modulation of eddy current

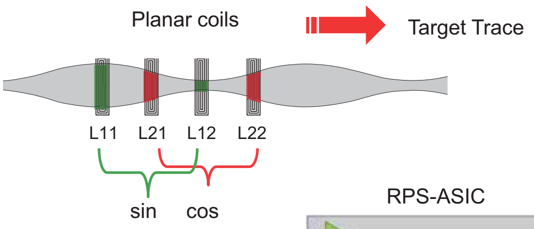
- The planar coil produces a high frequency magnetic field
- Eddy current is induced in the conductive target trace
- The resulting opposite field attenuates the inductance of the planar coil
- This effect varies by moving the shaped target trace



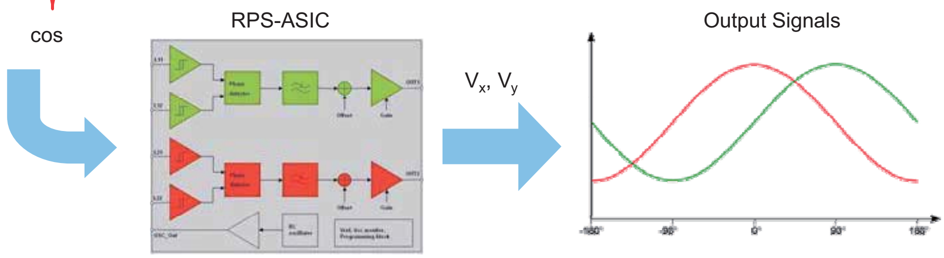
 6

Integrated signal processing

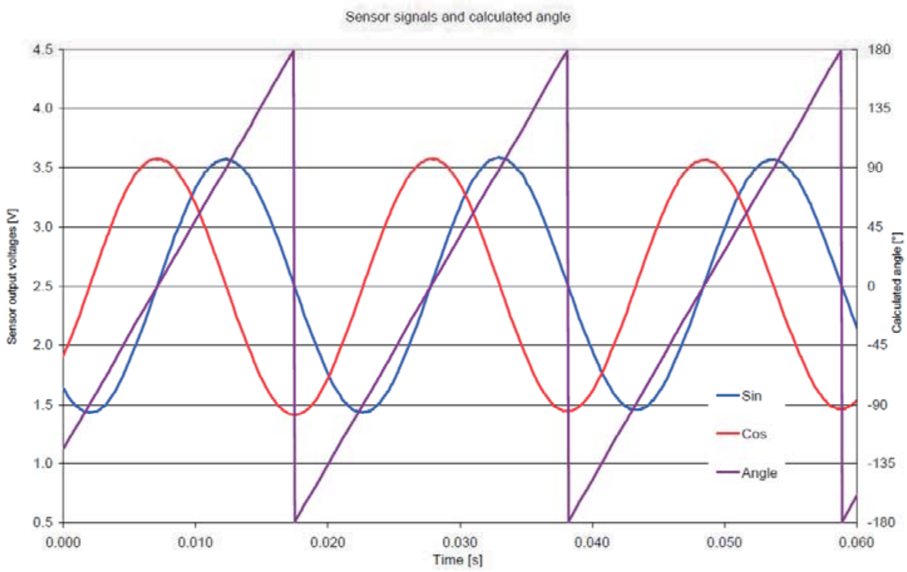
- Modulation of eddy current
- Differential phase comparison: planar coils in 180 deg offset
- Perpendicular sin/cos signals: 90 deg offset between to pairs of coils



$$V_x = V_{xOffs} + K \cdot (\varphi_{L11} - \varphi_{L12})$$
$$V_y = V_{yOffs} + K \cdot (\varphi_{L21} - \varphi_{L22})$$



Output signals and absolute angle



- Sin and Cos outputs are converted into absolute angle by inverter ECU
- Offset and gain compensation is necessary (page 26)

Operation frequency of RPS (conceptual)

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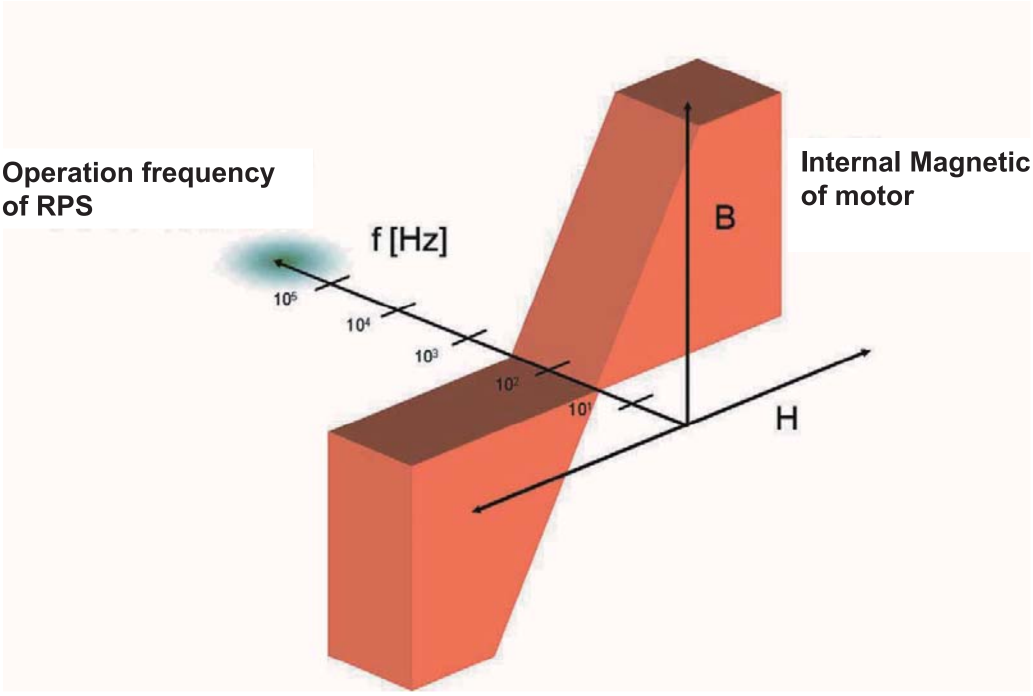

9

Simulation results

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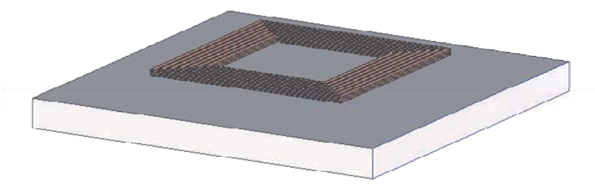
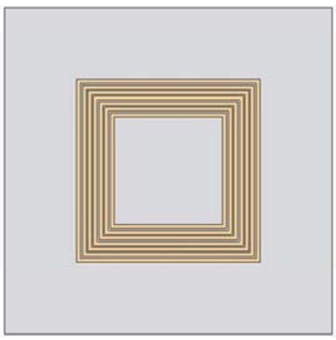
Basic Simulation Model of the planar coil

- 4 copper layer： 14*14*0.5 (mm)
- Target： 25*25*2 (mm)
- f=1 (MHz)





Dimension of the planar coil

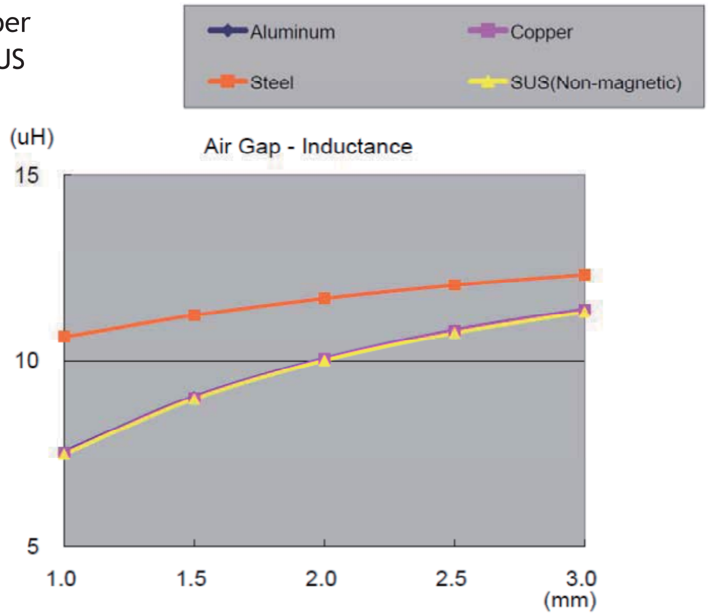
Size	Thickness	Width	Gap	Turns / Layer	Layers
14 mm * 14 mm	0.035 mm	0.3 mm	0.125 mm	7	4

10

Simulation results

Target Materials

- Aluminum, Copper
- Non-magnetic SUS
- Steel

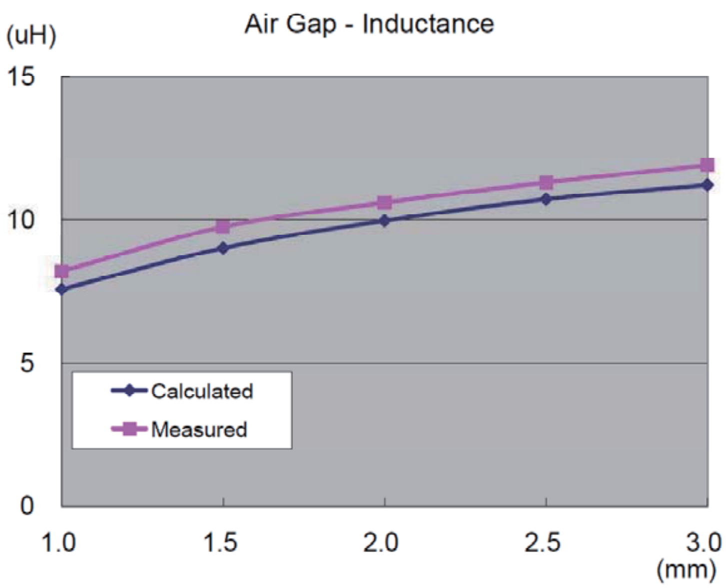


 11

Simulation results

Comparison of the measured and calculated Inductance

- Material: Aluminum



 12

Simulation results

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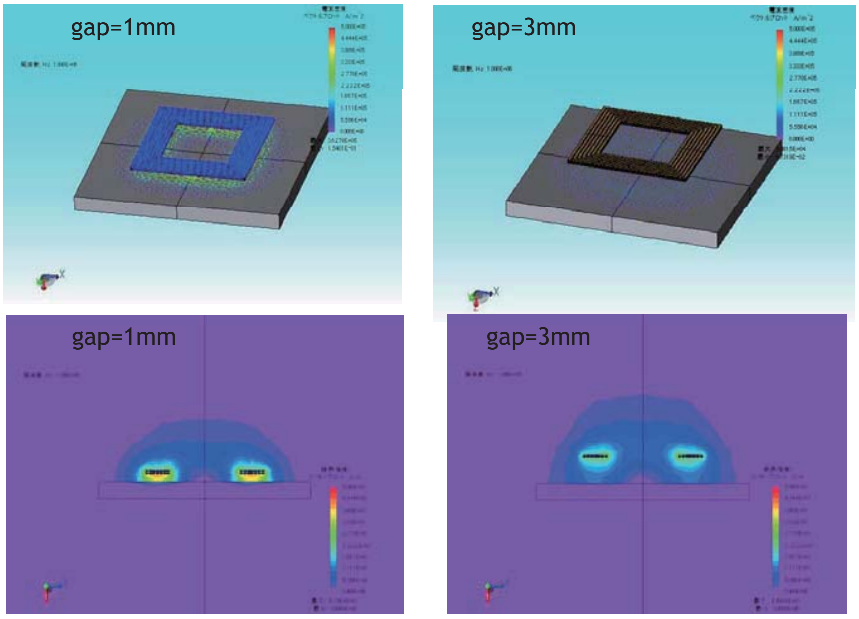
Aluminum Target

Current Density

Magnetic Field



 13

Configuration and Application

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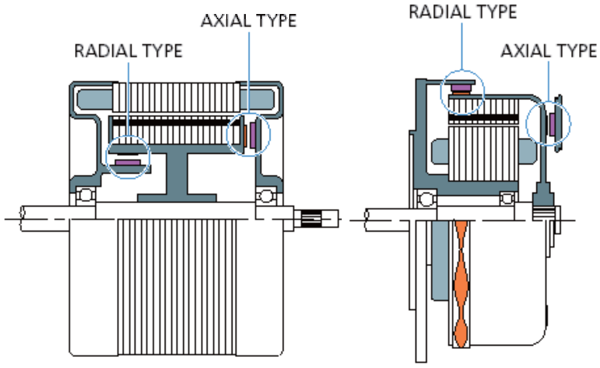
Application to different motors

- RPS designs available for axial and radial assembly
- Suitable to work with outer or inner rotor motor
- Possibility to mount the RPS from outside through the motor housing wall
- No need to occupy axial length on the motor shaft



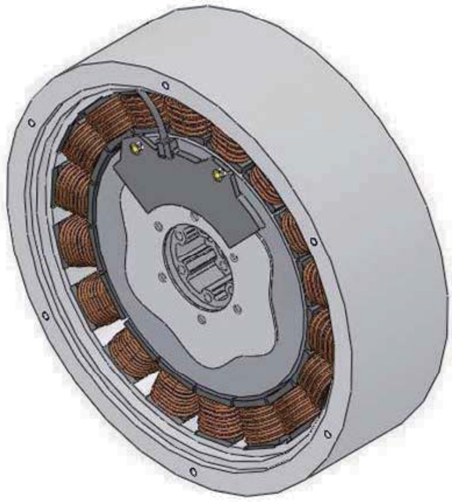
Inner Rotor Motor

Outer Rotor Motor

 14

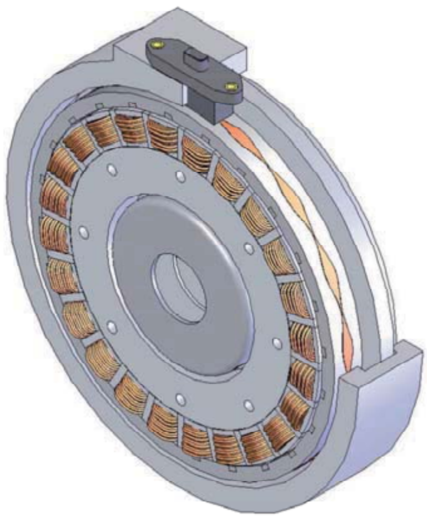
Layout example
Axial RPS for inner rotor motor

- Number of pole pairs: 6
- Target material: Aluminum
- Target Trace diameter: 130 mm
- Weight (sensor unit): 57 g
- Dimensions (L/W/T): 132 mm/62 mm/7 mm (T + 5 mm at cable outlet)
- Extremely flat sensor design



Layout example
Radial RPS for outer rotor motor

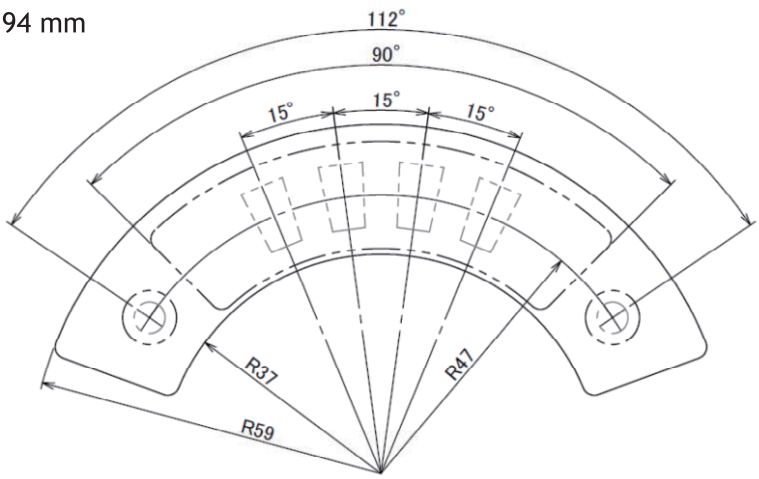
- Number of pole pairs: 16
- Target material: Copper (steel base)
- Target Trace diameter: 320 mm
- Weight (sensor unit): 48 g
- Dimensions (L/W/H): 98 mm/29 mm/37 mm (H = 54 mm incl. connector)
- Mounted from the outside of the motor housing



Sensor Design Example

Axial Type

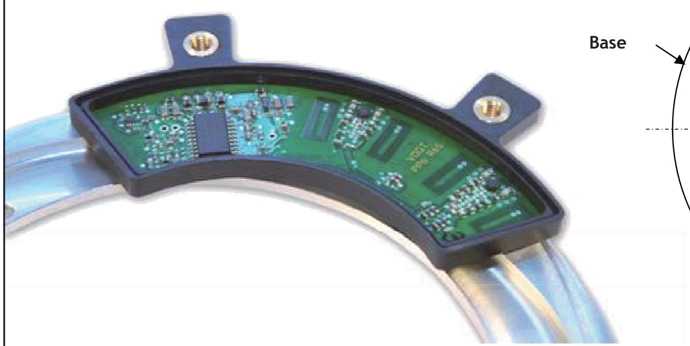
Number of electric cycles: 6
Target rotor diameter: 94 mm

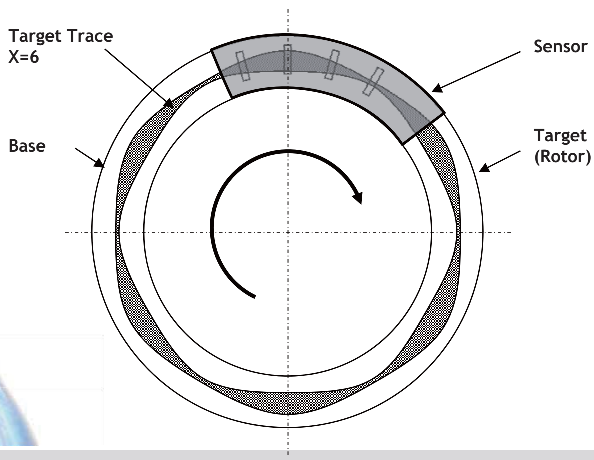


 17

Target structure & material

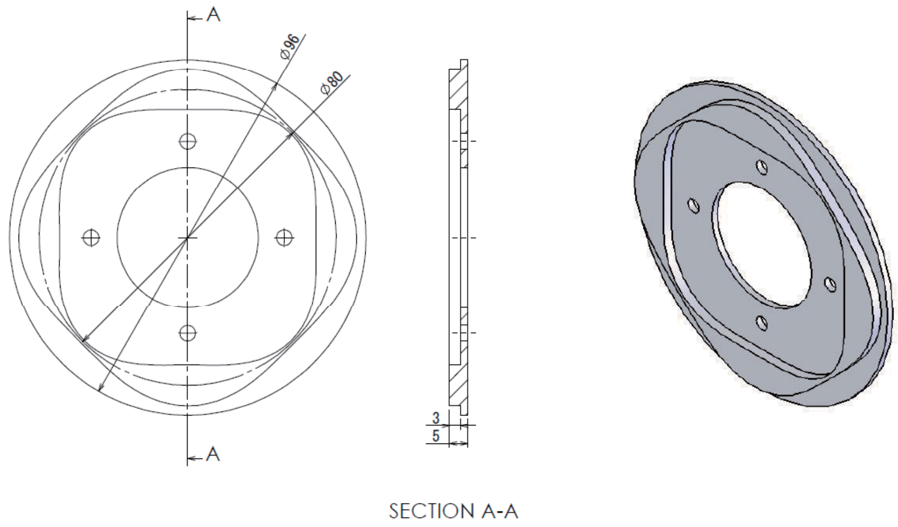
Base material		Trace material	Requirement
Metal	Al, Cu	Al, Cu	Trace embossed over base surface ≥ 3 mm
	Steel (magnetizable)	Al, Cu	Thickness of trace ≥ 0.15 mm
Plastic, Ceramics		Al, Cu	Thickness of trace ≥ 0.10 mm





 18

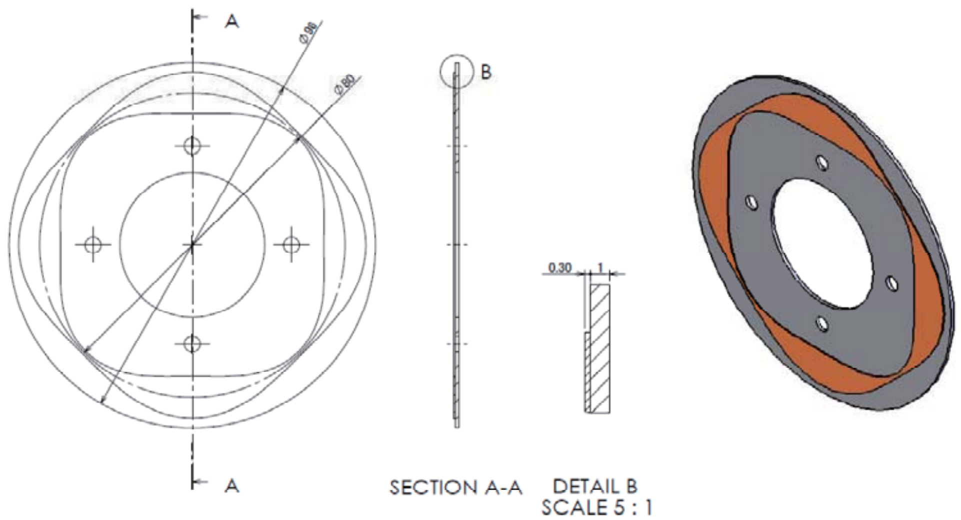
Double Edged Target (DET) - embossed



- Original double sine shape providing best angle accuracy
- Target structure embossed over base material
- Manufactured by CNC machining process
- Short time to prototype
- Material: Al

 19

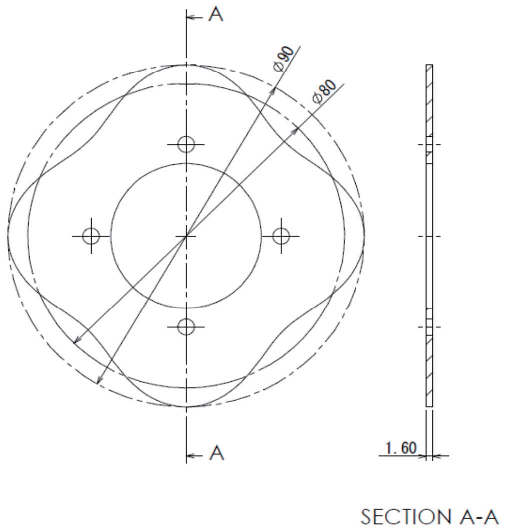
Double Edged Target (DET) - thin layer

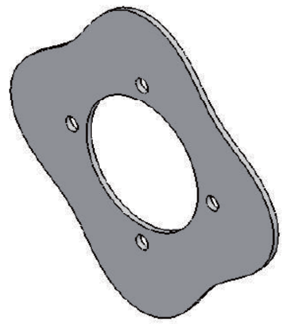


- Thin layer of conductive material requires minimal axial length
- Solution for integration onto existing rotor body
- Manufactured by selective plating process
- Combination of two materials, e.g.
  Cu trace on plastic base (insulator)
  Cu trace on (magnetizable) steel base

 20

Single Edged Target (SET)

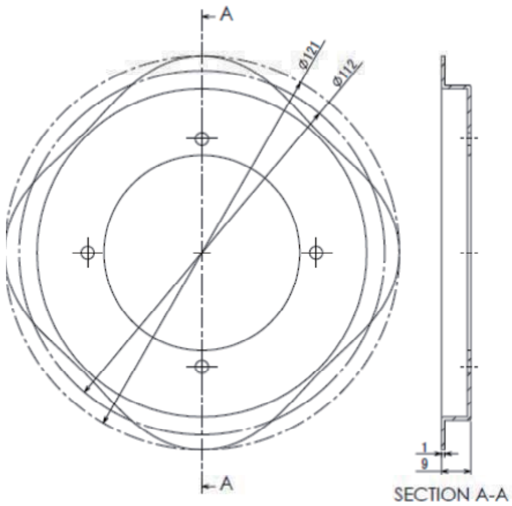


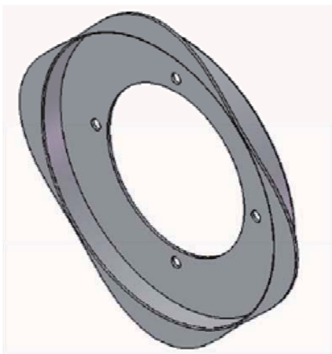


- Simplified „single edged“ sine shape
- Flat design requires small axial length
- Manufactured by machining or stamping process
- Short time to prototype
- Cost effective solution for mass production
- Material: Al

 21

Double Single Edged Target (DSET)





- Combination of Double and Single Edged Target
- Angle accuracy equal to DET
- Manufactured by deep drawing and stamping process
- Short time to prototype
- Cost effective solution for mass production
- Material: Al, non-magnetic steel

 22

Comparison of Target Designs

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= inferior (red)
= good (yellow)
= superior (green)

	DET Embossed	DET Thin layer	SET Flat sheet	DSET Deep drawn
Time to prototype	superior (green)	inferior (red)	superior (green)	good (yellow)
Robustness to radial runout	superior (green)	superior (green)	good (yellow)	superior (green)
Required axial length	good (yellow)	superior (green)	superior (green)	good (yellow)
Integration onto rotor	good (yellow)	superior (green)	good (yellow)	good (yellow)
Mass production cost	inferior (red)	good (yellow)	superior (green)	superior (green)
Weight	good (yellow)	superior (green)	superior (green)	superior (green)

Electrical Interface

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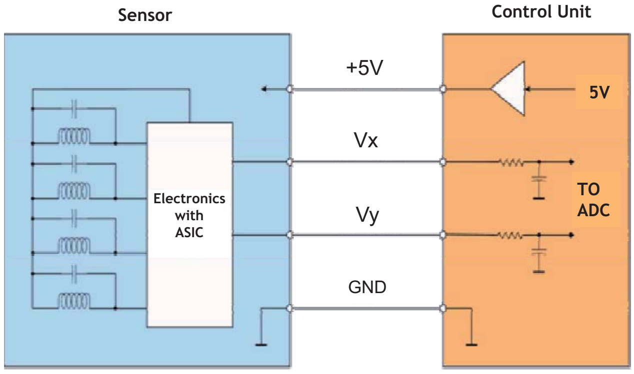
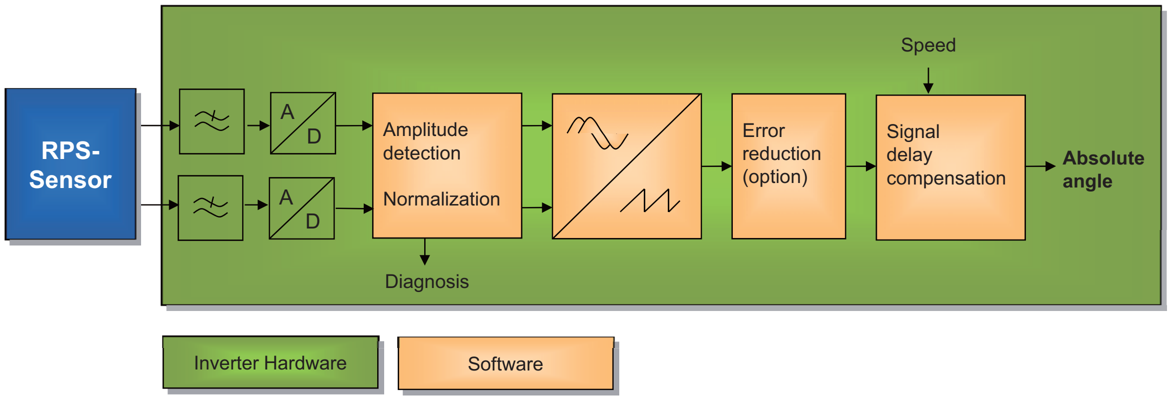
- Simple power supply (+5V, GND)
- Sin, cos analogue outputs
- Output signals without carrier frequency
- Angle conversion on ECU processor

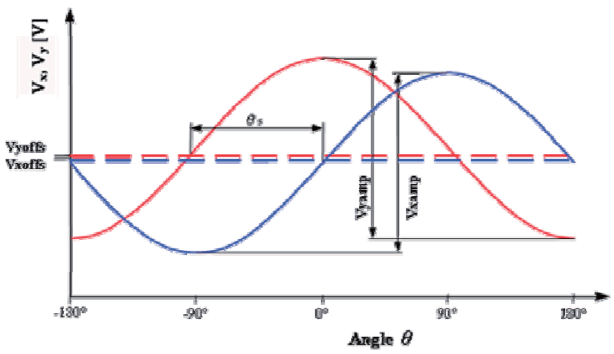


Overview of signal processing

- Analog input hardware: Typical peripherals of ECU processor can be utilized
- Sensor diagnosis by monitoring of input signals
- Angle conversion using software running on ECU processor
- Optional error reduction using correction table or advanced software filters



Offset and Gain compensation



Vxsig (t) : Output signal of RPS

Vxoffs : Offset voltage of Vxsig(t).

Vxamp : Amplitude of Vxsig(t).

NVx (t) : Normalized signal for sinus.

(Equivalent definition for Vy, NVy)

$$NV_X(t) = \frac{V_{Xsig}(t) - V_{Xoffs}}{V_{Xamp}}$$

$$NV_Y(t) = \frac{V_{Ysig}(t) - V_{Yoffs}}{V_{Yamp}}$$

Ratings

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No.	Group	Symbol	Item of Condition	Unit	Note
1	Operating temperature range	T_{Range}	-40 to 150	° C	(1)
2	Supply voltage	Vcc	5.0 ±0.2	V	
3	Current consumption	Ic	max. 30	mA	
4	Revolution range	f_{rev}	0 to 5,000	Hz	el. cycle (2)
5	Multiplication factor	X	2 to >20		(3)
6	Operating distance to target range	A_R	1.0 ±0.5	mm	(4)

(1) Sensor is durable under 150 ° C in limited period of time at peak temperature
(2) max. speed = 300,000 min^{-1} / X
(3) Usually X is chosen to be equal with the number of pole pairs of the motor.
(4) Standard airgap range, can be customized for the application.

Characteristics overview

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No.	Indication	Symbol	Specification	Unit	Condition
1-1	Signal offset	Vxoffs Vyoffs	Vcc * (0.5 ±0.03)	V	Nominal Conditions
2-1	Signal amplitude	Vxamp Vyamp	Vcc * (0.44 ±0.08)	V	
3-1	Basic amplitude ratio	X/Yamp	± 10%		
4-1	Noise amplitude of the signals	Vxripp Vyripp	Typ 10, Max 15	mV	(1)
5-1	Phase shift between sin and cos signal	θs	-90 ±2	° el	(2)
6-1	Angle error	Fs	Typ 0.5	° el	(2)
7-1	Signal propagation delay	dtsig	17 ±3.5	μs	

(1) Vcc overlaid ripple voltage max. 5mV
(2) RMS error (standard deviation, 1σ) of electric angle within one mechanical revolution, with No. 5-1 phase shift between sin/cos -90° ±0.3.
Unit of ° el is converted into unit of mechanical angle : ° el/X (X is multification factor)

Summary

Advantages of RPS:

- Compact size & light weight
- Insensitive to magnetic distortion
- Easy assembly & service
- Good robustness to mechanical tolerance
- Analogue Sin/Cos output signals, without carrier
- High no. of electric cycles possible
- Adaptable to various motor concepts

 29