Application guidelines on Speed Sensor DG6, DG7 and installation and layout of tone wheels

BOSCH

Y 281 E22 002-E

From	Written by	Telephone no.	Fax no.	Feuerbach
K5/ESK1 Version 2.0	Klenk	(07 11) 8 11- 33022	(0711) 811-45108	03.08.2000 Page 1 of 22

K5/VIV, K5/VRV, K5/VDN, K5/VMN, K5/VBM, K5/VRN, K5/VVW, K5-N/AVG3, K5/VDC, K5/VFI, K5/VFO, K5/AVN, K5/VOM, K5/VPC, K5/VNS, K5/VSV, K5/VUS, K5/VPK, K5/EMF, K5/EAC, K5/ESC, K5/ERR, K5/SBC, K5/SBR, K5/SBV, K5/ESM, K5/ESN, RBAJ/EED2, K1-Si/ECS12, K3/ESI1, K3/VDC

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File: K5/ESK central files for development documents.

Report for customer distribution : YES

Validity

Sensor:	Typ DG6 corresponding to modular system or DG7
EDC systems:	AS3/4 VP36/37 VP29/30 VP44 PDE/UI PLD UIP CR CP
Evaluation circuits:	CY03, CY09 (segment- and increment wheels) (MSA11/12/15,EDC15Vx,MS6.x,EDC7) CJ911 (increment wheels z.B 60-2 teeth) (EDC15Cx/P+) CY310 (increment wheels z.B 60-2 teeth) (EDC16C/CP/UP, PSG16)

Revision table

No.	Revision	Date	sgn.	chk.
K5/ESK-94/004 u. 94/005 (E)	Replacement by Y281 E22 002-E	08.12.97	Gl	Se
1	Initial edition	08.12.97	Gl	Se
2	Modifications: 4.1/4.2/4.2.1/4.2.2/4.2.3/4.3.1/4.3.2/4.3.3/4.3.5.1/5.1/6.1/6.4/6.6/7.2.2/7.3.1/7.3.2/7.3.3/7.3.4	03.08.00	Kl	-

Signatures

Dept. / Co:	K5/SBE	K5/ESK	K5/ESK1		
Signature:	gez. i.V. K5/ESK1 Dr.W.Böhner	gez. Dr.W.Böhner	-		
Date:	08.08.00	08.08.00			

1 Table of contents and figures

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2 List of designations used in this report

AWS	Evaluation circuit
a	Angular spacing of cam sensor to segment tooth
b	Tooth width (notch width)
b_{Imp}	Pulse width of positive DZG signal
C	Spacing between impulse-giving geometrie, (e.g. toothwheel: length of tooth gap)
c	Pin diameter (hole diameter)
C_{Last}	Load capacitance of control unit or the corresponding test circuit
D_A	Diameter of tone wheel
d	Thickness of tone wheel
DZG	Rotational-speed sensor
DZI	Increment sensor for crankshaft signal (e.g., 60-2 teeth tone wheel)
DZS	Segment sensor for camshaft or crankshaft signal (number of teeth corresponds to the number of cylinders, camshafts applications have an additional „synchronization tooth„)
e	Angular spacing of synchronization tooth to segment tooth
g	Imbalance, Eccentricity of the tone wheel
GND	Ground
h	Tooth height (pin height, notch depth)
k	Correction factor for matching the DZG pole core to the tooth design
KW (°KW)	Crankshaft (Degree crank)
l	Tooth length (notch length)
LS	Air gap [mm] between speed sensor and tone wheel
Ls_{max}, LS_{min}	Upper (Lower) tolerance limit of the adjusted air gap LS
NW	Camshaft
n	Rotation speed [RPM]
$n_{min\ KW}$	Minimum speed (starter speed), crankshaft applications
$n_{min\ NW}$	minimum speed (starter speed), camshaft applications ≡ $n_{min\ crankshaft}$ /2
n. OT	After TDC (cylinder1)
φ_S	Segment angle (360°/number of cylinders)
$\varphi_{k,k+j}$	Phase shift between over j tooth
φ	General phase shift: distance from when the signal crosses zero to the mechanical tooth flank)
φ_P	systematic phase shift, phase angle based on phase for DZG
$d\varphi_P$	Random phase error, angular phase difference, e.g. sample variation
p	Diameter of pole core (DG6 fixed 3.5mm)
R_A, D_A	Radius, diameter of tone wheel
R_{Last}	Load resistance of control unit or corresponding test circuit
SG	Control unit
s_{Imp}	Distance between two positive DZG pulses
t	Hole depth
T_{max}, T_{min}	maximum, minimum ambient temperature at DZG
ü	rectangular on wheel projected surface of pole core
Ü	Degree of overlap of DZG pole core p with teeth, notches, etc.
$+U_A$ ($-U_A$)	DZG output voltage, positive (negative) sinusoidal half-wave
U_{SS}	Output voltage, peak-to-peak, of one sinusoidal voltage
V	Voltage [V]
z	Number of cylinders
z-tooth	Tooth mechanically referenced to one cylinder
Z_Z	Number of teeth

3 Introduction

In order for the total EDC system to function without any problems, the camshaft and crankshaft speed sensor signals should be correctly sampled and processed by the control unit. This report contains guidelines for the application of the inductive speed sensor DG6 (following DZG). There are guidelines and explanations for the correct mechanical and electrical installation of the rotational-speed sensor for sampling the increments and segments on the crankshaft and camshaft. The installation and design of the tone wheel is also described. Special emphasis is given to the tooth geometry, as well as the matching of the sensor wheel to the rotational-speed sensor. Information is given for an EDC suitable speed sampling regarding the signal voltage and the tolerance stack-ups that need to be considered. The information is based on the requirements of the system development. Deviations are possible but have to be discussed between sensor responsible person and customer. Further requirements are found in the respective Technical Customer Information (TCI or TKU). This application guideline may be forwarded to the customer.

4 Signalgeneration, signalprocessing and necessary measurements

4.1 Polarity of the rotational-speed sensor, pin assignment

First the rotational-speed sensor DZI and the cam segment sensor DZS[1] must be checked for correct polarity (Figure_01).
The plug for the inductive DZG has 3 connections: The solenoid with the connections A and B as well as the shielding, which is routed from the connection cable to the DZG housing. The pin assignment at the plug, as well as the electrical data of the connection lines, is found in the respective customer offer drawing (AZ). For connection to A (PIN1) (refer to the corresponding customer offer drawing) when a magnetically conductive material passes by, the first sinusoidal half-wave induced is positive. The use of a tone wheel with holes necessitates exchanging connections A and B.

Figure_01 displays a DZI- and a DZS- signal with the correct polarity:

- The increment sensor DZI has correct polarity if the signal at the start of the gap (reference mark, missing tooth of, for example, a 60-2 tooth tone wheel) has a falling flank and at the end showing an increasing flank.

  positive sinusoidal half-wave is measured and then a negative sinusoidal half-wave follows.

[1] The inductive DZG can be used as cam segment sensor, if the wheel diameter is big enough, as usually in truck engines. In car systems e.g. EDC15C a cam DZG needn't be considered, because for cam-crank synchronization a Hall-sensor is used.

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DZI
Crankshaft signal of, for example, a 60-2 tooth increment tone wheel, voltage increase in the area of the reference mark. The output voltage increase is to avoid. Corrective action: 7.3.3

DZS
With inductive DZG sampled camshaft signal on for example, a NW-Segment tone wheel with z-teeth + 1 synchronization tooth.

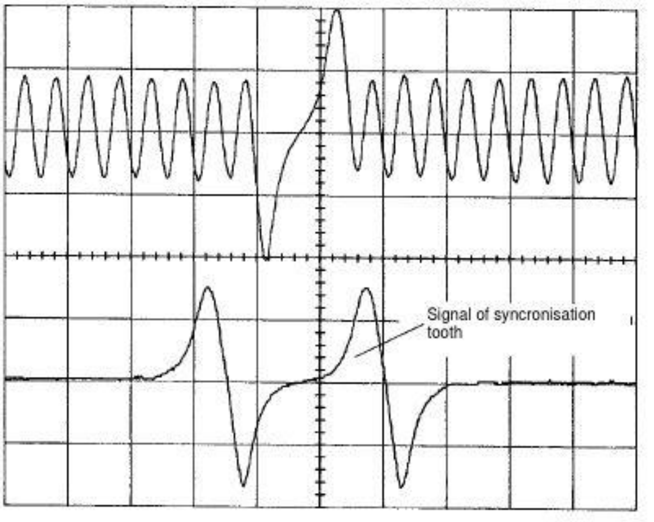


Figure_01: DZI and DZS analog signal with a right polarized speed sensor

4.2 Processing the analog speed sensor signal

To process the analog DZG signals, a conversion into digital square-wave signals must be done. This conversion occurs in a peripheral module of the control unit e.g. CY03, CY09, CJ911 or CY310. The peripheral module depends on the sort of the control unit. All evaluation circuit processes the „zero-crossings" of the falling DZG analog voltages. But this is not valid for gasoline applications.
The minimum output voltage allowed corresponds to the basic trigger threshold (upper tolerance limit) of the corresponding evaluation circuit (AWS). The trigger threshold must be applied so that there is a sufficiently large distance from the maximum expected disturbance pulse.

Trigger threshold:
If the analog DZG signal exceeds the trigger threshold, then the output signal is set (*Figure_02)*. When „crossing zero" ($+U_A$ to $-U_A$) there is a reset, polarity according to what AWS is used. In the control unit, the time between two zero-crossings is sampled and processed further.

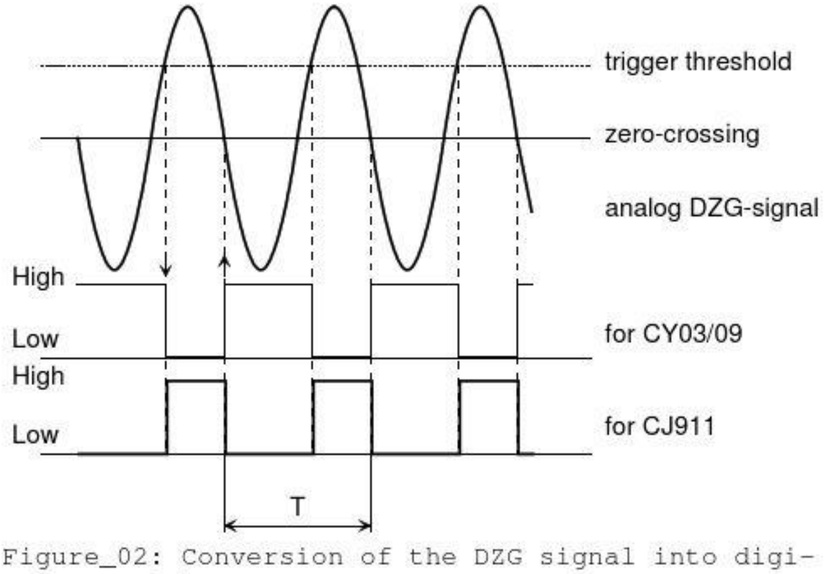


Figure_02: Conversion of the DZG signal into digital square-wave
Polarity depending on AWS

Overview of used EDC peripheral modules:

system	SG-family	CY03	CY09	CJ911	CY310
RP/VP	**PKW:**				
	AS3/4			x	
	NKW:				
	MS5.x (nur RP)	only CY12			
	MS6.x		x		
VP36/37	MSA11	x			
	MSA12	x			
	MSA15	x			
	EDC15V	x		optional	
	EDC15VM+2V	x		optional	
VP29/30/44	EDC15M	x			
	EDC15VM+2M (VP44)	x		optional	
	PSG16 (VP44)				x
PDE/UI	**PKW:**				
	EDC15P		x		
	EDC15P+			x	
	EDC16U				x
	NKW:				
	MS6		x		
	EDC7U		x		
UIP	**PKW:**				
	EDC16UP				x
	NKW:				
	EDC7UP		x		
CR	**PKW:**				
	EDC15C4/C11			x	
	EDC16C1/C4				x
	NKW:				
	EDC7C		x		
CP	**PKW:**				
	EDC16CP5				x
	NKW:				
	EDC7CP		x		

4.2.1 CY03, CY09

The output signal voltage of the DZG signal depends on the rotation speed. The module CY03/CY09 offers a stepless trigger threshold (dynamically adaptive trigger threshold depending on amplitude of the output signal voltage). The threshold adaptation must however react quickly that even with the largest accelerations/decelerations occuring at the sensor wheel (e.g. quick clutching), a signal miss does not happen. A typical value for the trigger basis-threshold for the evaluation circuit CY03 or CY09 is $+U_A$ = 500mV. The trigger threshold is tracked with a time constant of 0.1 sec.

Note 1: measurement of the minimum output voltage

For speed sampling using a z-toothed tone wheel (4-, 5-, 6-, 8 teeth) the disturbance signal at the current operating point, taking into account all extreme operating conditions (temperature, eccentricity, magnetic disturbance fields, etc.) should not be larger than **33% of the trigger threshold**. The reason for this is the threshold trigger tracking, which lowers the trigger threshold during the time between the individual speed sensor signals, and thus lowers the safety margin against disturbance.

Also note that by using a tone wheel with holes at higher speeds, even minimal roughness and material imperfections (altered ferromagnetic behavior) and other rotating ferromagnetic components can cause voltage spikes. If these voltages are above the trigger threshold, then error pulses are created.

Note 2: measurement of impulse width

In order to guarantee an error-free function of the threshold trigger tracking with the evaluation circuit CY03 and CY09 , the ratio of the positive DZG pulse width (b_{Imp}) to the gap of two DZG pulses (s_{Imp}) has to be measured (see Figure_03).

For a z-toothed sensor wheel, the ratio is for **b_{Imp}/s_{Imp}: typ. 6...10 %.** If these values are not met, then it must be guaranteed that the disturbance pulses are maximum 33% of the adjusted trigger threshold. In this case, a rise of the trigger threshold can be taken into considerations.

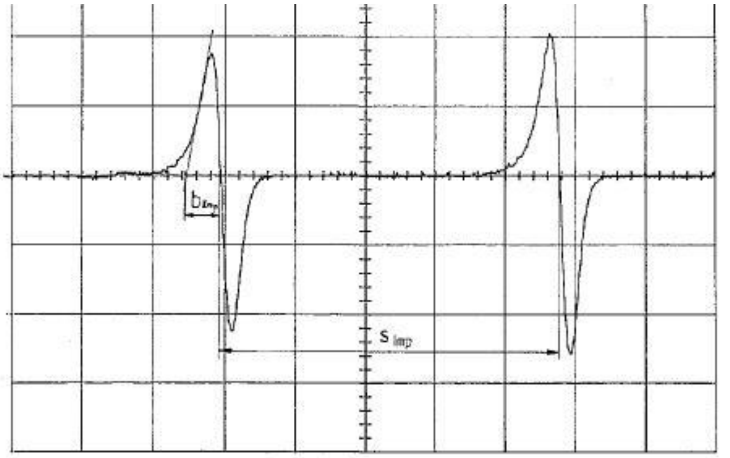


Figure_03: Measurement of impulse width

4.2.2 CJ911 (EDC15)

The electric circuit CJ911 is different from the CY03 and CY09 types because it has a differential input and add-on interference suppression filters.

The upper trigger threshold is not stepless like the modules CY03/CY09, but instead switches in two steps. The thresholds for the CJ911 evaluation circuit after the input voltage separator are typically at 30mV and 360mV.

4.2.3 CY310 (EDC16)

The module CY310 offers the following modes for adjusting the trigger threshold:

A) one fixed threshold (selectable out of 8 thresholds)

B) speed-dependent switching between 2 thresholds (each selectable out of 8 thresholds)

C) starting with one fixed threshold (selectable out of 8 thresholds). Above a certain speed an amplitude-dependent switching between the remaining 7 thresholds follows.
The speed above that the amplitude-dependent switching is released, is applieable.

Overall there are 8 fixed thresholds after the input voltage separator: 30mV, 60mV, 120mV, 210mV, 330mV, 510mV, 790mV, 1200mV.
Besides it is possible to activate four different input filters against noise signals (filter times= 3.2µs/6.25µs/12.5µs/25.0µs).
The parameters must be adapted to the respective application. The choice depends on different points:

- the minimal output voltage must reach under measurement conditions (see 4.3.3) the trigger threshold.
- a sufficiently large distance between trigger threshold and maximum expected disturbances must be guaranteed.

Additional notes for the definition of input devider and switching parameters are found in the application guidelines for CY310
http://www.diesel.bosch.de/ou/ecu_hw/ (for authorized K5-employees only).

4.3 Measurements

4.3.1 General measurement conditions

Because of the mechanical and electrical disturbances resulting from influences such as screws, markings on the V-belt pulley, starting motor, alternator, disturbance voltage peaks from solenoid valve switching, etc., measurements are to be taken if at all possible on the original installation of the

Tolerances for air gaps, eccentricity, overlap, temperature, rotational-speed sensor sample variance (output voltage, inductance), and the maximum disturbances expected have to be considered during the measurements.
If eccentricities can not be reproduced for the measurements, then this may be considered by changing the air gap. The induced rotational-speed sensor output voltage is to be loaded preferably with the control-unit evaluation circuit or with the test circuit shown in Figure_04.
The values R_{Load} and C_{Load} are to be taken from the interface definition of the current control unit. The tolerances for load resistance and load capacitance must also be taken into account.

4.3.2 Maximum speed sensor output voltage $+U_A$ and $-U_A$

The maximum allowed output voltage peaks for the rotational-speed sensor is according to the control unit interface definition:

$$- 100V < U_A < + 100V$$

If the output voltage of the DZG exceeds this e.g., due to a too small air gap or through a too low load resistance, then this can lead to a damage of the control unit (defective load resistance R_{load}).

The maximum output voltage is measured under following conditions:

Maximum engine speed, see *Figure_06 $U_A=f(n)$*	n_{max}
Load resistance upper tolerance limit, see *Figure_04*	$R_{Load\ max}$
Load capacitance lower tolerance limit, see *Figure_04*	$C_{load\ min}$
Ambient temperature, range	-40°C to +150°C
Overlap Ü at upper tolerance limit, see *Figure_05*	Ü=100%
Lower tolerance limit for the adjusted air gap (LS) Considering the tolerances of installation location, eccentricities,...	LS_{min}

Output voltage increase at the reference mark: only for increment tone wheel

Figure_01 displays an output voltage increase at the reference mark. This has to be avoided. It must be guaranteed that especially the 2[nd] tooth after the reference mark can be evaluated (crossing zero at high speed). Corrective actions are described under 7.3.3 .

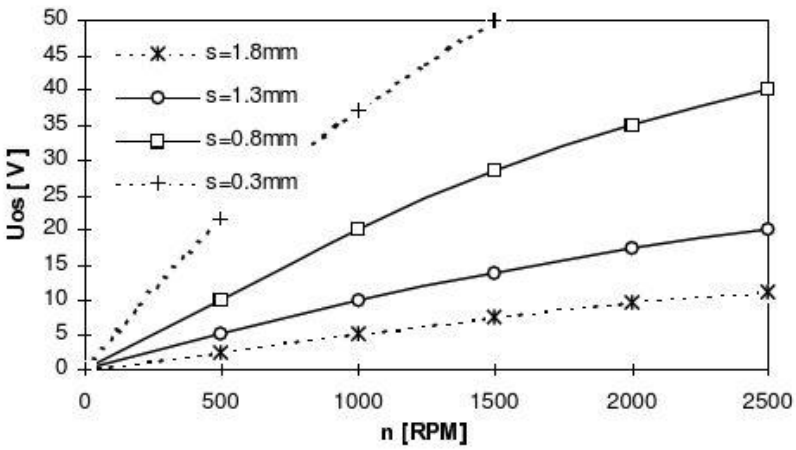


Figure_06: Speed-dependent output voltage of DZG (typ.)

4.3.2 Maximum speed sensor output voltage +U_A and -U_A

The maximum allowed output voltage peaks for the rotational-speed sensor is according to the control unit interface definition:

$$-100V < U_A < +100V$$

If the output voltage of the DZG exceeds this e.g., due to a too small air gap or through a too low load resistance, then this can lead to a damage of the control unit (defective load resistance R_{load}).

The maximum output voltage is measured under following conditions:

Maximum engine speed, see *Figure_06 U_A=f(n)*	n_{max}
Load resistance upper tolerance limit, see *Figure_04*	$R_{Load\ max}$
Load capacitance lower tolerance limit, see *Figure_04*	$C_{load\ min}$
Ambient temperature, range	-40°C to +150°C
Overlap Ü at upper tolerance limit, see *Figure_05*	Ü=100%
Lower tolerance limit for the adjusted air gap (LS) Considering the tolerances of installation location, eccen-tricities,...	LS_{min}

Output voltage increase at the reference mark: only for increment tone wheel

Figure_01 displays an output voltage increase at the reference mark. This has to be avoided. It must be guaranteed that especially the 2nd tooth after the reference mark can be evaluated (crossing zero at high speed). Corrective actions are described under 7.3.3 .

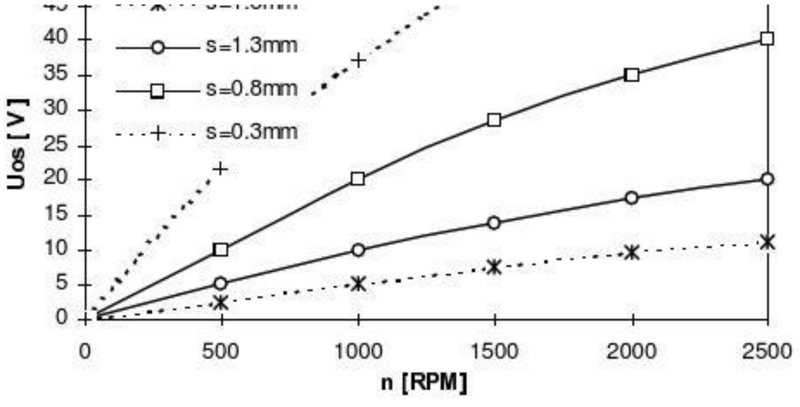


Figure_06: Speed-dependent output voltage of DZG (typ.)

4.3.3 Minimum DZG output voltage $+U_A$ and $-U_A$

If the minimal output voltage does not reach the trigger threshold then the engine does not start (cold start).

U_{min} > trigger threshold (upper tolerance)

The minimum output voltage must be measured under following conditions:

Minimum starter motor speed : battery low , T_{min}, decide whether cam or crank is used, *see Figure_06 U_A=f(n)*	n_{min} Crank ≈ 50 RPM n_{min} Cam ≈ 25 RPM
Load resistance lower tolerance limit, *see Figure_04*	$R_{Load\ min}$
Load capacitance upper tolerance limit, *see Figure_04*	$C_{load\ max}$
Ambient temperature, range	-40°C to +150°C
Overlap (Ü) (DZG pole core/tooth or hole) minimum according to tolerance situation of sensor- and tone wheel - mounting in the investigated application	Ü≤100%
Upper tolerance limit of the adjusted air gap (LS) considering the tolerances of installation location, imbalance,...	LS_{max}
DZG sample made to tolerance limits[2] with minimum output voltage	$U_{A\ min}$

LS= 1.8mm speed=50 1/min

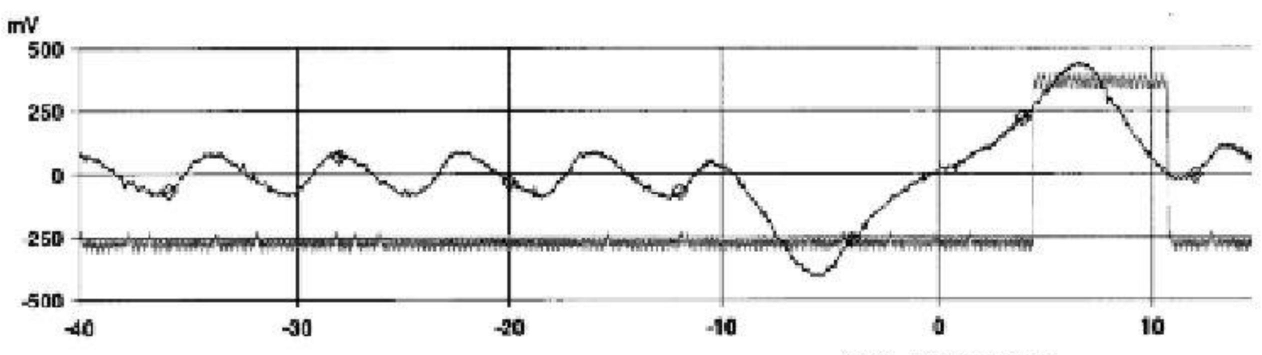


Figure_07: Minimal output voltage (analog and digital)
In this example the analog output voltage does only cross the trigger threshold at the reference mark because of an inadmissible output voltage increase!

For evaluation cicuit CY03, CY09: see note 4.2.1

4.3.4 Signal gradient dU_A/d_φ, signal trace

In order to have an exact switching point when crossing zero from a positive to a negative sinusoidal half-wave, a sufficiently gradient at the trigger point is needed (for zero-crossing see Figure_08).

[2] Sample have to be ordered by K5/ESQ2 Mr. Dinkel.

Meas. conditions: Specify tolerances for air gap etc., so that the output voltage $+U_A$ is at a minimum.

Speed range: Low-idle speed ≤ n ≤ breakaway speed

Required $dU_A/d\varphi$: z-toothed tone wheel: **≥ 1.8V/°crank**

60-2 tone wheel (increment): **≥ 0.3V/°crank**

Comments: For applications using increment tone wheels which have gaps (e.g., 60-2 toothed tone wheels) it is important that the curve of the analog sensor output voltage is also continuous in the gaps. Thus, the signal may not have a reverse point.

4.3.5 Phase shift φ, phase error

Phase shift φ means in this context the angle between the mechanical tooth flank of a tone wheel and the electrical signal flank (crossing zero, EDC-reference) of an inductive rotational-speed sensor. With an inductive speed sensor, the phase shift includes a systematic and a random component (Figure_08).

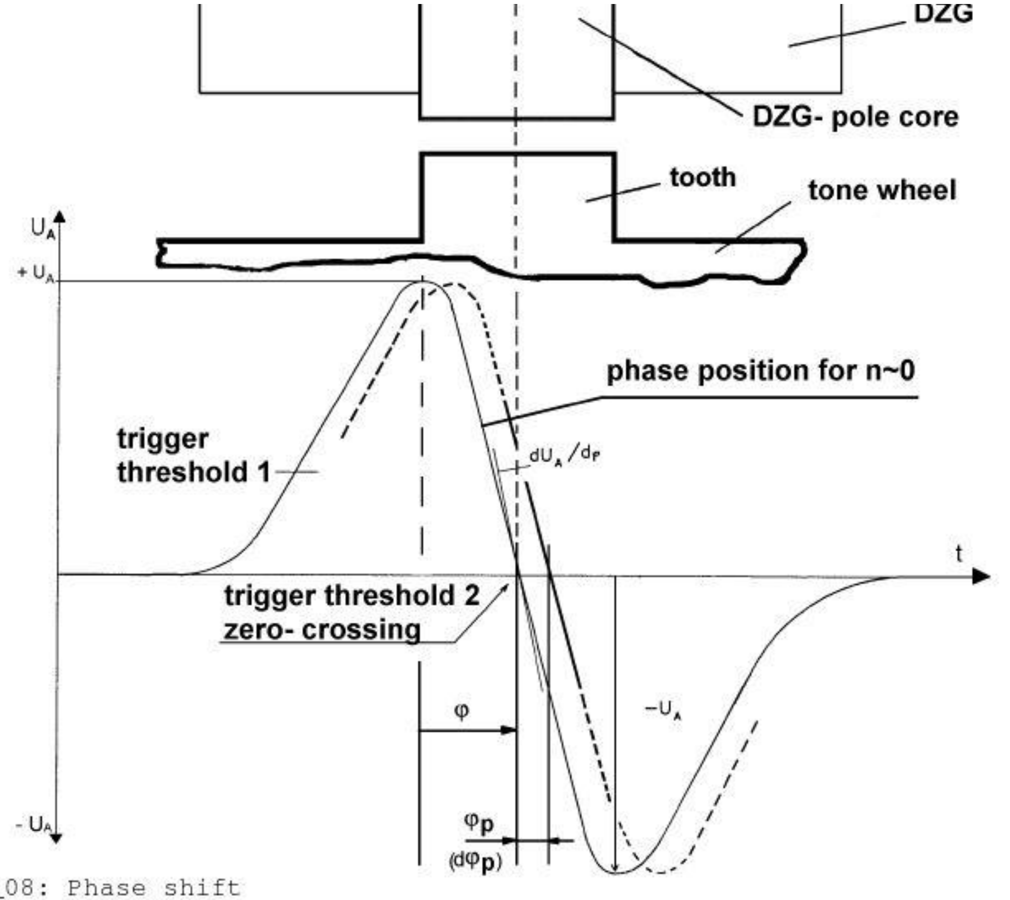


Figure_08: Phase shift

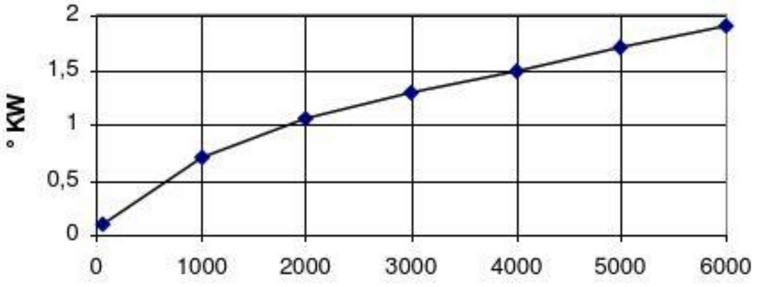
(Signal slew rate $dU_A/d\varphi_P$, phase shift φ, systematic phase error φ_P, random phase error $d\varphi_P$)

4.3.5.1 Correctable phase error (systematic phase error)

The systematic phase error φ_p *of* the rotational-speed sensor is the phase shift dependent on the rotational-speed (circumferential speed), see Figure_09. The systematic error component can be compensated in the control unit in two ways:

A) By applying the speed-dependant quantity and start-of-injection maps with the DZG-signal (i.e. DZG-phase error is included in the maps). The maps have to be recorded with exactly that type of DZG, which is later used in series production.

B) By using the phase correction map (Bsp. EDC15C4: zuoPHIkorr). The measured phase error of the DZG is stored here.



4.3.5.2 Uncorrectable phase error (random phase error)

The random phase error $d\varphi_p$ is an unforeseen deviation of the zero-crossing from the nominal. With an inductive speed sensor, the sample-to-sample spread of the inductance causes the largest part of the random phase error $d\varphi_p$ (angular phase difference). The inductance deviations, caused by fluctuations of the pole core material, different numbers of windings and other influences are about ±15%. Additional parameters which can cause smaller phase errors are: air gap fluctuations, temperature, e.g., due to imbalance, or longitudinal or horizontal tilting. In a „worst case„ scenario, the total of the random components of the DG6 is < ± 0.5° crank.

This random phase error can't be compensated in the control unit and therefor must be taken into account during the tolerance study (see Chapter 5) and measurements. The measurement of the angular phase difference should occur with limit samples[2] of inductance.

In addition to the sensor phase deviations, the error due to the integrated disturbance filter must be considered, if the CJ911 evaluation unit is used. The systematic error due to the typical filter time (12.5µs) has to be eliminated by a corresponding correction curve. The random error due to the min/max. filter tolerances must be taken into account in the system. (Typical value for the min/max. tolerance of the filter is ± 4.5µs)

[2] Sample have to be ordered by K5/ESQ2 Mr. Dinkel

5 Electrical and mechanical peripheral conditions

Tolerance requirements for the system must be fulfilled. In conjunction with this, the evaluation accuracy and tone wheel tolerances must be met.

5.1 Tolerance requirement for the n-governor and injection-control

The tolerance requirement for the n-Governor applies to 500 RPM< n <5000 RPM. The correct function of the cylinder balancing governor (LRR), active surge damper (ARD) and low-idle governor (LLR) is dependent upon, among other things, the quality of the segment speed information. The accuracy of the speed information depends on the tooth spacing error and the error due to the evaluation circuit.

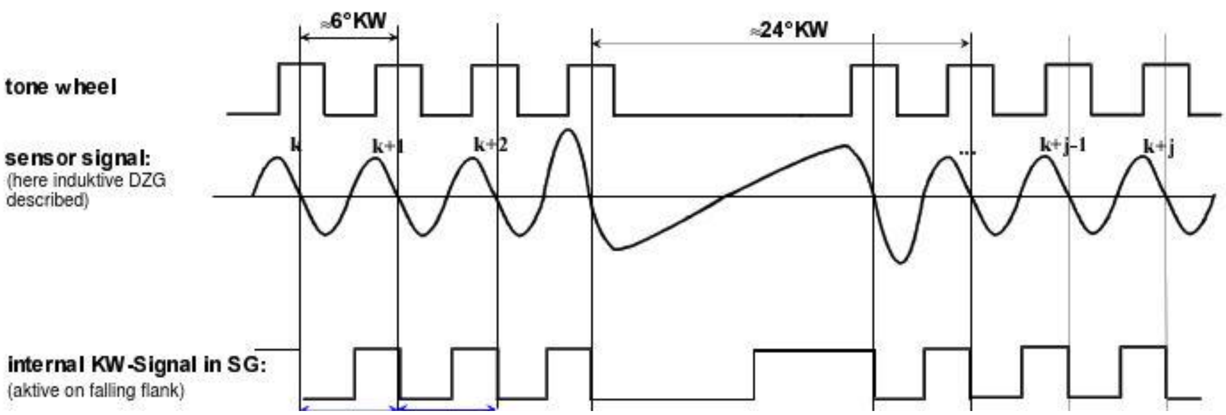
Requirement:

Evaluated flank-flank Signal ("analog tooth-tooth tolerance") < ± 0.10°crank and over any evaluated flank ("analog tooth") < ± 0.10°crank.

Note: This doesn't refer to the geometrical teeth position but to **the evaluated digital flank** in the control unit (see Figure_10).

$$\left|\varphi_{k,k+j} - j \cdot 6°KW\right| < 0{,}1°KW$$

For all k= 1,2,3,..
*for n-governor j=k*360°/(z*6°)*
for start-of-injection control j=k



5.2 Tolerance requirement for the system

The requirement for correct start-of-injection governing is a total of (geometric addition) < ± 1°crank for the maximum angular error to mechanical TDC. The tolerances are spread out, for example, over the following tolerance stack-ups:

Components	Tolerance	Responsibility
Evaluation circuit + Gate Array in control unit	± 0.15°crank	BOSCH
Inductive speed sensor DG6 (worst case)	± 0.50°crank	BOSCH
Sensor installation accuracy (shift from TDC)	± 0.25°crank	Customer
tone wheel installation accuracy (shift from TDC)	± 0.20°crank	shown are typical values
Tooth tolerance (spacing error, flanks)	± 0.10°crank	
Engine (e.g., crank tolerance)	± 0.70°crank	
geometric addition	< ± 1.00°crank	BOSCH/Customer

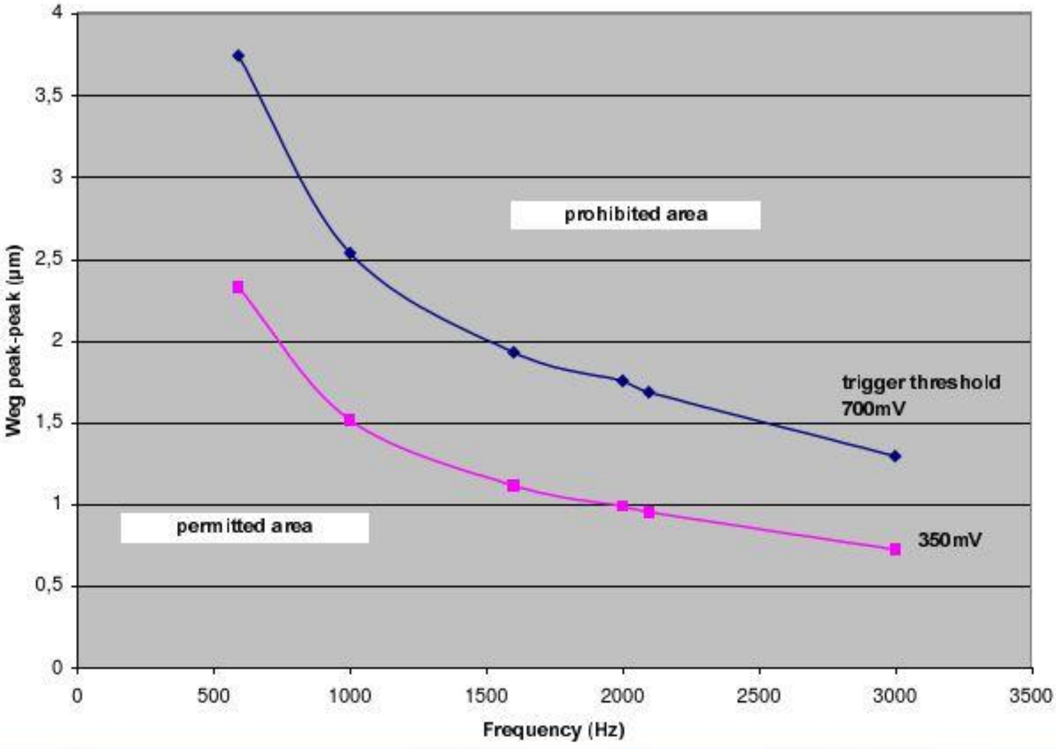
Remarks: With solenoid valve systems, the tolerances concerning the injector and the injector control must also be considered.

6 Mechanical installation of the rotational-speed sensor (DZG)

6.1 Installation location of the DZG

The DZG should not be installed in an position that is subject to large vibrations or oscillations, (e.g., at the free end of the crankshaft).
Relative vibrations between DZG and tone wheel (Addition of the vibration at DZG location and vibration of the tone wheel) must be avoided. If a relative oscillation occurs, then at small air gaps a output signal can be induced in the DZG, that exeeds the trigger threshold. This leads to a synchronization error. Therefor the tone wheel must be designed as rigid as possible.

Tests with a DG7 and an measuring tooth have shown, that at an air gap of LS=0.3mm a vibration of 1.5µm at 1kHz is enough to exceed the applicated trigger threshold of 700mV (see Figure_11).



For the DZG installation the following dimensions must be fulfilled (see Figure_12). Based on information available, this will guarantee that the DZG will function correctly. It is possible to have deviations from these dimensions (Measurements are necessary).

Gap between sensor and the ring gear
M1: ≥ 8 mm

Radius from the middle of the sensor head to the rotating screw heads, etc.
M2: ≥ 40 mm

Gap between sensor and protective cover, cap etc., (non-moving, good conductive parts)
M3: ≥ 3 mm
Holder material see 6.2

Gap between sensor - starter: > 150 mm (as large as possible!)

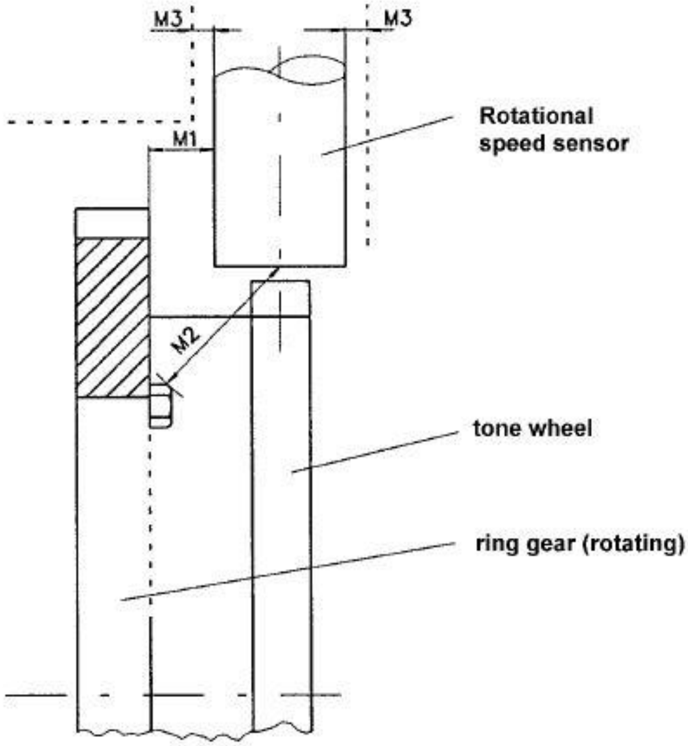


Figure_12: Installation location of DZG

6.2 Material of sensor holder

The magnetic conductivity of the DZG holder should be less than that of St 37 (relative permeability μ < 1900). Eddy-currents in the speed sensor holder can be prevented by using slots or by using material that is a poor conductor of electricity (electrical resistance > 0.3 Ω mm^2/m) .

6.3 Foreign magnetic fields

Allowable foreign magnetic fields with opposing field from all directions ≤ 2kA/m (2,5mT). How often and how long the DZG is exposed to the magnetic field has no effect.

The air gap is the distance from the DZG to the soft-magnetic material of the tone wheel. It is normally in the range of

0.5mm ≤ LS ≤ 1.5mm
for all eccentricities that occur

The air gap tolerance should be calculated from the customer based on the following elements:

- design:
  - static tolerance: DZG-length, sensor position, tone wheel (Radius tolerance), crankshaft (mounting tolerance, axial/radial clearance,...)
  - dynamic tolerance: tone wheel (runout, radial imbalance), crankshaft (eccentricity)

- running parameter:
  - dynamic parameter (clutch, vibration,..)
  - temperature (expansion, aging wear)

The air gap is defined based on the measurements described in 4.3 .

6.5 Installation location and tolerances for the speed sensor

Permitted tilt of the DZG with a radial installation (see Figure_05). The air gap range must be maintained.

Longitudinal tilt of DZG:	ALPHA	= 0°± 1°
Horizontal tilt of DZG:	BETA	= 0°± 5°

6.6 DZG cable

For this, the requirements mentioned in the Wiring Harness Guidelines K5/ESK2 Y 281 E22 013 have to be taken into account. (http://www.diesel.bosch.de/ou/fachapplikation/Application-Support/Appl-SupportEDC15.html.de). The wiring harness guidelines recommend that shielded, twisted lines are used for the rotational-speed sensor. The signal-to-noise ratio defined by the system development, has to be maintained.

The temperature profile at the cable must be measured to assure that the allowed temperatures for the used DZG cable are not exceeded. The cable must be assembled tension-free. For cables that have heavy mechanical stress, a protection tube corresponding to the DG6 modular design must be used.

7 Laying out the tone wheel

7.1 Material selection

For the tone wheel soft-magnetic and material with low remanence must be used. Machining steel, tempered steel, sintered material such as St 37, 9 SMn28, C45, GG-20, GGG-40 and X8Cr17 have been tested.

ses on the speed signal are always less than 33 % of the trigger threshold of the used evaluation circuit.

7.2.1 Corrosion protection

The surface treatment such as dipping process or galvanic treatment may not change the magnetic characteristics of the tone wheel. In addition, the correct adjustment of the air gap may not be impaired.

7.2.2 Manufacturing process

The manufacturing process is suitable if the required tolerances and tooth designs are fulfilled and if the mechanical stability is sufficiently guaranteed. For stamped-bended parts or "slight" (with small weight or small rigidity) some vibration can be critical. Open tone wheels (no edge) offer very little protection again teeth damage during handling and are not allowed.

Figure_13: Inadmissible tone wheel geometry
(m: displacement from the middle of the tooth,
p: pole core diameter)

7.3 Dimensions of sensor wheel and tooth geometry

7.3.1 General comments on the sensor wheels

Diameter

The tone wheel geometry is matched on the EDC system.

- 60-2 tone wheel: CR-system application at crankshaft
- z teeth tone wheel: distributor pump application at crankshaft
- z+1 teeth tone wheel: truck application at camshaft for limp-home function

The diameter (D_A) of the tone wheel is decisive for the output voltage. Depending on the application the following diameter are required (recommended):

	passenger car	commercial vehicle, truck
60-2 tone wheel (crank)	$D_A \geq 190$ mm	$D_A \geq 190$ mm
z teeth tone wheel (crank)	$D_A \geq 150$ mm	$D_A \geq 300$ mm
z+1 teeth tone wheel (cam)	-	$D_A \geq 100$ mm

If the minimal diameter is smaller than the recommended diameter the following problems can occur:

- cold start problem: The smaller the tone wheel, the lower is the output voltage. Only for small deviation from the recommended diameter it is possible to compensate the decrease of the output voltage by reducing the air gap. Consequence: the starting speed for the engine must be increased.
- Sensitive to disturbances: The trigger threshold must be set very low to make an engine start possible. Following this the distance to disturbance is reduced.
- Increase output (overshoots) after the reference mark at high speed until loss of tooth (corrective action: see 7.3.3)

Besides the smaller the tone wheel is, the harder is it to fulfill the geometry tolerances.

Thickness

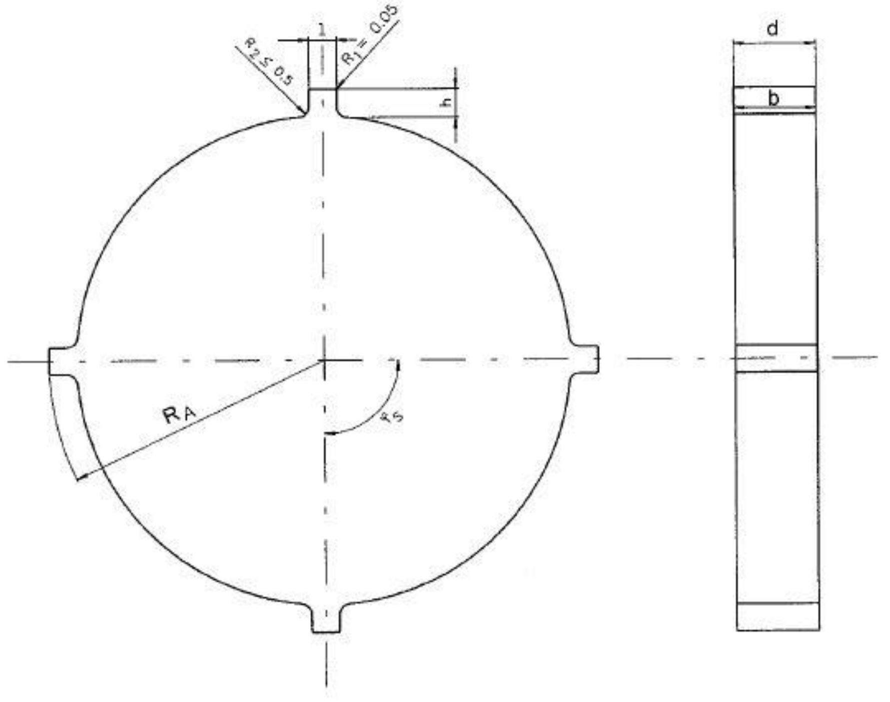
Tone wheel thickness **d ≥ pole core diameter p** of DZG (DG6, p=3.5mm)

Note:

The tone wheels for gasoline and diesel applications are different:

- the evaluation circuit are different. At K3 the trigger thresholds are symmetrical to zero crossing. Consequence: The tooth length depends at gasoline application on the wheel diameter. At diesel application the tooth length is fixed independent on the diameter.
- the accuracy requirements of the diesel engines are higher than the requirements of gasoline engines. Therefor is the tooth tolerance smaller and the signal gradient higher.

7.3.2 Tooth geometry and reference mark geometry at radial sensing



The radius R1, R2 and the angle of the tooth flank should be as small as possible. Reduced steepness of tooth flanks and large radius R1, R2 reduce the induced voltages and thus result in lower slope gradients when crossing zero.

R1 = 0,05 mm

R2 ≤ 0,5 mm

Figure_14: Tooth segment wheel with z teeth

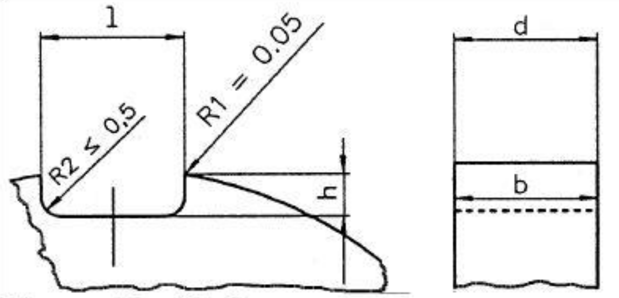
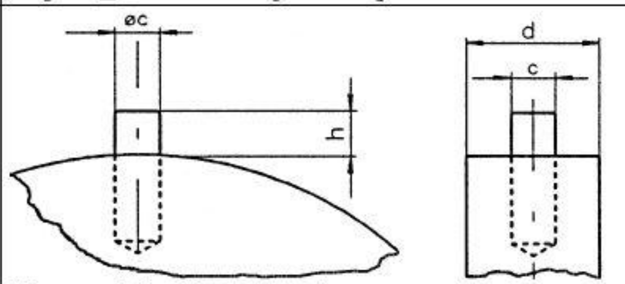
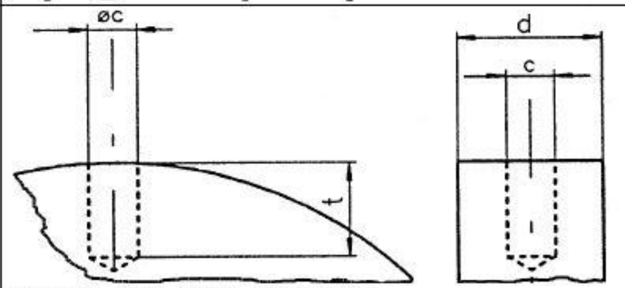
Formula: length (l) or diameter (c)= **k * p**

corrective factor (empirical determination) — pole core diameter

Width (tooth, notch) **b ≥ p** (b = wheel thickness d)

Height (tooth, pin) or depth (notch, hole) **h ≥ 5mm**

Note: If the DZG is set axially to the tone wheel then tooth width and height have to be exchanged.

Geome-try	k	l or c for DG6 (mm)	Figure
tooth	0.95...1.05	3.325...3.675	Figure_14
notch	1.8...2.4	6.3...8.4	 Figure_15: Notch geometry
pin	1.0...2.0	3.5...7.0	 Figure_16: Pin geometry
hole	1.8...2.4	6.3...8.4	 Figure_17: Hole geometry

If k becomes smaller, then this causes a lower effective signal. This must be compensated by reducing the air gap. If k becomes larger, this causes a flattening of the signal when crossing zero and thus decreases switching accuracy.

7.3.3 60-2 toothed sensor wheel (increment wheel)

For increment wheels (individual solenoid-valve controlled systems) the geometries in 7.3.2 are valid. In addition the following comments apply:

Abbr.	Designation	Nominal dimensions	Remarks / Tolerance
Z_Z	Number of teeth	60-2	Reference mark: 2 missing teeth
D_A $=2*R_A$	Tip circle diameter	$D_A = \frac{((k \cdot P)+C)\cdot 60}{\pi}$	Recommended for standard sensor wheel: D_A = 190mm
C	Spacing between impulse-giving geometries see Figure_18	tooth wheel: C_{min} = 4.5mm hole wheel: C_{min} = 3.5mm	recommended: $C_{toothwheel}$ >6.6mm A smaller C results in a lower useable signal. This must be compensated by decreasing the air gap.
$\varphi_{k,\ k+j}$	angle over any j teeth	6° * j < ± 0.1°	Very important for: - j=1 tooth spacing angle - j=60/number of cylinders (segment angle)

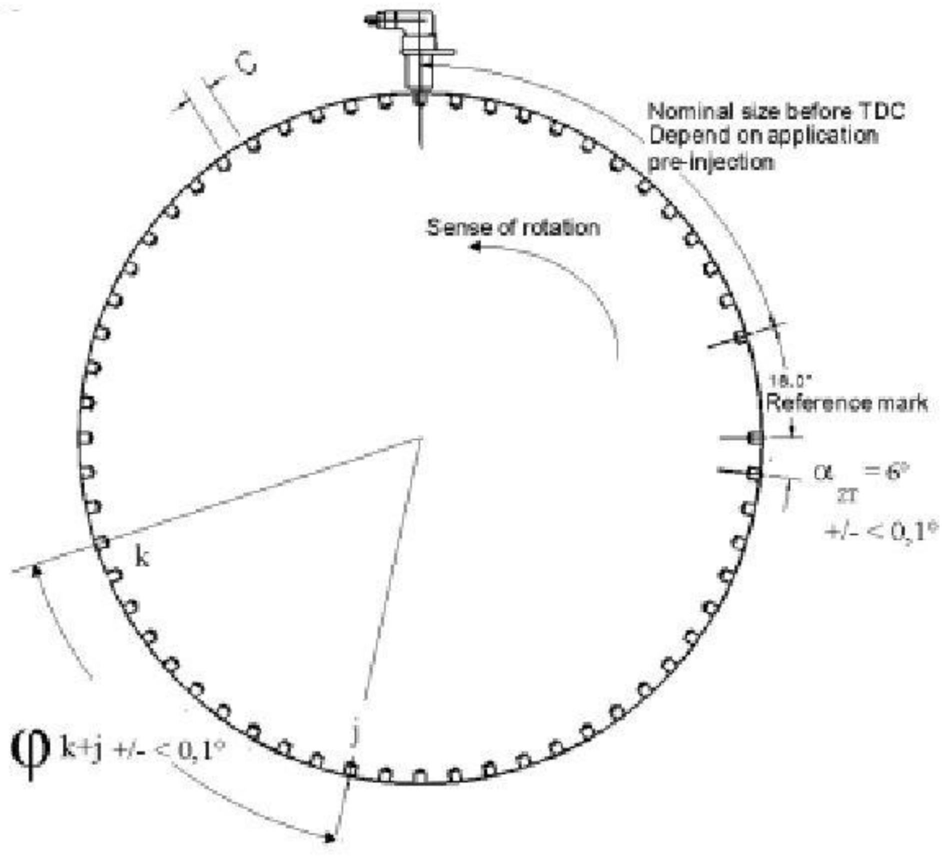


Figure_18: 60-2 tone wheel (e.g. holes)

Comments: The position of the sensor in dependance on gaps, segment teeth, and synchronization tooth has to be agreed with the respective software-department. Reference in each case is the middle of tooth, slot or notch. This is corresponding to the zero crossing signal (EDC reference).

Increase output voltage at the reference mark (Figure_07):
If the recommended geometry is not respected, the first tooth after the reference mark (voltage increase) could not attain a „crossing zero„. Then the following helps can be used:

- Using a higher load of DZG in the control unit, that means a lower parallel resistance value.
- Realize at tooth-type tone wheels a lower gap depth in the reference mark (e.g., by halving the depth of the gap).
- Decrease at hole-type tone wheels the diameter in the area of the reference mark (e.g., by halving the hight of the tooth).

The increase output voltage should not be upper 25% of the output voltage amplitude from the following tooth (particularly 2nd tooth after the reference mark) or preceding tooth (last tooth before the reference mark). It must be particularly considered for every speeds, for which the signal amplitude of the increase output is enough to switch to an higher trigger threshold.

7.3.4 Crankshaft wheels with z teeth, camshaft wheels with z+1 teeth

Number of teeth, pins, notches or holes z = 4, 5, 6, 8 (Number of cylinders)

Adjustment range of the tone wheel for control of beginning injection:
To define accurately the start-of-injection, it is important that shortly after the injection a segment tooth follows. The time between the signal of the needle travel sensor (NBF) and the next segment tooth is needed for controlling the of start-of-injection. A sensitive compromise between a safety margin and accuracy is between 5° to 10° crank. The precise position of the segment tooth has to be discussed with the Software Development.

Number of cylinder (z)	4,5,6	8
angular spacing (e)	15°	12°

Segment angle φ_s:
Distance between middle of tooth (hole, notch, pin) to middle of next tooth (see Figure_14)

$$\varphi_S = \frac{360°}{z} \pm 0.1°$$

tone wheel diameter	car	commercial vehicle
z teeth (crank)	$D_A \geq 150$ mm	$D_A \geq 300$ mm
z+1 teeth (cam)	–	$D_A \geq 100$ mm, the minimum voltage must be reached at the starter speed (worst case)

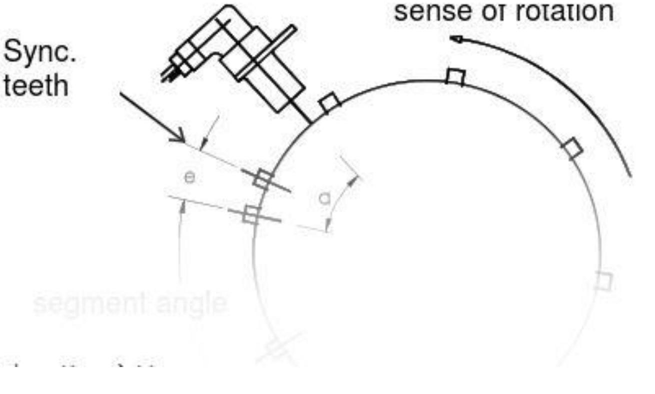


Figure_19: Camshaft wheel with synch. tooth

Camshaft sensor wheel for commercial vehicles (e.g.,