

7. SENZORI PROTOKA

Primena u sistemu upravljanja radom motora SUS

- Potrebna **količina goriva** predstavlja jednu od osnovnih regulisanih veličina u savremenim elektronskim sistemima upravljanja radom SUS motora.
- Određuje se na osnovu parametara samog motora i vrednosti raznih merljivih veličina stanja sistema upravljanja.
- Od posebne važnosti je ostvaren protok vazduha kroz SUS motor, koji je potrebno egzaktno odrediti.
- **Odnos masa vazduha i goriva** predstavlja osnovni faktor kvaliteta procesa sagorevanja, usled čega je neohodno precizno merenje količine usisanog vazduha.

7. SENZORI PROTOKA

- Maksimalan protok vazduha zavisi od zapremine motora i obično se nalazi u području od 400 do 1200 kg/h.

$$Q_{min} : Q_{max} = 1 : 100$$

$$\text{tačnost} = \pm 1 - 2 \%$$

- Merni uređaji koji mere protok zovu se **PROTOKOMERI** i razlikujemo:

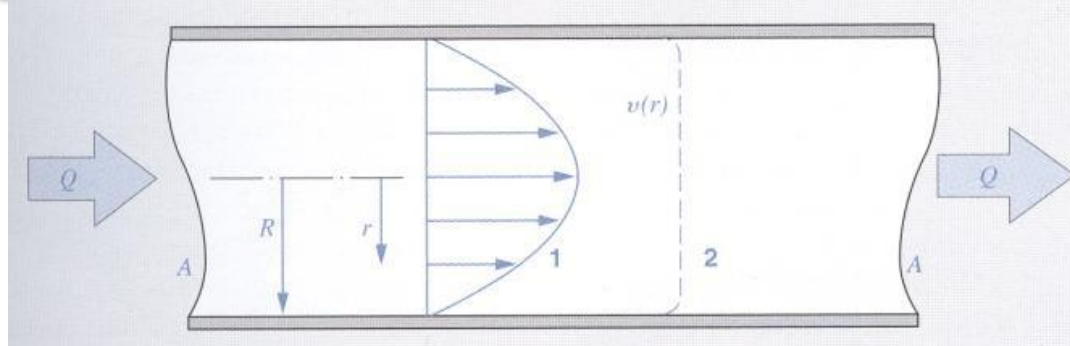
- **zapreminske** (VAF- *Vane Air Flow*)

- **masene** (MAF- *Mass Air Flow*)

$$Q_v = \frac{dV}{dt} [m^3 / s]$$

$$Q_m = \frac{dm}{dt} [kg / s]$$

Merni principi



- 1 Laminar flow profile
- 2 Turbulent flow profile
- A Cross-sectional area of the tube
- Q Flow
- R Tube radius
- r Distance from the tube center
- $v(r)$ Flow profile

$$Q_V = v \cdot A$$

$$Q_M = \rho \cdot v \cdot A$$

$$Re = v \cdot D / \eta$$

1 Pulsating air-mass flow Q_{LM} in the intake tract

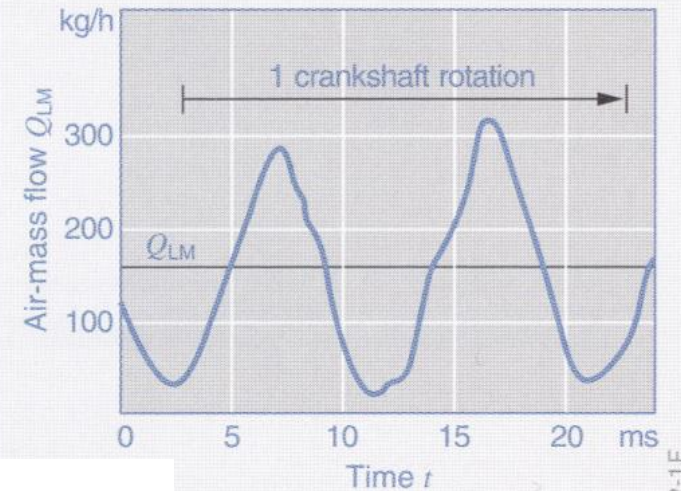


Fig. 1

At full load with engine speed $n = 3,000$ rpm, intake-manifold pressure $p_s = 0.96$ bar, mean air-flow rate $Q_{LMm} = 157.3$ kg/h

Merni principi

3 Impact-pressure flowmeter

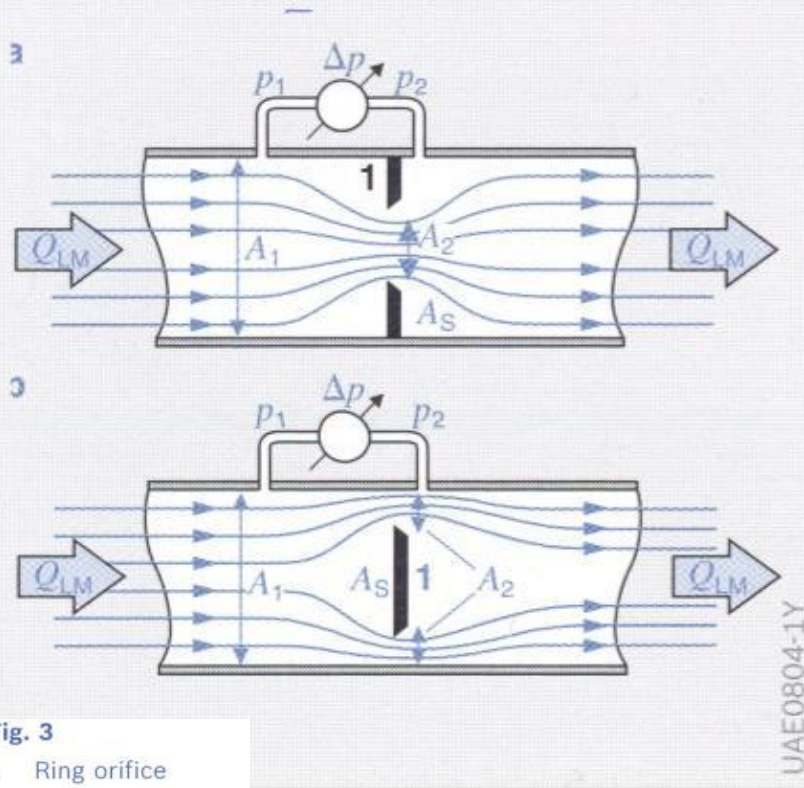


Fig. 3

- a Ring orifice
- b Sensor plate
- 1 Orifice plate
- A_S Disk cross-section
- $A_{1,2}$ Measuring cross-section
- $p_{1,2}$ Measured pressures
- Δp Pressure drop
- Q_{LM} Air-mass flow

- Merenje protoka kroz neku cev bazira se na dva osnovna zakona dinamike fluida:

- *Jednačina kontinuiteta* i

- *Bernulijeva jednačina*

- Pod pretpostavkom konstantne gustine $\rho = \rho_1 = \rho_2$ to rezultira padom pritiska Δp :
- Ovaj pad pritiska može se meriti bilo direktno senzorom diferencijalnog pritiska, ili pomoću sile koja deluje prema tzv. senzorskoj ploči.

$$\rho \cdot v_1 \cdot A_1 = \rho \cdot v_2 \cdot A_2 = \text{const}$$

$$p_1 + \frac{1}{2} \cdot \rho \cdot v_1^2 = p_2 + \frac{1}{2} \cdot \rho \cdot v_2^2 = \text{const}$$

$$\Delta p = Q_V^2 \cdot \rho \cdot \left(\frac{1}{A_2^2} - \frac{1}{A_1^2} \right)$$

$$Q_{St} = \text{const} \cdot \sqrt{\rho} \cdot v = \text{const} \cdot \sqrt{Q_V \cdot Q_M}$$

Protokomer sa "L"-klapnom

4 Impact-pressure air-mass meter

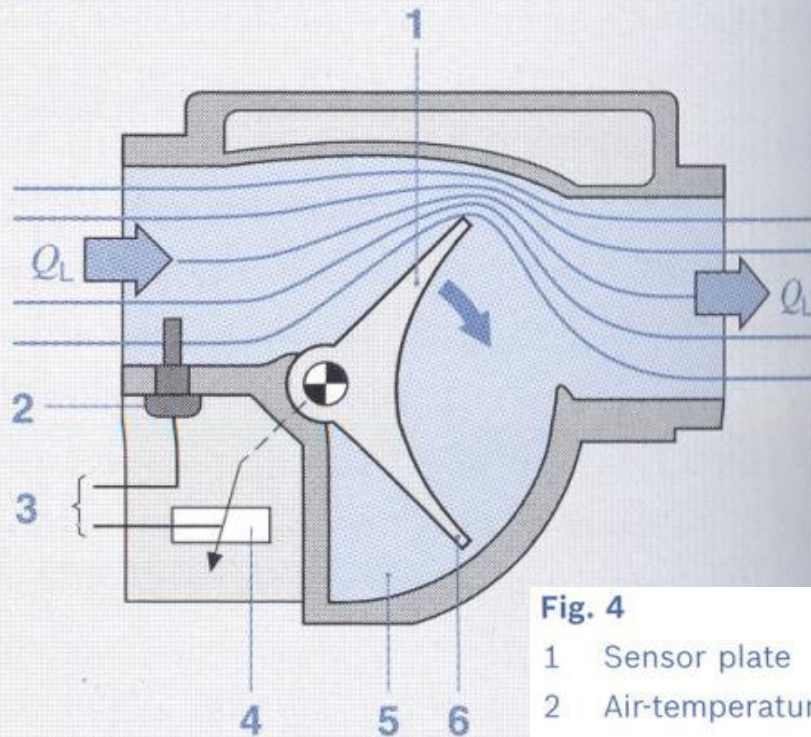


Fig. 4

- 1 Sensor plate
- 2 Air-temperature sensor
- 3 To control unit
- 4 Potentiometer
- 5 Damping chamber
- 6 Compensation flap
- Q_L Intake-air flow

- Spada u zapreminski (volumetrijski) tip protokomera.
- Obrtna merna ploča-klapna se zakreće pod uticajem protoka vazduha i preko osovinice povezana je sa klizačem potenciomera, koji generiše izlazni naponski signal.
- izlazni signal ima logaritamsku zavisnost u odnosu na količinu usisanog vazduha. Na taj način, u području malih protoka (prazan hod) dobijene su znatno veće inkrementalne promene izlaznog signala u odnosu na područje rada s velikim količinama protoka (gornje područje opterećenja motora).
- Veoma pouzdan protokomer.

Zapreminski protokomeri

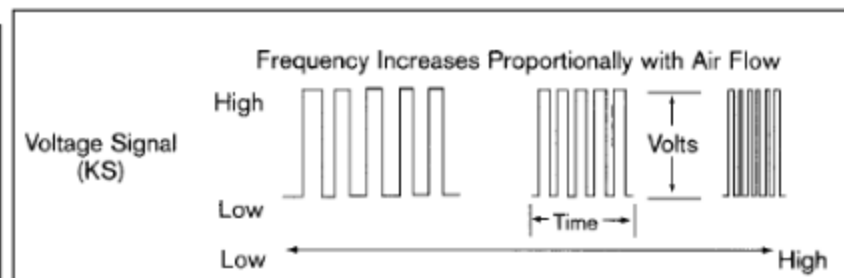
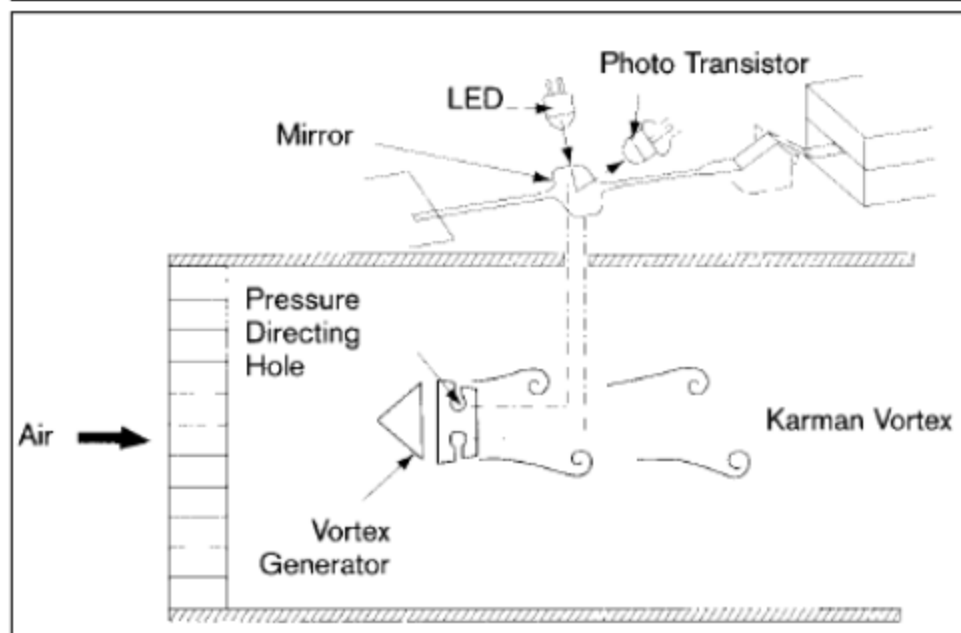
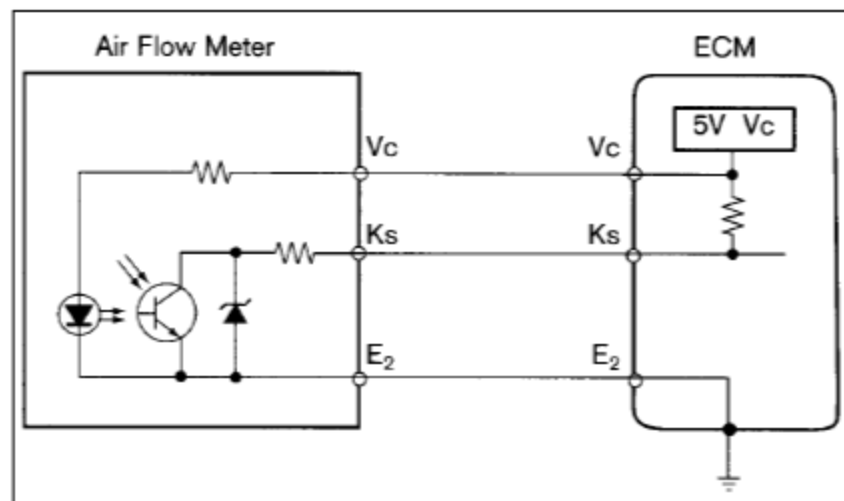
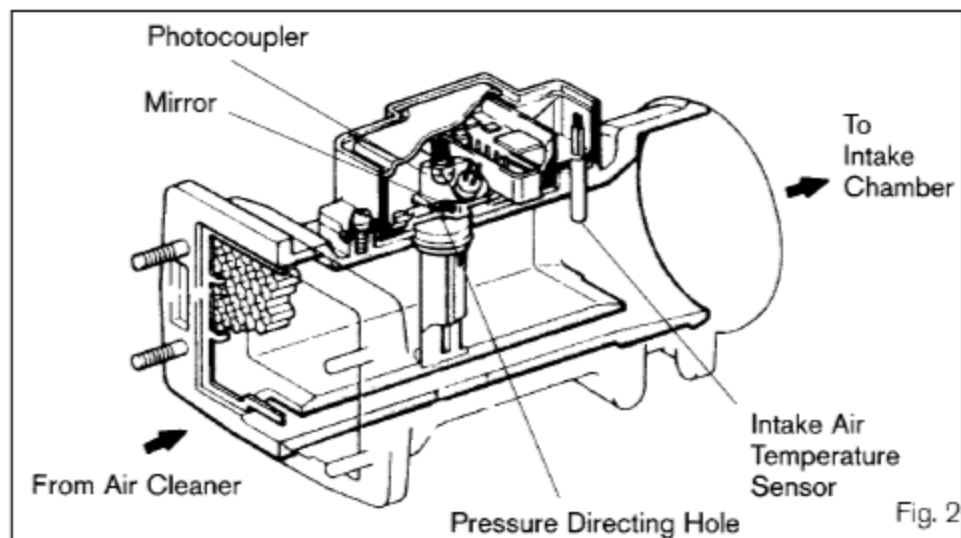
- **Princip merenja** zasniva se na tretiranju zapremine (volumena) supstance koja protiče kroz poprečni presek na osnovu merenja nekog parametra, koji je rezultat međusobnog delovanja toka fluida i tela postavljenog u tok.
- Jedan od zapreminskih principa merenja je ***Karman-Vorteksov*** princip.
- Ukoliko se pri laminarnom strujanju fluida u protočnoj cevi postavi izvesna prepreka, opstrujavanjem prepreke formiraju se vrtložna strujanja na određenom rastojanju iza prepreke, u smeru strujanja fluida.

Zapreminski protokomeri

- Frekvencija vrtložnih strujanja je direktno proporcionalna ostvarenom zapreminskom protoku, usled čega je posredstvom merenja diferencijalnog pritiska ili zvučnog talasa moguće odrediti periodičnost te promene, prema izrazu

$$f = 1/T \approx \text{const } Q_v$$

- Osnovni nedostatak ogleda se u činjenici da pulsacije vazduha mogu izazvati greške pri merenju !!!



Maseni protokomeri

- Princip rada masenih protokomera na vozilima zasniva se na ***kalorimetrijskom principu*** i realizuju se sa „užarenom žicom“ ili „užarenim filmom“.
- Ne sadrži pokretne mehaničke delove.
- Merenjem struje grejne žice (grejača) ostvaruje se izuzetna preciznost merenja mase usisanog vazduha.
- Upravljačko kolo sa povratnom spregom nalazi se u kućištu protokomera i održava konstantnu temperaturnu razliku između temperature tanke platinaste žice ($100\text{ }^{\circ}\text{C}$) ili otpornika u tehnici tankog filma ($75\text{ }^{\circ}\text{C}$) i temperature usisanog vazduha koji struji kroz protokomer.

Maseni protokomeri

- Ima visoku osetljivost, a zbog rešenja sa povratnom spregom, ovaj tip protokomera ima i dobre dinamičke karakteristike i uspešno prati promene protoka reda milisekunde (*ms*).
- Da bi se osigurale pouzdane karakteristike tokom eksploatacionog veka, nakon aktivnog rada, odnosno nakon svakog gašenja motora, sistem mora spaliti sve akumulirane nečistoće na površini vrele žice, što se ostvarje zagrevanjem žice na oko 1000 °C.
- **NEDOSTATAK:** ne može prepoznati povratna strujanja vazduha kao posledicu izraženih pulsacija u usisnoj grani, koje mogu uzrokovati određene merne greške (područje visokih opterećenja i broja obrtaja).

5 Hot-wire air-mass meter (circuit)

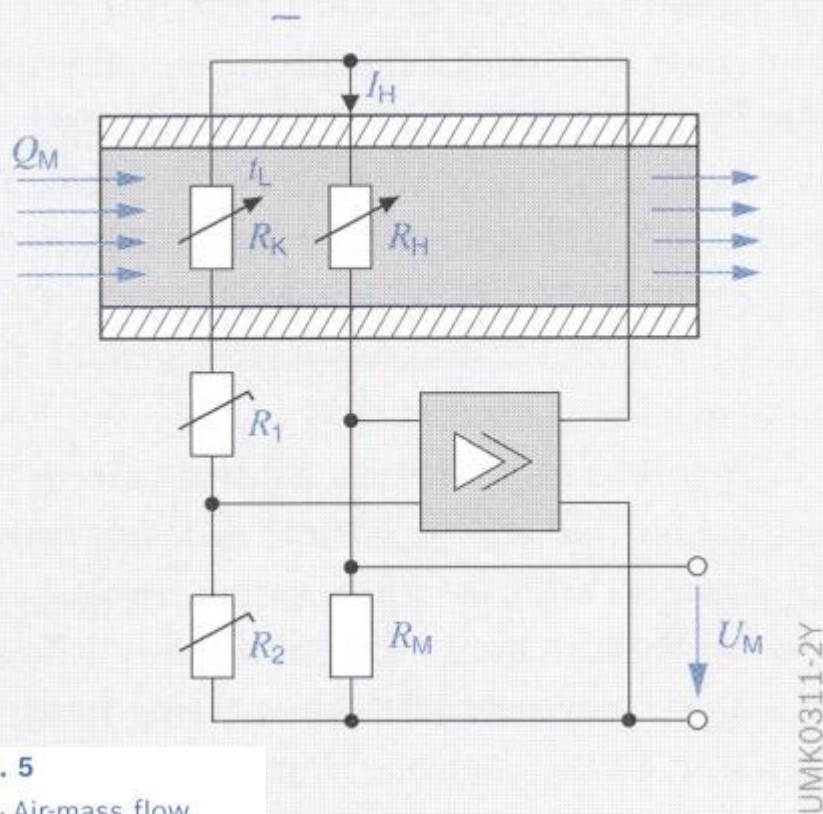


Fig. 5

Q_{LM} Air-mass flow

U_M Measurement voltage

R_H Hot-wire resistor

R_K Compensation resistor

R_M Measuring resistor

$R_{1,2}$ Calibration resistors

$$P_{el} = I_H^2 \cdot R = P_V = c_1 \cdot \lambda \cdot \Delta \vartheta$$

$$\lambda = \sqrt{\rho \cdot v} + c_2 = \sqrt{Q_{LM}} + c_2$$

$$I_H = c_1 \cdot \sqrt{(\sqrt{Q_{LM}} + c_2) \cdot \sqrt{\frac{\Delta \vartheta}{R}}}$$

6 Hot-wire air-mass meter (components)

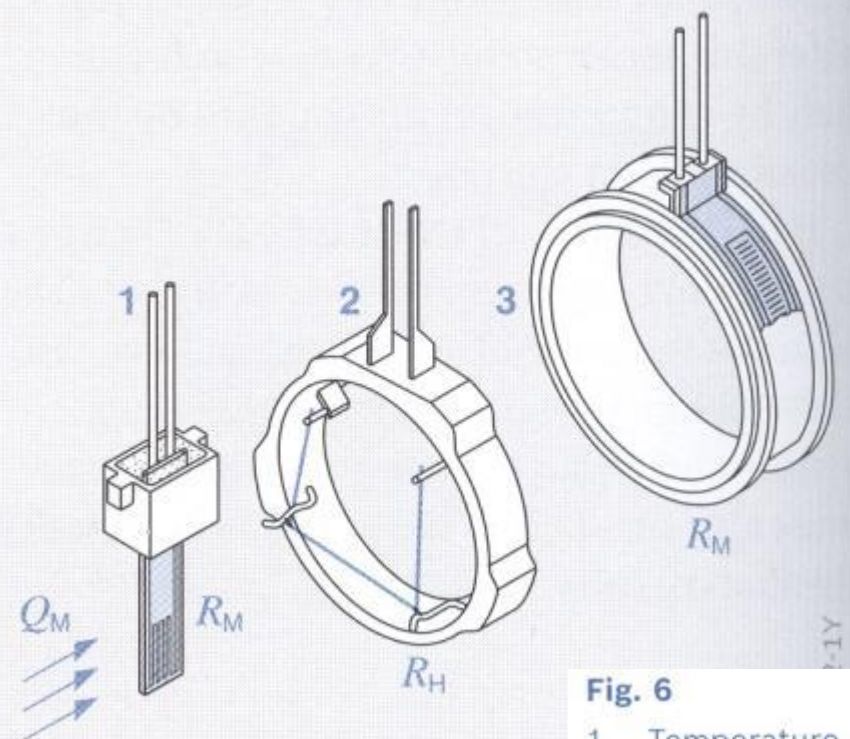


Fig. 6

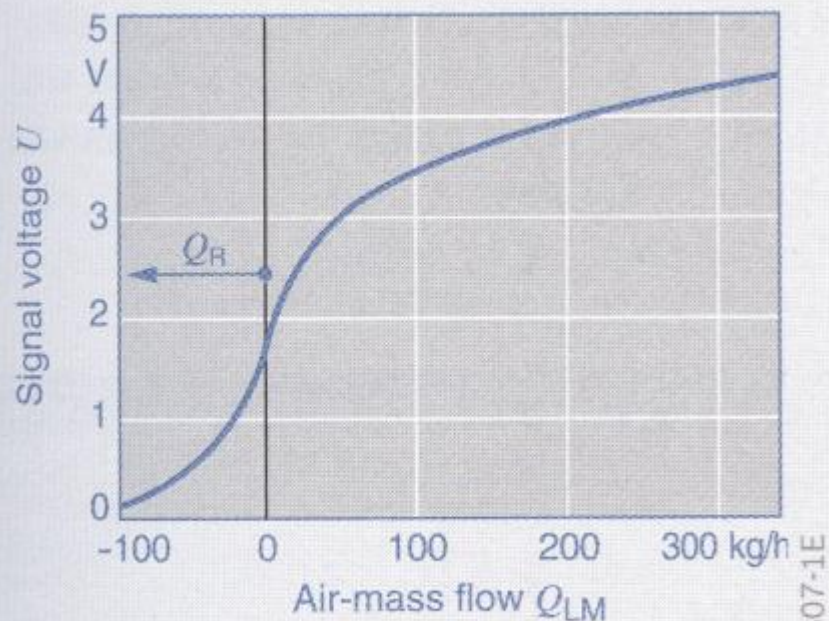
1 Temperature compensation resistor R_K

2 Sensor ring with hot wire R_H

3 Precision measuring resistor (R_M)

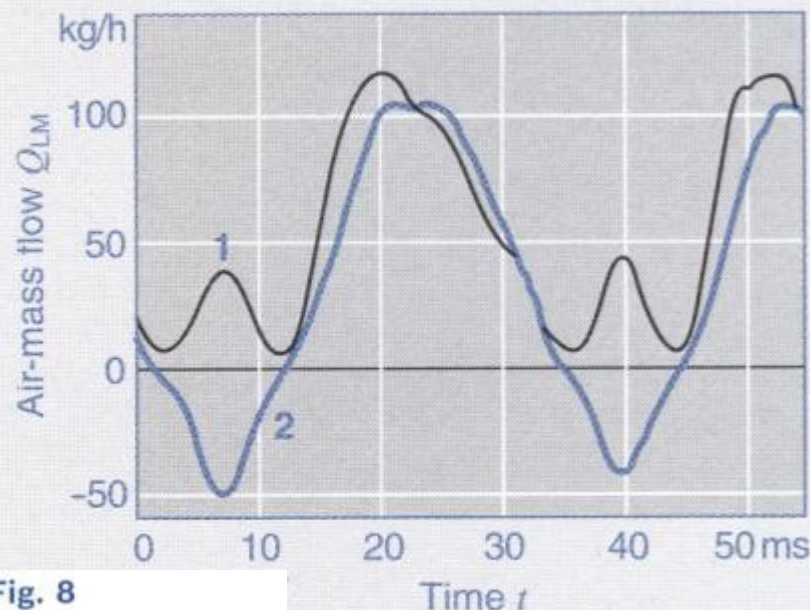
Q_M Air-mass flow

7 Micromechanical hot-film air-mass meter with air-quantity measurement in both directions



UAE0807-1E

8 Determination of the pulsating air-mass flow in a 4-cylinder engine



UAE0808-1E

Fig. 8

At full load and engine speed $n = 900$ rpm

- 1 Hot-wire air-mass meter
- 2 Hot-film air-mass meter

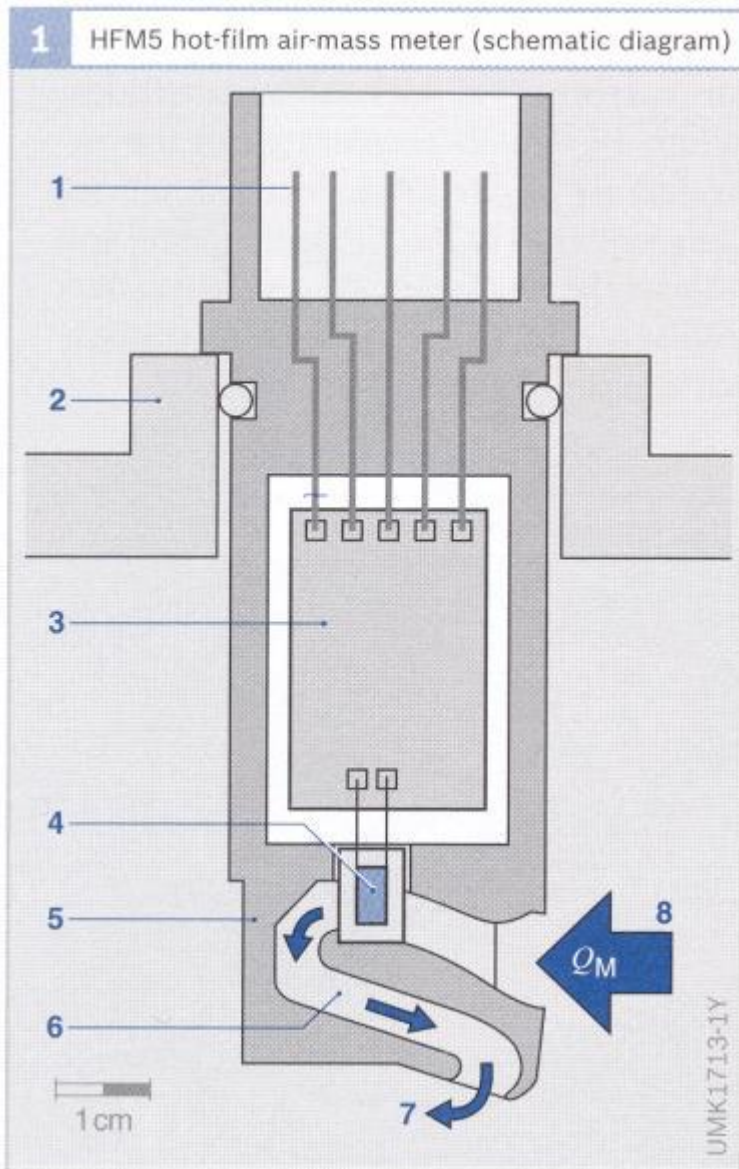
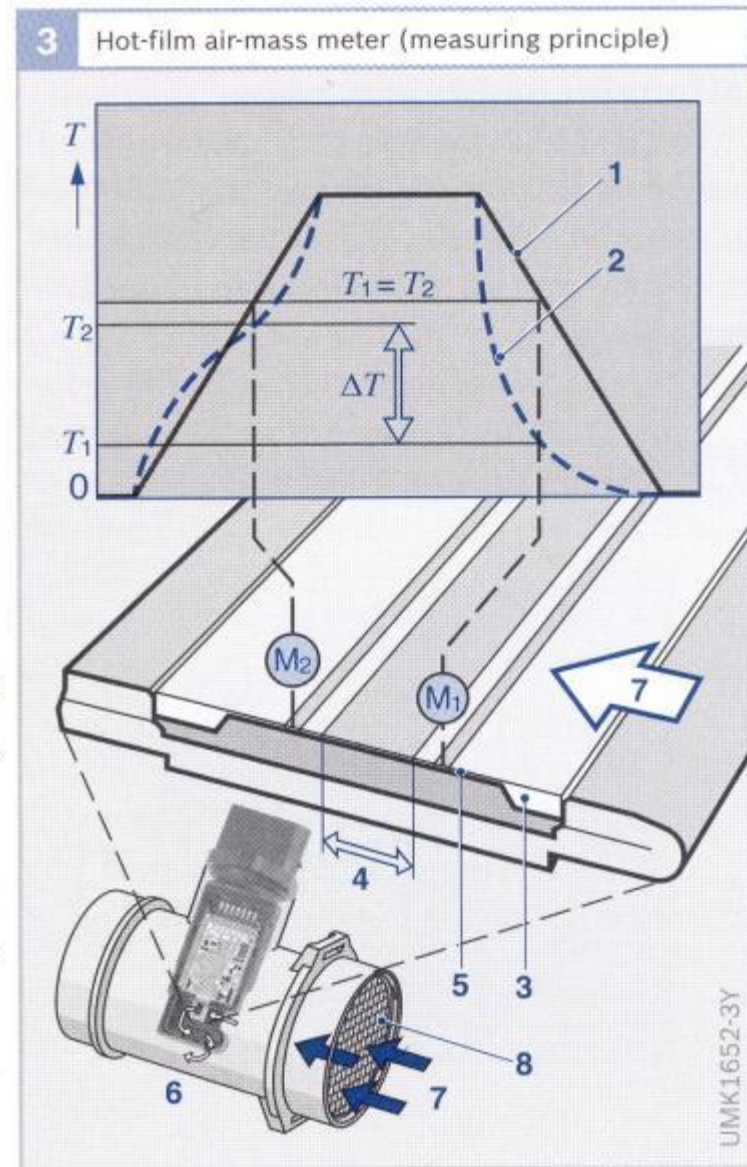


Fig. 1

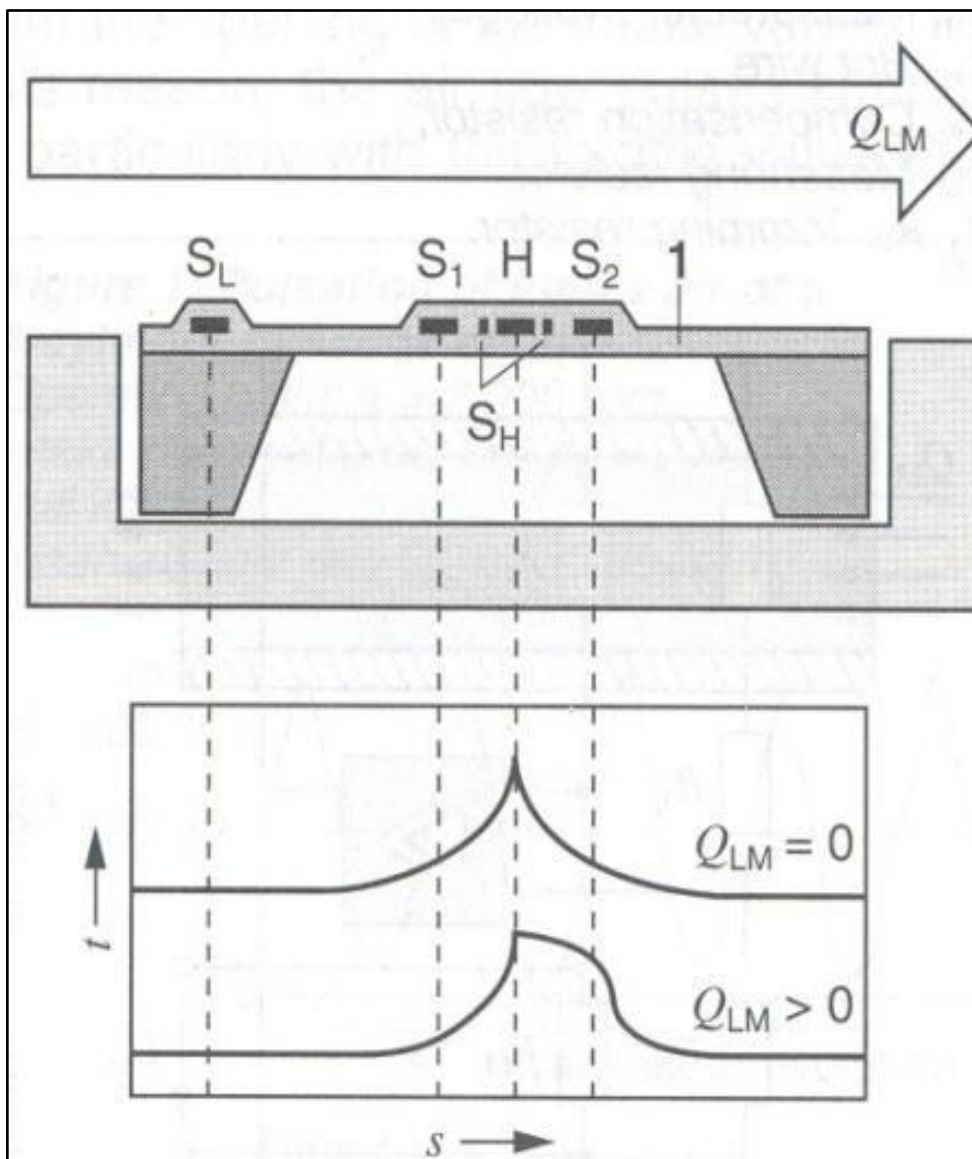
- 1 Electric connections (plug)
- 2 Measuring-tube or air-filter housing wall
- 3 Evaluation electronics (hybrid circuit)
- 4 Sensor measuring cell
- 5 Sensor housing
- 6 Partial-flow measuring passage
- 7 Outlet, partial air flow Q_M
- 8 Intake, partial air flow Q_M

Fig. 3

- 1 Temperature profile without air flow
- 2 Temperature profile with air flow
- 3 Measuring cell
- 4 Heating zone
- 5 Sensor diaphragm
- 6 Measuring tube with air-mass meter
- 7 Intake-air flow
- 8 Wire mesh
- M_1, M_2 Measuring points
- T_1, T_2 Temperature values at measuring points M_1 and M_2
- ΔT Temperature difference



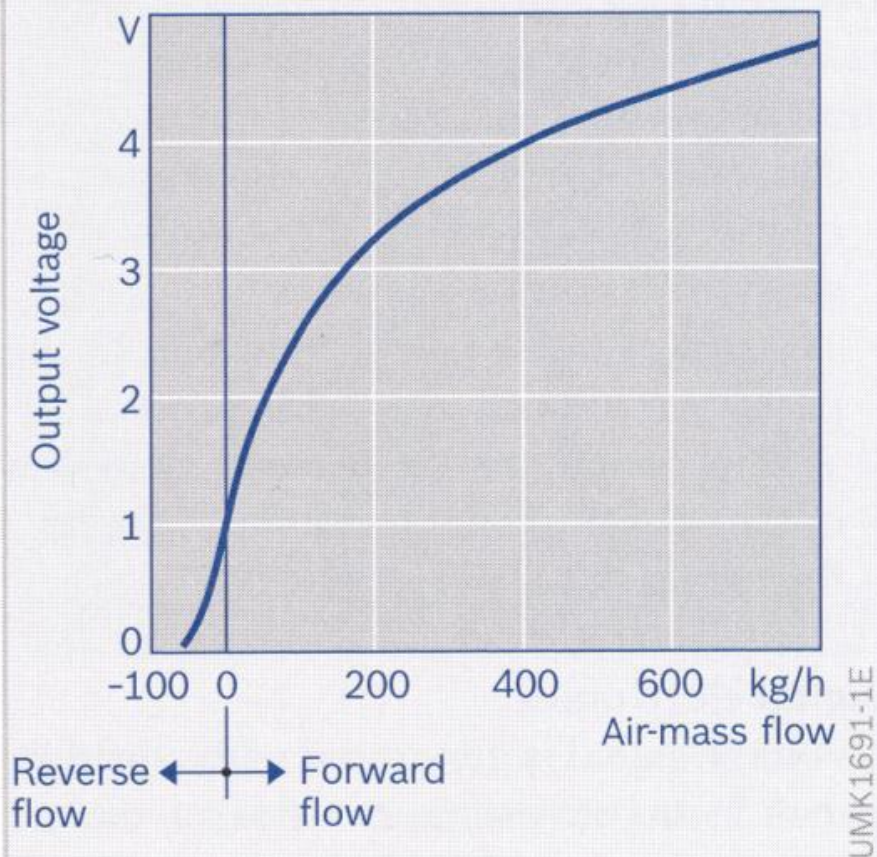
Mikromehanički maseni protokomer sa užarenim filmom



1 – dielektrična diafragma,
 H – grejni otpornik,
 S_H – senzor temperature grejača,
 S_L – senzor temperature vazduha,
 S_1, S_2 – senzori temperature (ispred i iza)
 Q_M – protok vazduha,
 s – merna tačka,
 t – temperatura

- Izlazni signal se izvodi na osnovu razlike temperatura vazduha izmerene između dva senzora temperature S_1 i S_2 .
- karakteristika senzora protoka (kao i kod prethodnih rešenja) ostaje nelinearna, ali činjenica da početna vrednost pokazuje smer strujanja predstavlja poboljšanje u odnosu na prethodno rešenje sa merenjem struje užarene platinaste žice.

2 Hot-film air-mass meter (characteristic curve)



4 HFM6 with improved contamination protection

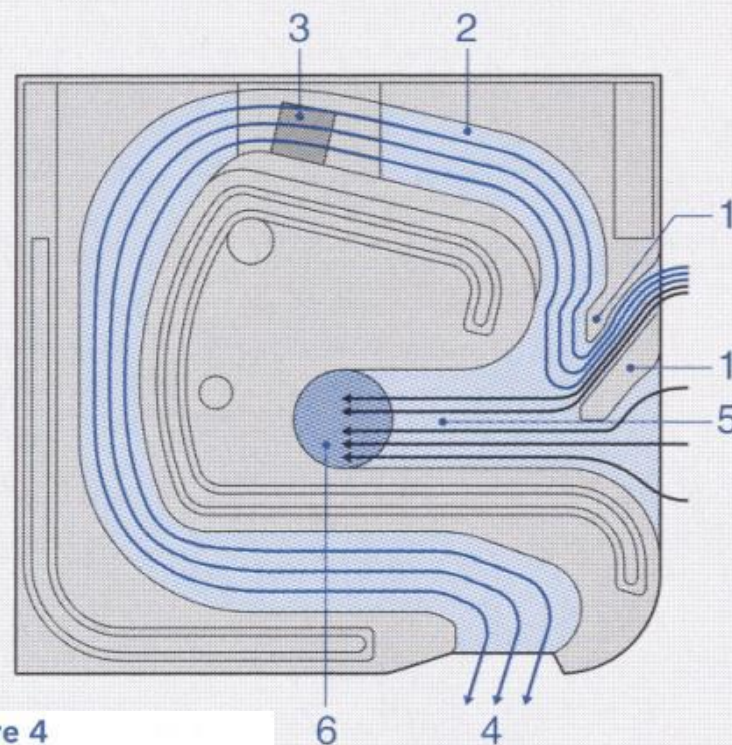
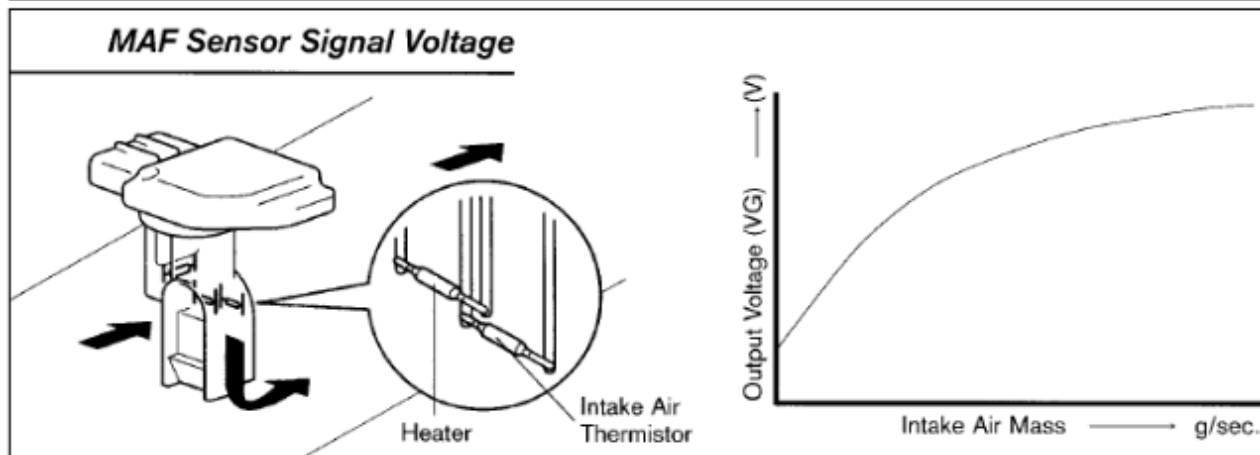
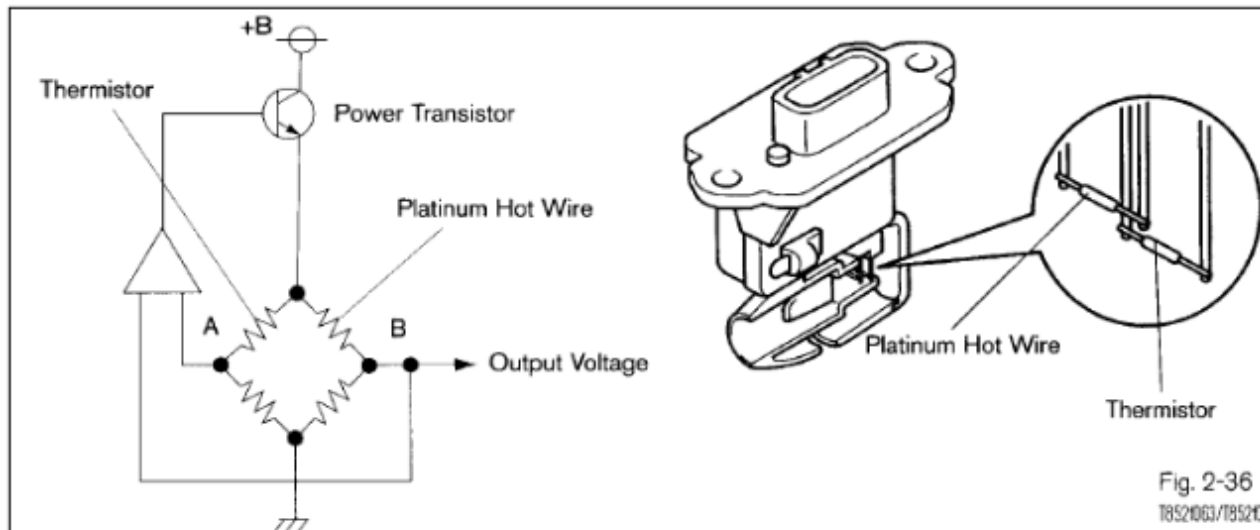
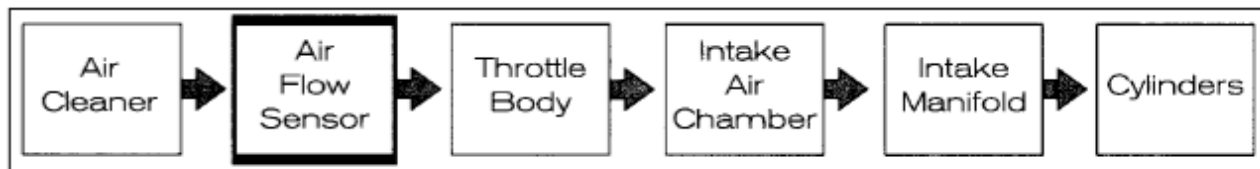


Figure 4

- 1 Diverting edge
- 2 Partial-flow measuring passage (first duct)
- 3 Sensor element
- 4 Air outlet
- 5 Second passage
- 6 Particulate and water outlet

Primeri senzora protoka na motornim vozilima



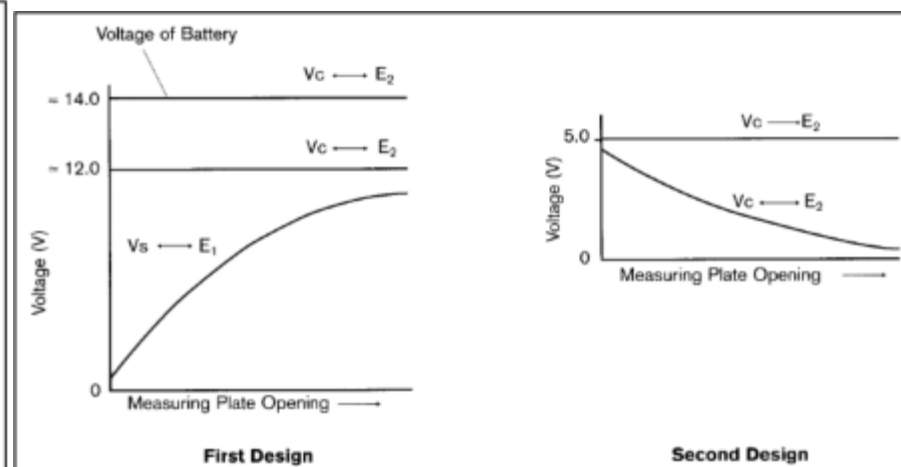
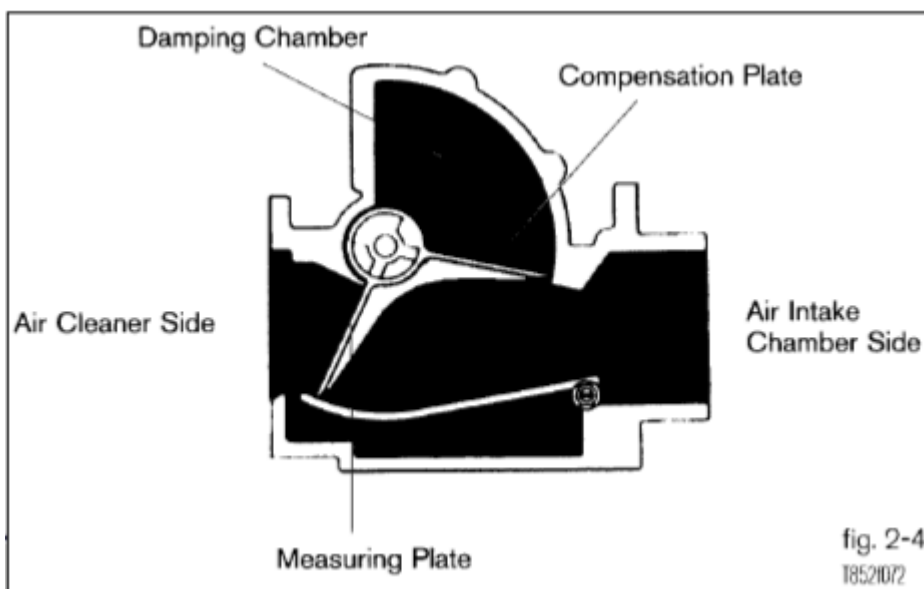
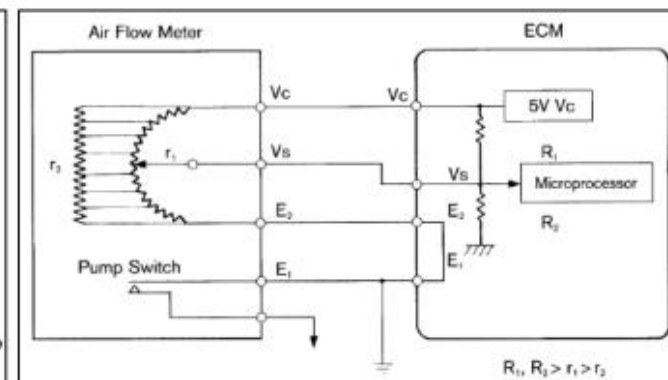
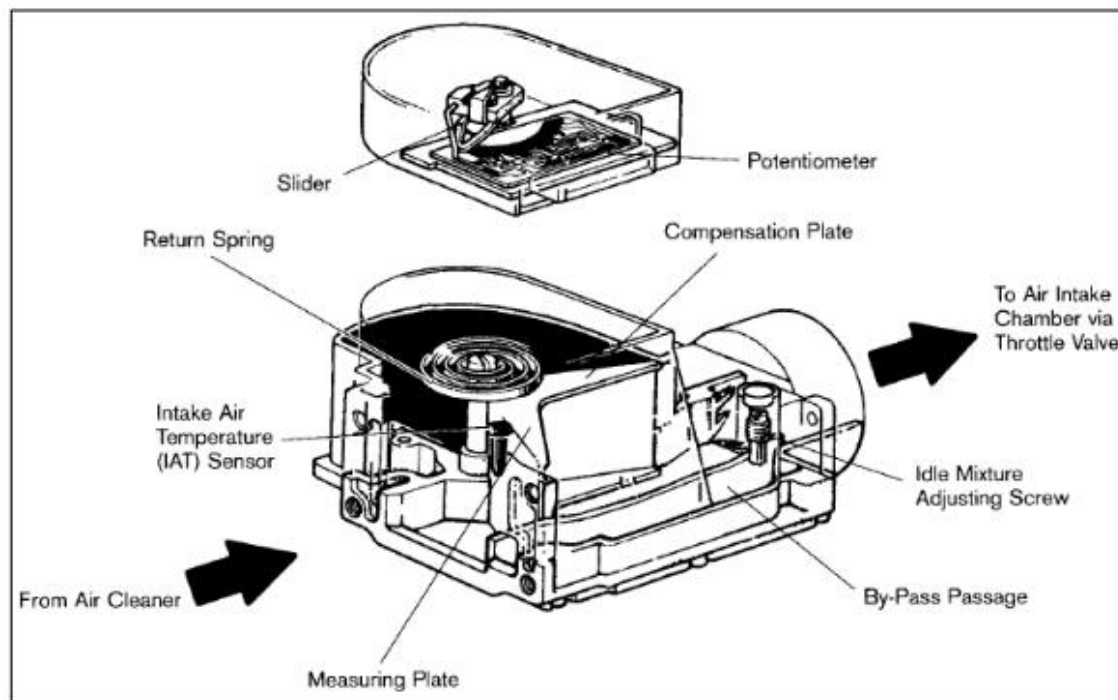


fig. 2-4
18521072

Hot-film air-mass meter, type HFM 2

Measurement of air-mass throughflow up to 1080 kg/h

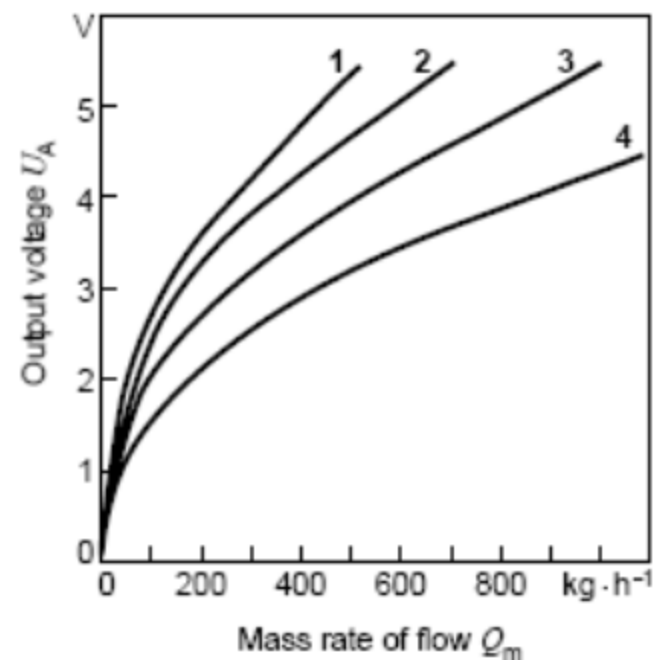
Technical data / Range

Part number		0 280 217 102	0 280 217 120 0 280 217 107	0 280 217 519	0 280 217 801
Characteristic curve		1	2	3	4
Installation length L	mm	130	130 96	130	130
Air-flow measuring range	kg · h ⁻¹	10...350	10...480	12...640	20... 1080
Accuracy referred to measured value	%	±4	±4	±4	±4
Supply voltage	V	14	14	14	14
Input current					
at 0 kg · h ⁻¹	A	≤ 0,25	≤ 0,25	≤ 0,25	≤ 0,25
at $Q_{m \text{ nom}}$	A	≤ 0,8	≤ 0,8	≤ 0,8	≤ 0,8
Time constant ¹⁾	ms	≤20	≤20	≤20	≤20
Temperature range					
Sustained	°C	-30...+110	-30...+110	-30...+110	-30...+110
Short-term	°C	-40...+125	-40...+125	-40...+125	-40...+125
Pressure drop at nominal air mass	hPa				
max.	mbar	<15	<15	<15	<15
Vibration acceleration					
max.	m · s ⁻²	150	150	150	150

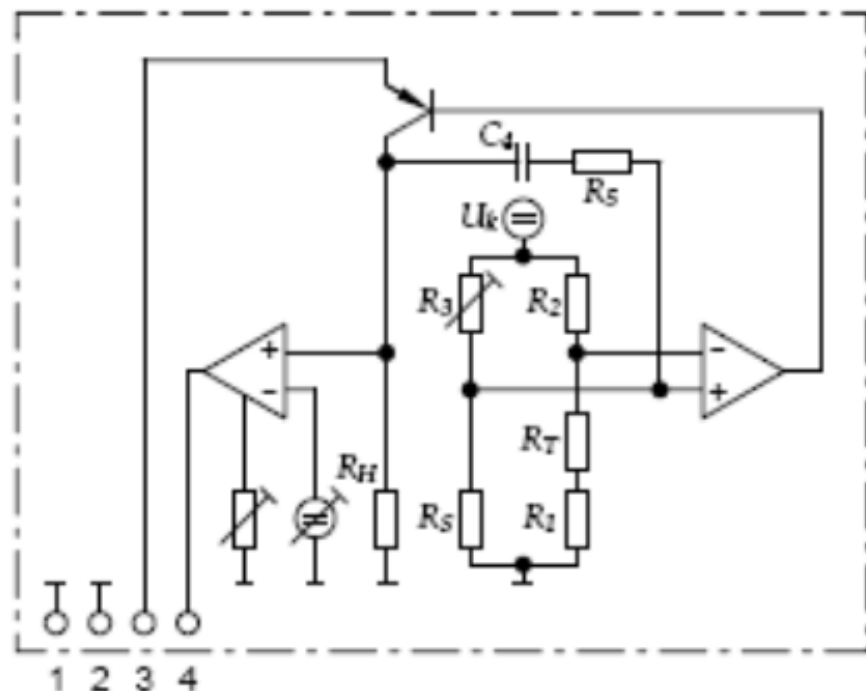
¹⁾ In case of sudden increase of the air-mass flow from 10 kg · h⁻¹ auf 0.7 $Q_{m \text{ nominal}}$, time required to reach 63% of the final value of the air-mass signal.



Characteristic curves.



Operating principle.



R_1 Trimmer resistor
 R_2, R_3 Auxiliary resistors
 R_5, C_4 RC element
 R_H Heater resistor
 R_S Platinum metal-film resistor
 R_T Resistance of the air-temperature-sensor resistor
 U_K Bridge supply voltage
 U_A Output voltage
 U_V Supply voltage

Pin 1 Ground
 Pin 2 $U_A(-)$
 Pin 3 U_V
 Pin 4 $U_A(+)$

Hot-film air-mass meter, type HFM 5

Measurement of air-mass flow up to 1200 kg/h

Technical data

Rated supply voltage	U_N	14V
Supply-voltage range	U_V	8 ... 17 V
Accuracy	$\Delta \dot{m} / \dot{m}$	$\leq 3 \%$
Pressure drop at $\dot{m}_N^1)$	Δp	$< 15 \text{ hPa}$
Output voltage	U_A	0 ... 5 V
Current input	I_V	$< 0,1 \text{ A}$
Permissible vibration acceleration	a_v	$\leq 150 \text{ m/s}^2$
Time constant $\tau_{63}^{2)}$		$\leq 15 \text{ ms}$
Time constant $\tau_{\Delta}^{3)}$		$\leq 30 \text{ ms}$
Temperature range ⁴⁾		-40 ... + 120 °C

1) Measured between input and output.

2) Time required for step response of output voltage to 63 % of final value given an abrupt change in air mass from 10 kg/h to 310 kg/h.

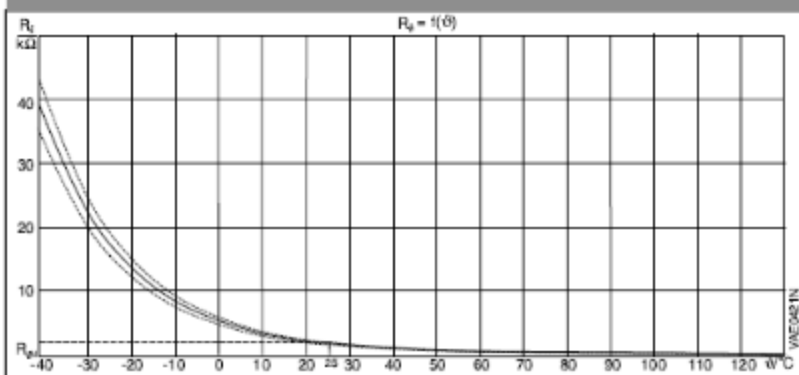
3) Delay on switch-on and after any change in flow rate until the output voltage has attained the relative measurement deviation $|\Delta \dot{m} / \dot{m}| \leq 5 \%$.

4) Up to 130 °C for brief periods ($\leq 3 \text{ min.}$).

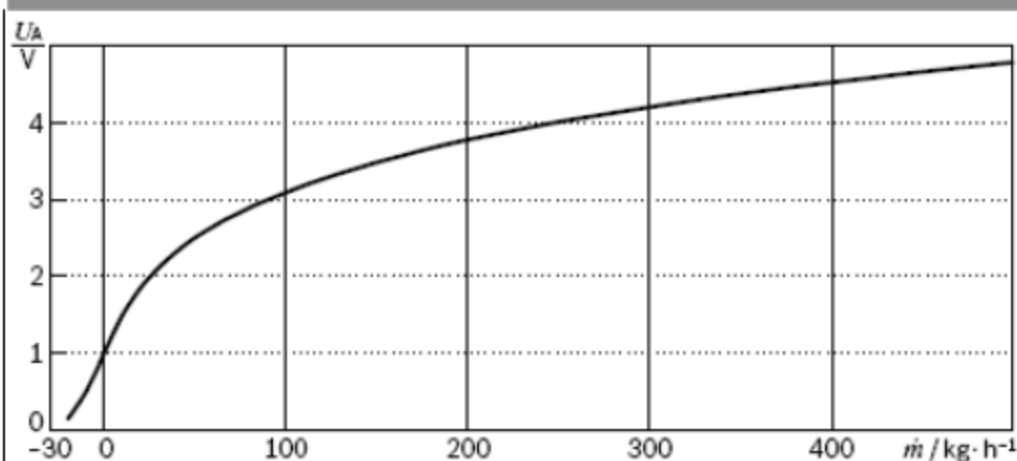


$\dot{m}_N$	Air mass throughput
$\Delta \dot{m}$	Absolute accuracy
$\Delta \dot{m} / \dot{m}$	Relative accuracy
τ_{Δ}	Time until measurement error $< 5 \%$
τ_{63}	Time for 63 % measured value change

Resistance profile of temperature sensor

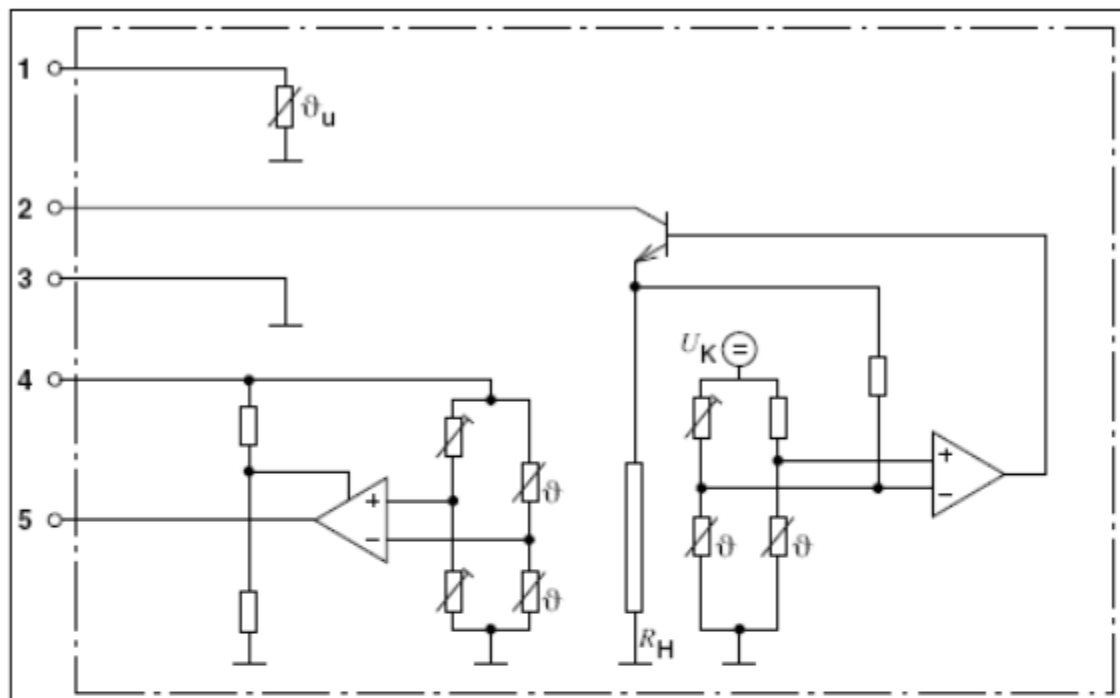


Air-mass characteristic curve at ambient temperature

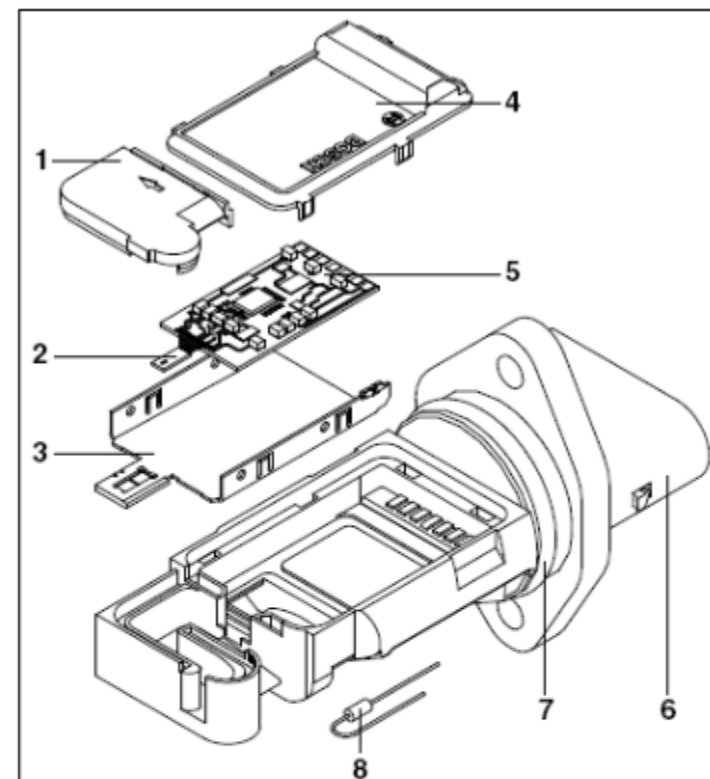


0 280 218 119 $\dot{m}_N$ -15 ... 480 kg/h

SENZORI I AKTUATORI



- 1 Additional temperature sensor ϑ_u
- 2 Supply voltage U_V
- 3 Signal ground
- 4 Reference voltage 5 V
- 5 Measurement signal U_A .
- ϑ Temperature-sensitivity of resistor
- R_H Heating resistor
- U_K Constant voltage



- 1 Measurement-channel cover
- 2 Sensor
- 3 Mounting plate
- 4 Hybrid cover
- 5 Hybrid
- 6 Plug-in sensor
- 7 O-ring
- 8 Additional temperature sensor

0 280 218 113	$\dot{m}_N$	10 ... 480 kg/h
0 280 218 087	$\dot{m}_N$	-30 ... 850 kg/h
0 280 218 089	$\dot{m}_N$	-50 ... 1100 kg/h

Hot-film air-mass meter, type HFM 6

Measurement of air-mass flow up to 800 kg/h

Technical data

Rated supply voltage	U_N	14V
Supply-voltage range	U_V	7,5 ... 17 V
Relative accuracy ¹⁾	$\Delta \dot{m}/\dot{m}$	$\pm 2\%$
Temperature range ²⁾		-40 ... 120 °C
Pressure drop at $\dot{m}_N$	Δp	< 18 hPa
Current input	I_V	< 0,06 A
Vibration acceleration	a_v	$\leq 180 \text{ m/s}^2$
Time constant τ_{63} ³⁾		$\leq 10 \text{ ms}$
Time constant τ_{Δ} ⁴⁾		$\leq 30 \text{ ms}$

¹⁾ For $0,04 \leq \dot{m}/\dot{m}_N \leq 1,3$

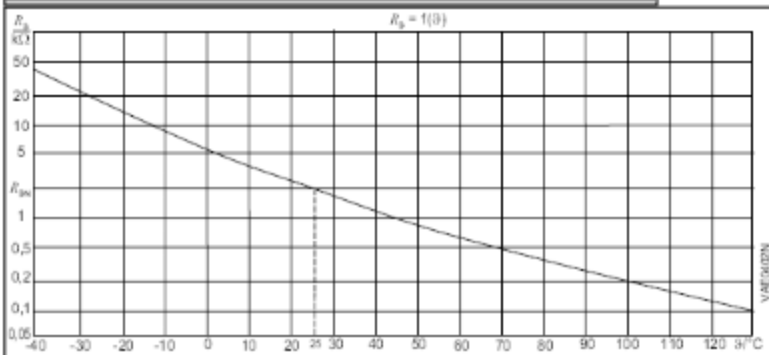
²⁾ up to 130 °C for brief periods ($\leq 3 \text{ min.}$)

³⁾ Time required for step response of output voltage to 63% of final value given an abrupt change in air mass from 10 kg/h to 310 kg/h.

⁴⁾ Delay on switch-on and after any change in flow rate until the output voltage has attained the relative measurement deviation $|\Delta \dot{m}/\dot{m}| \leq 5\%$



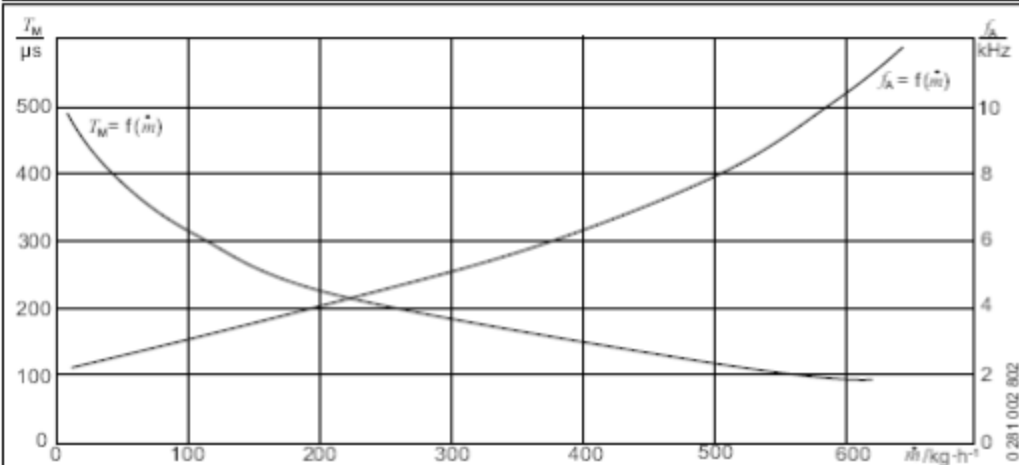
Resistance of temperature sensor



0 281 002 764 $\dot{m}_N$ -60 ... 800 kg/h

0 280 218 176 $\dot{m}_N$ -40 ... 620 kg/h

Air-mass characteristic curve at ambient temperature



0 281 002 802 $\dot{m}_N$ -40 ... 620 kg/h