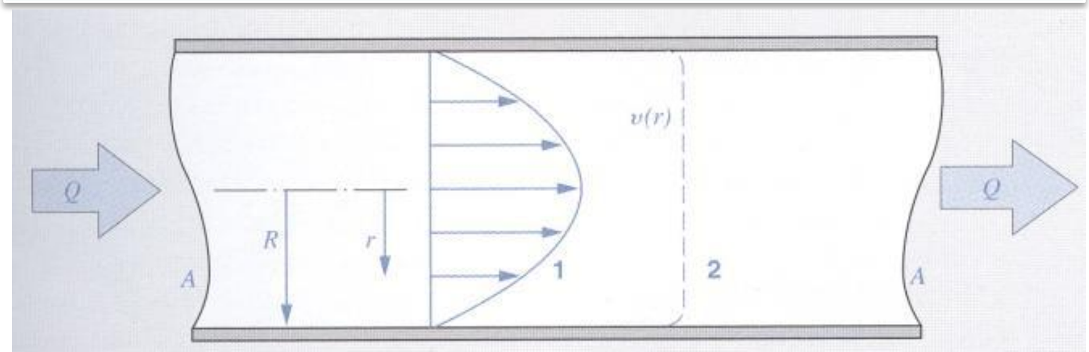
# 7. SENZORI PROTOKA

## 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 izmeriti.
- Odnos masa vazduha i goriva predstavlja osnovni faktor kvaliteta procesa sagorevanja, usled čega je neohodno precizno merenje količine usisanog vazduha.
- Maksimalan protok vazduha zavisi od zapremine motora i obično se nalazi u području od 400 do 1200 kg/h.
- Merni uređaji koji mere protok zovu se **PROTOKOMERI** i razlikujemo:
  - **zapreminske** (VAF- *Vane Air Flow*) $Q_V = \frac{dV}{dt} \; [m^3/s]$
  - **masene** (MAF- *Mass Air Flow*) $Q_m = \frac{dm}{dt} \; [kg/s]$

## 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

$$Q_V = v \cdot A$$

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

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

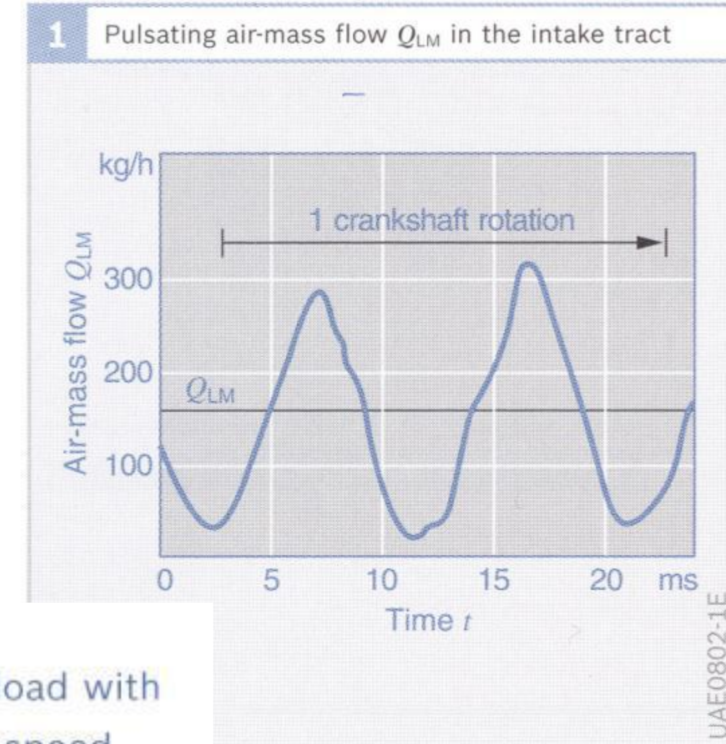



**Fig. 1**
At full load with engine speed $n$ = 3,000 rpm, intake-manifold pressure $p_S$ = 0.96 bar, mean air-flow rate $Q_{LMm}$ = 157.3 kg/h

## Merni principi

**3** Impact-pressure flowmeter

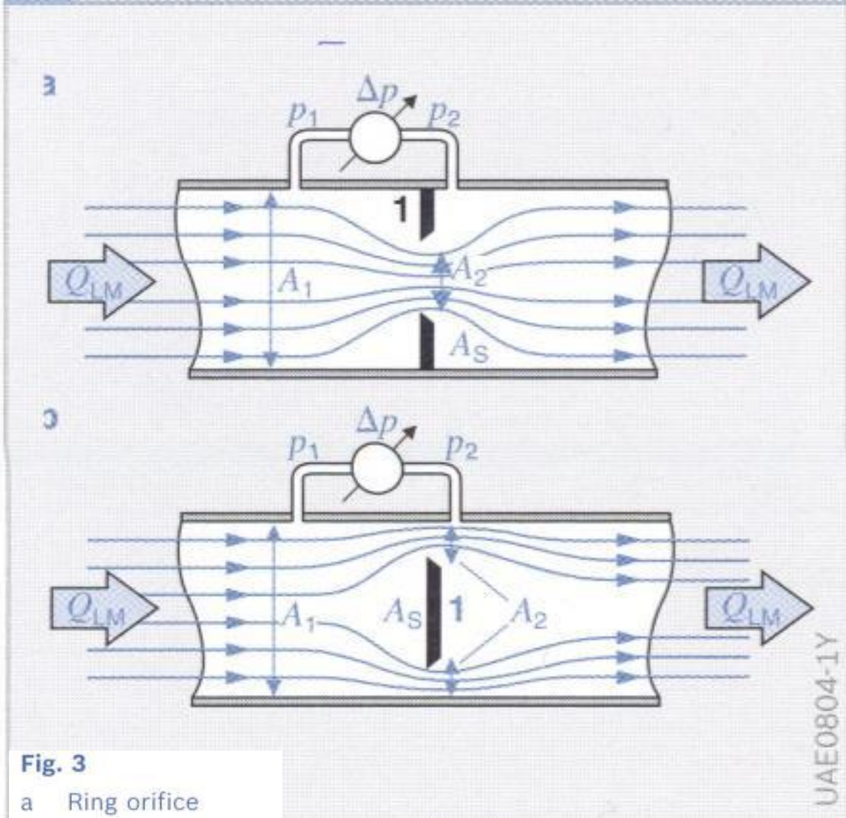



**Fig. 3**
a Ring orifice
b Sensor plate
1 Orifice plate
$A_S$ Disk cross-section
$A_{1,2}$ Measuring cross-section
$p_{1,2}$ Measured pressures
$\Delta p$ Pressure drop
$Q_{LM}$ Air-mass flow

- 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 $\Delta p$:
- Ovaj pad pritiska može se meriti bilo direktno senzorom diferencijalnog pritiska, ili pomoću sile koja deluje prema tzv. senzorskoj ploči.

$$\rho_1 \cdot v_1 \cdot A_1 = \rho_2 \cdot v_2 \cdot A_2 = const$$

$$p_1 + \frac{1}{2} \cdot \rho_1 \cdot v_1^2 = p_2 + \frac{1}{2} \cdot \rho_2 \cdot v_2^2 = const$$

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

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

## Protokomer sa “L”-klapnom

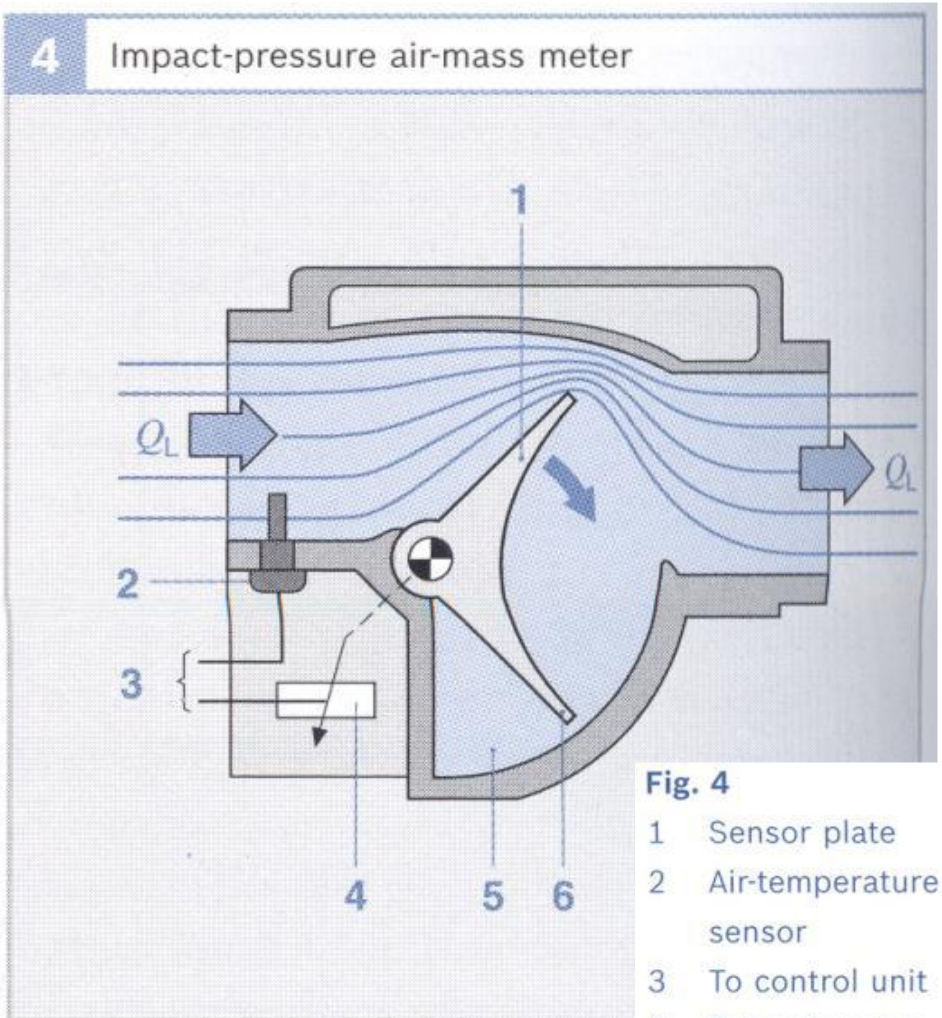



**Fig. 4**

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

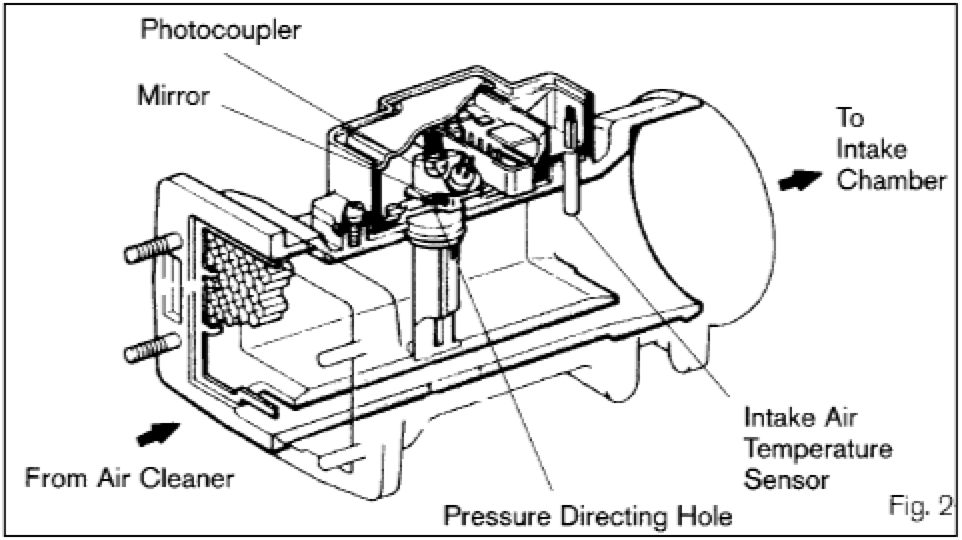
- Spada u zapreminski tip protokomera.
- Obrtna merna ploča-klapna se zakreće pod uticajem protoka vazduha i preko osovinice povezana je sa klizačem potenciomera, koji generiše izlazni naponski signal.
- izlazni signal ima logaritamsku zavisnost u odnosu na količinu usisanog vazduha. Na taj način, u 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.

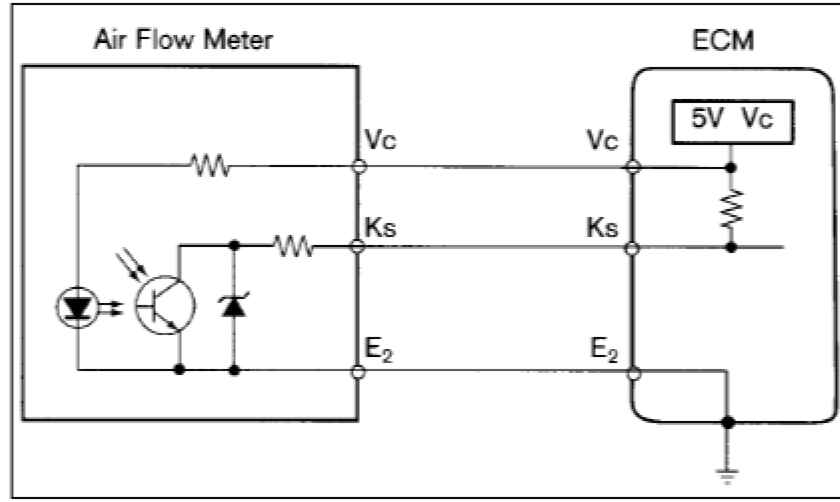
## ZAPREMINSKI PROTOKOMERI

- **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.
- 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

$$f = 1/T \approx const\ Q_v$$

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


Photocoupler
Mirror
To
Intake
Chamber
Intake Air
Temperature
Sensor
From Air Cleaner
Pressure Directing Hole
Fig. 2


Air Flow Meter
ECM
5V Vc
Vc
Vc
Ks
Ks
$E_2$
$E_2$

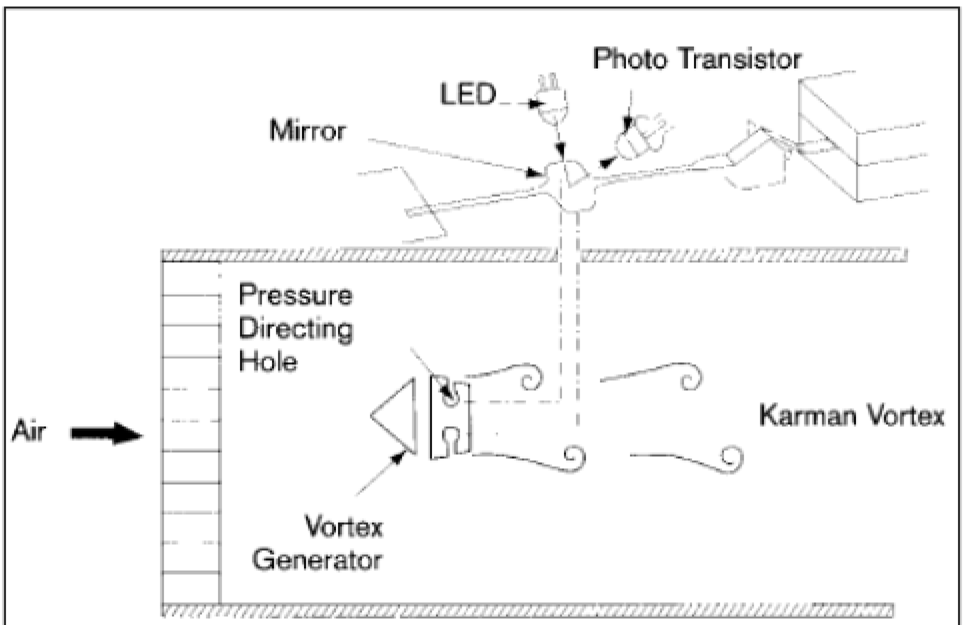
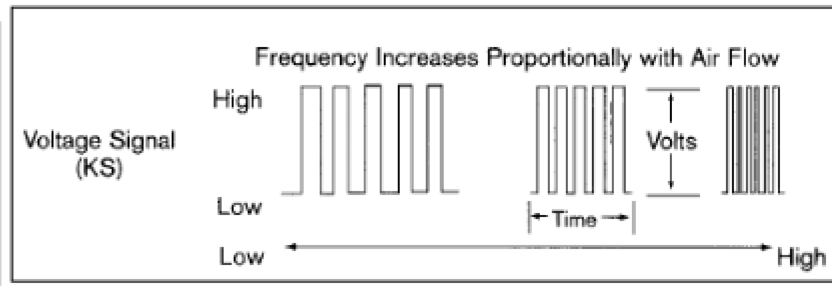
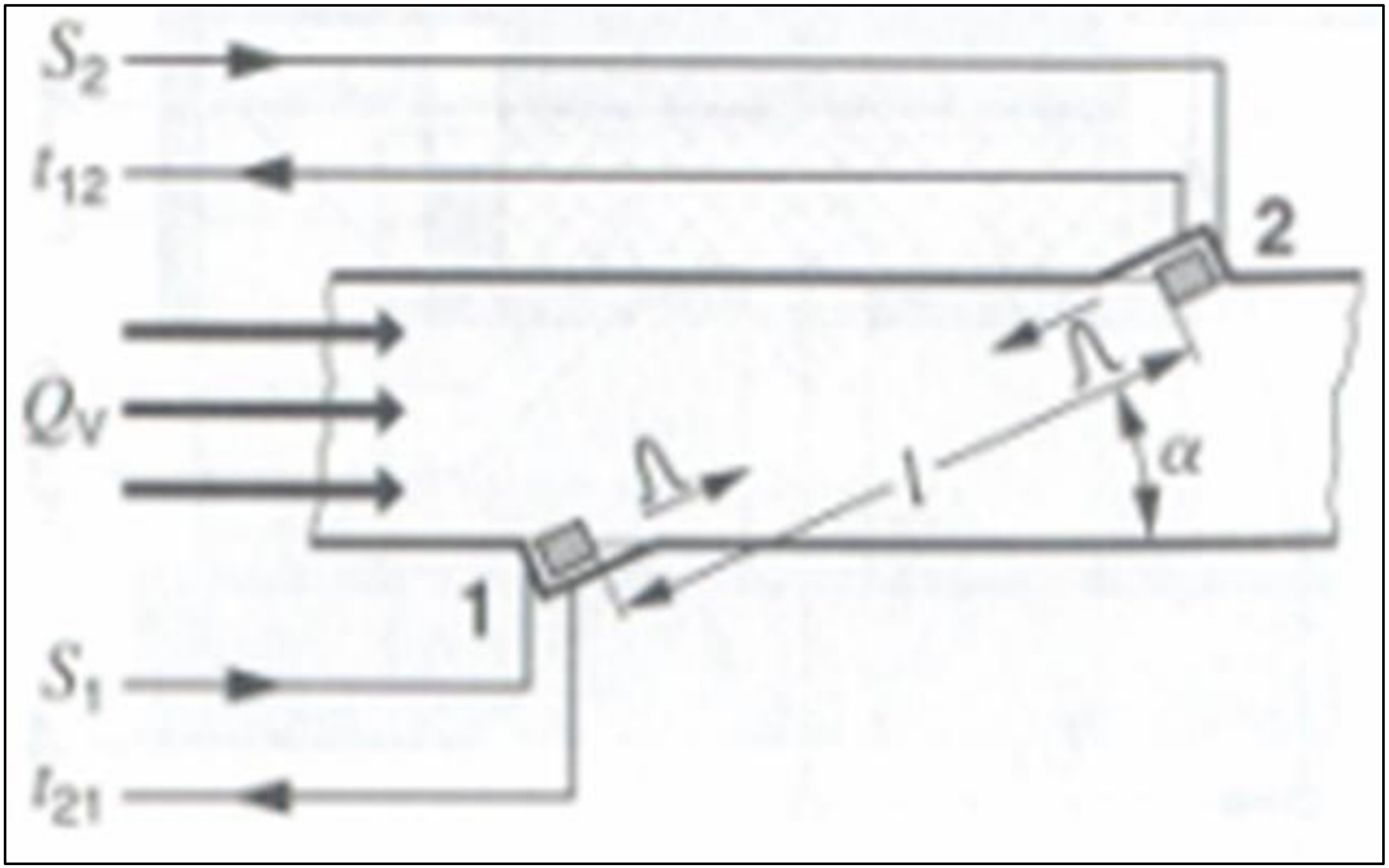


Photo Transistor
LED
Mirror
Pressure
Directing
Hole
Air
Karman Vortex
Vortex
Generator


Frequency Increases Proportionally with Air Flow
High
Voltage Signal
(KS)
Low
Volts
Time
Low
High

## Zapreminski protokomeri

**Ultrazvučno merenje protoka** zasniva se na merenju vremena prostiranja zvučnog talasa ***t*** koji prolazi kroz fluid (vazduh) pod uglom ***α***.



## MASENI PROTOKOMERI

- Princip rada masenih porotokomera na vozilima zasniva se na kalorimetrijskom principu i realizuju se sa „užarenom žicom“ (HLM) ili „užarenim filmom“ (HFM).
- Ne sadrži pokretne mehaničke delove.
- Merenjem struje grejne žice (grejača) ostvaruje se izuzetna tačnost merenja količine usisanog vazduha.
- Upravljačko kolo sa povratnom spregom nalazi se u kućištu protokomera i održava konstantnu temperaturnu razliku između temperature tanke platinaste žice (100 $^0$C) ili otpornika u tehnici tankog filma (75 $^0$C) i temperature usisanog vazduha koji struji kroz protokomer.
- Ima visoku osetljivost, a zbog rešenja sa povratnom spregom, ovaj tip protokomera ima i dobre dinamičke karakteristike i uspešno prati promene protoka reda *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 $^0$C.
- Ne može prepoznati povratna strujanja vazduha kao posledicu izraženih pulsacija u usisnoj grani, koje mogu uzrokovati određene merne greške (područje visokih opterećenja i velikog broja obrtaja).

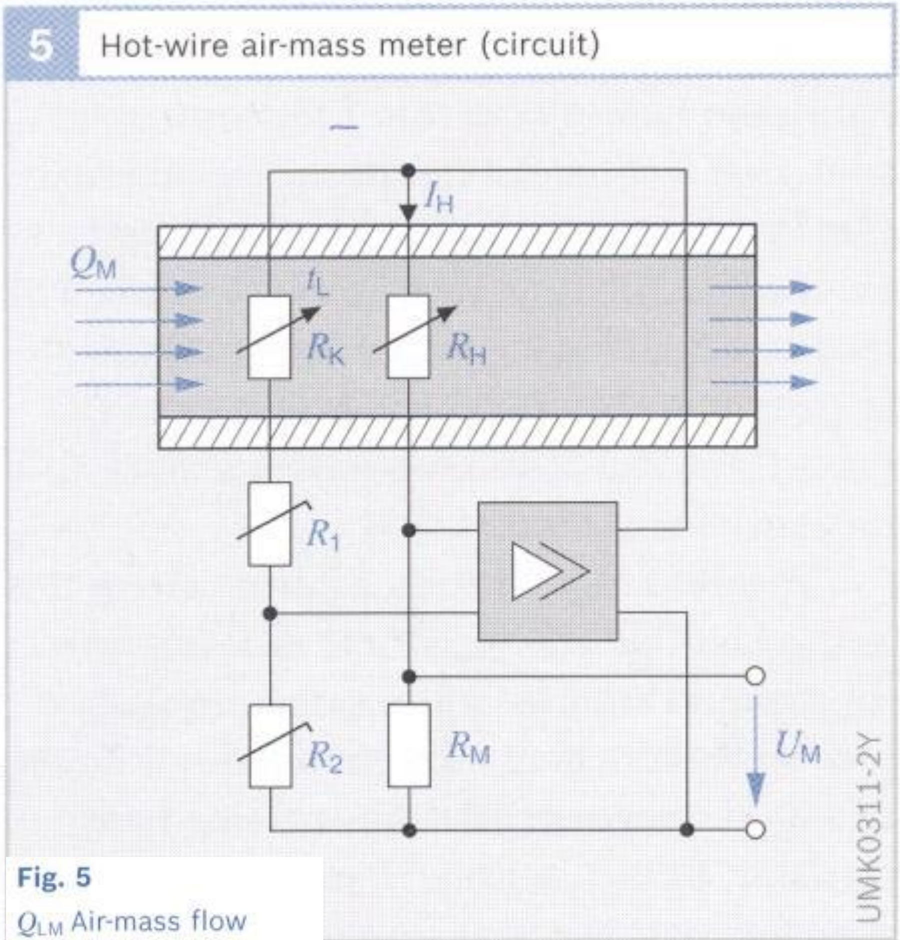



**Fig. 5**

$Q_{LM}$ 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

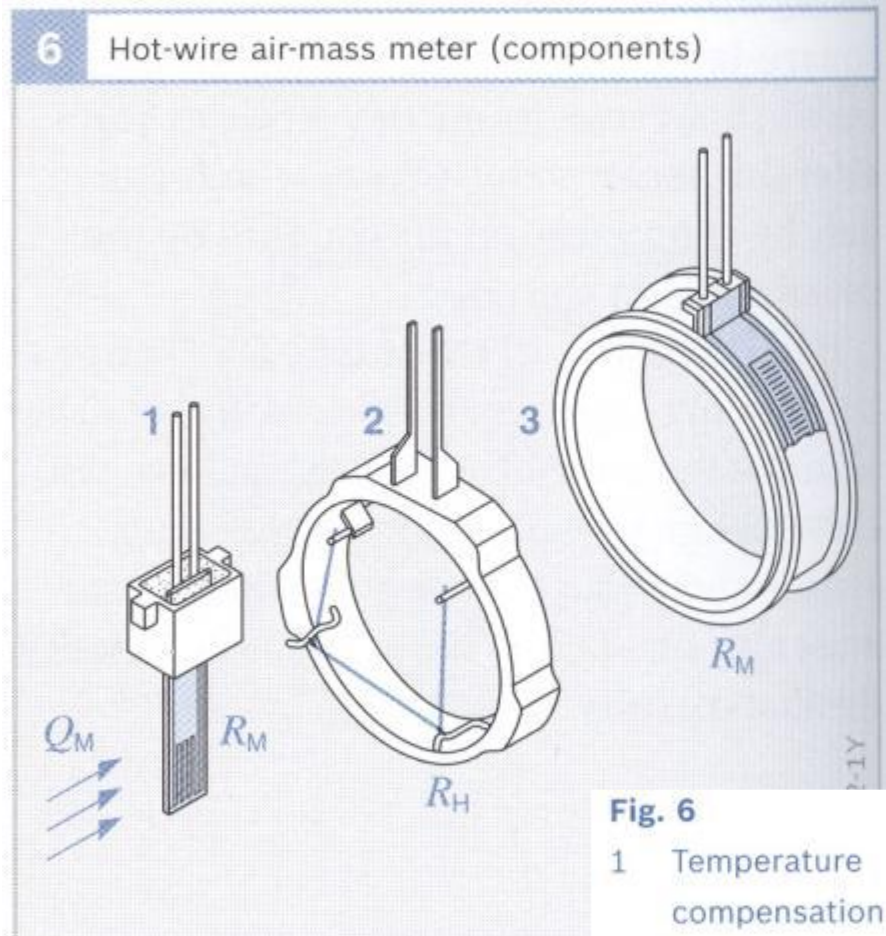



**Fig. 6**

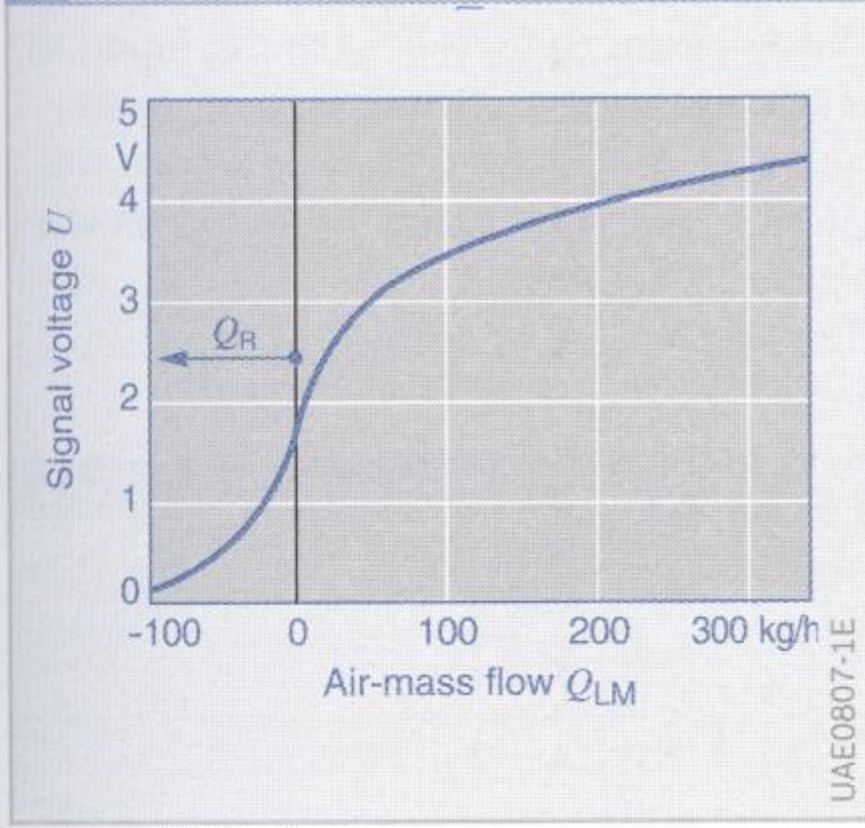
1 Temperature compensation resistor $R_K$
2 Sensor ring with hot wire $R_H$
3 Precision measuring resistor ($R_M$)
$Q_M$ Air-mass flow

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

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

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

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




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

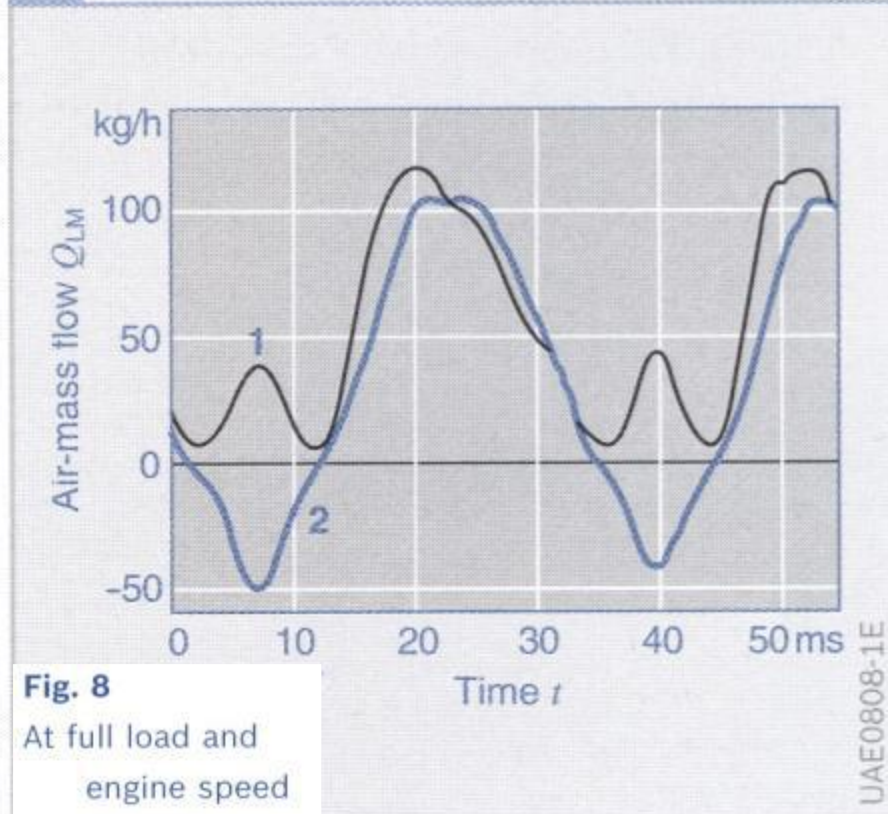



**Fig. 8**
At full load and engine speed $n$ = 900 rpm
1 Hot-wire air-mass meter
2 Hot-film air-mass meter

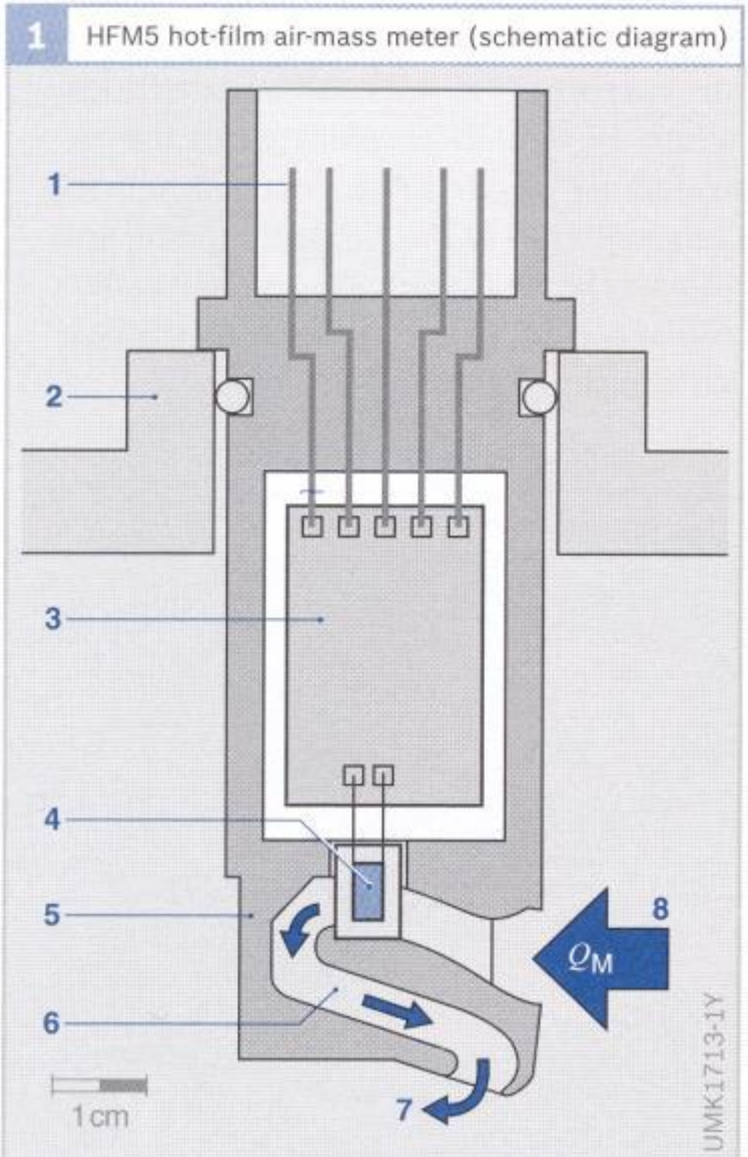
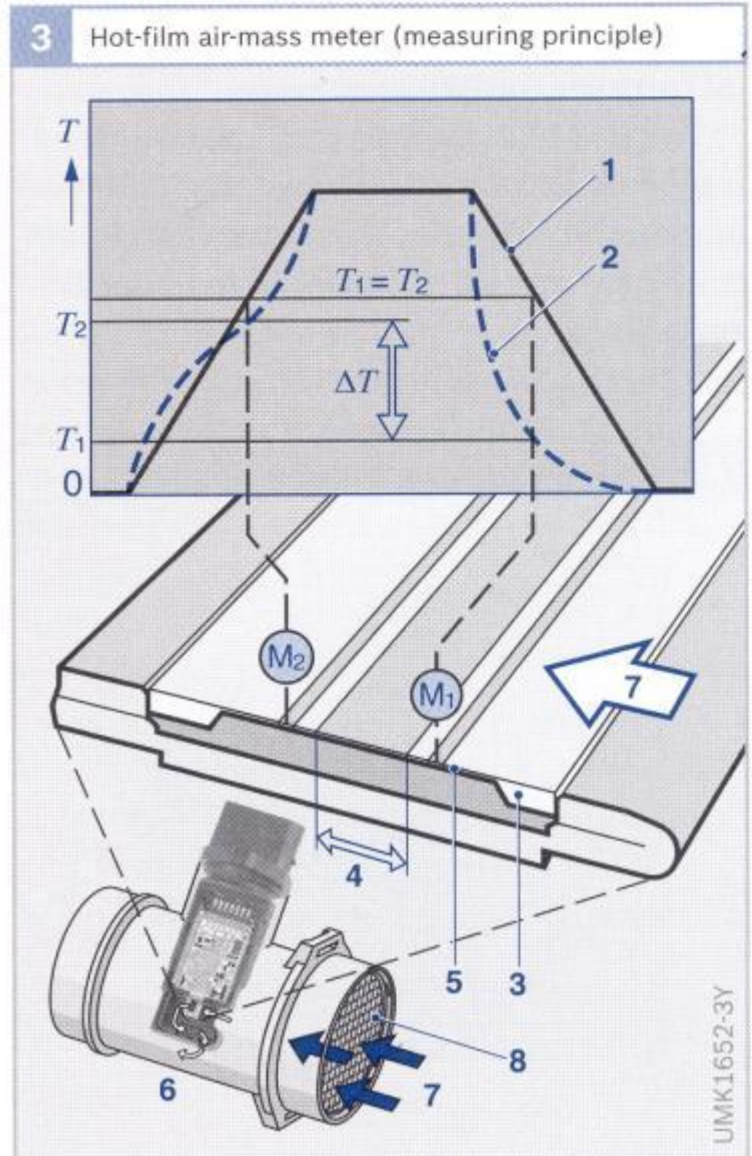



**Fig. 1**

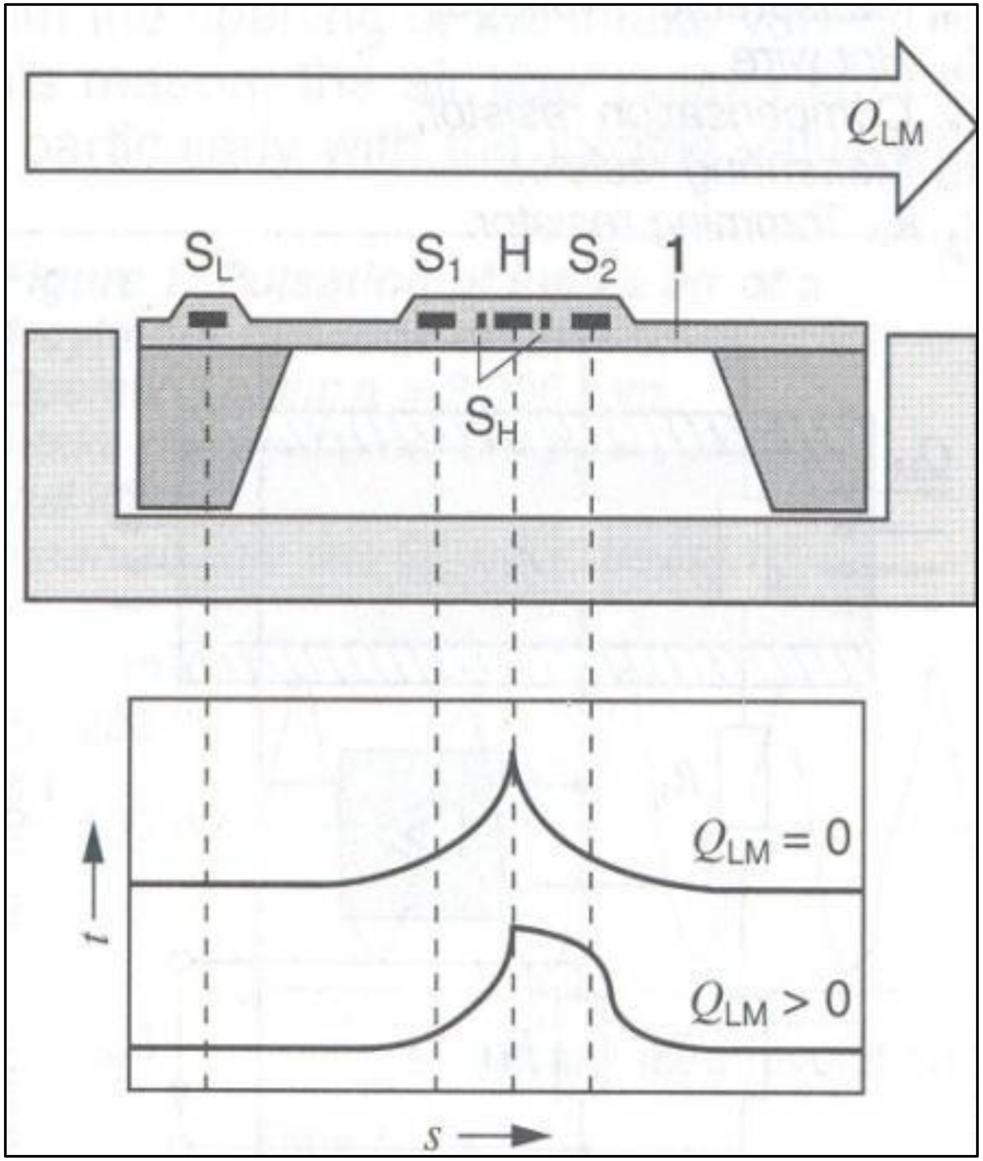
1 Electric connections (plug)
2 Measuring-tube or air-filter housing wall
3 Evaluation electronics (hybrid circuit)
4 Sensor measuring cell
5 Sensor housing
6 Partial-flow measuring passage
7 Outlet, partial air flow $Q_M$
8 Intake, partial air flow $Q_M$

**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 $M_2$
$\Delta T$ Temperature difference

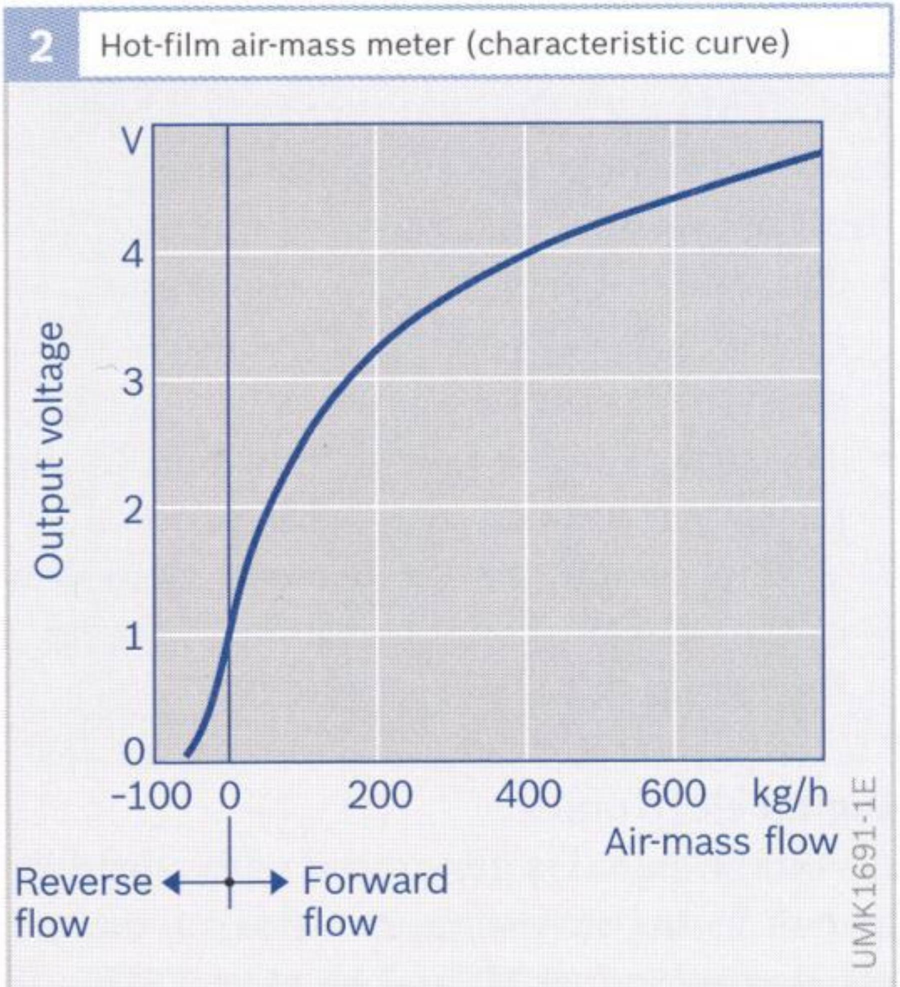


## Mikromehanički maseni protokomer sa užarenim filmom




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.



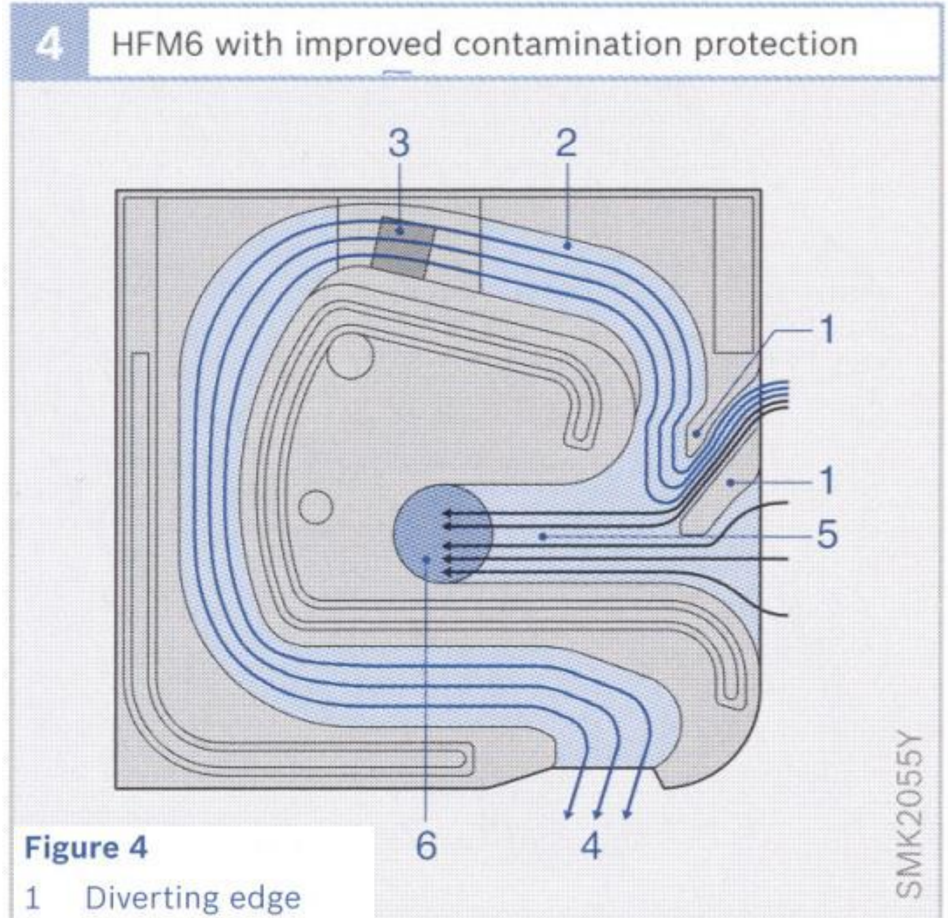
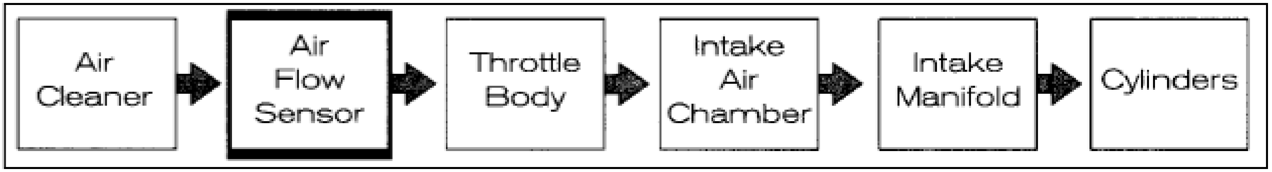
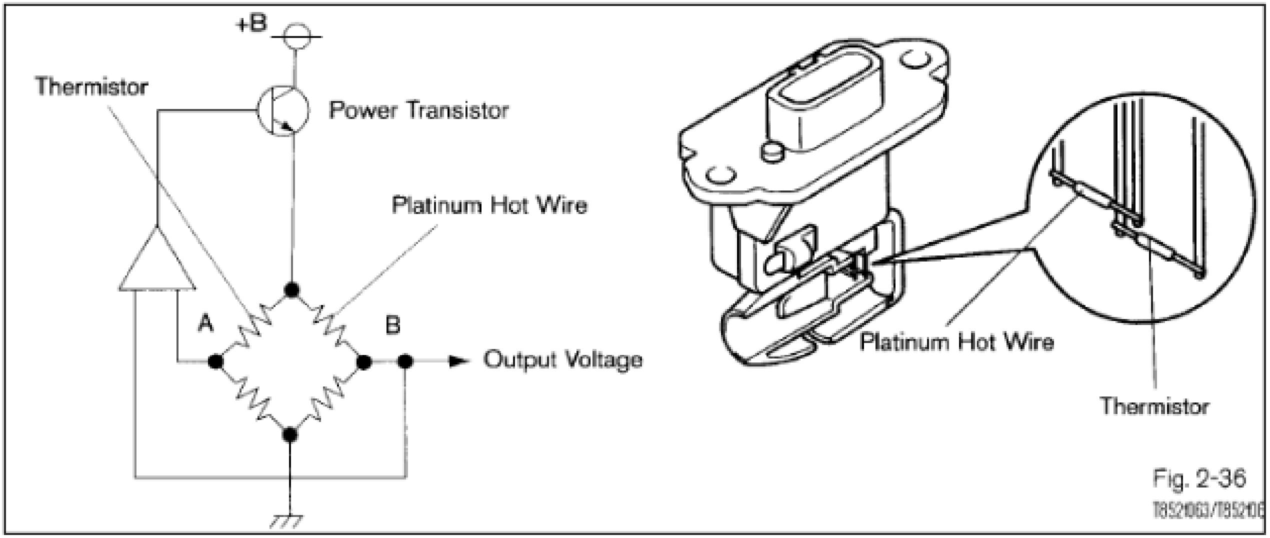



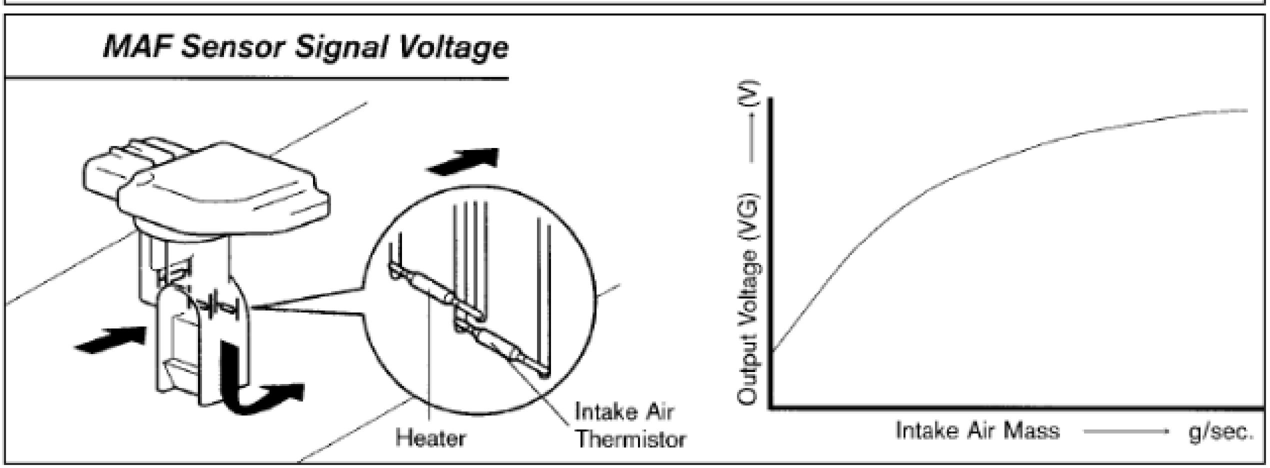

**Figure 4**

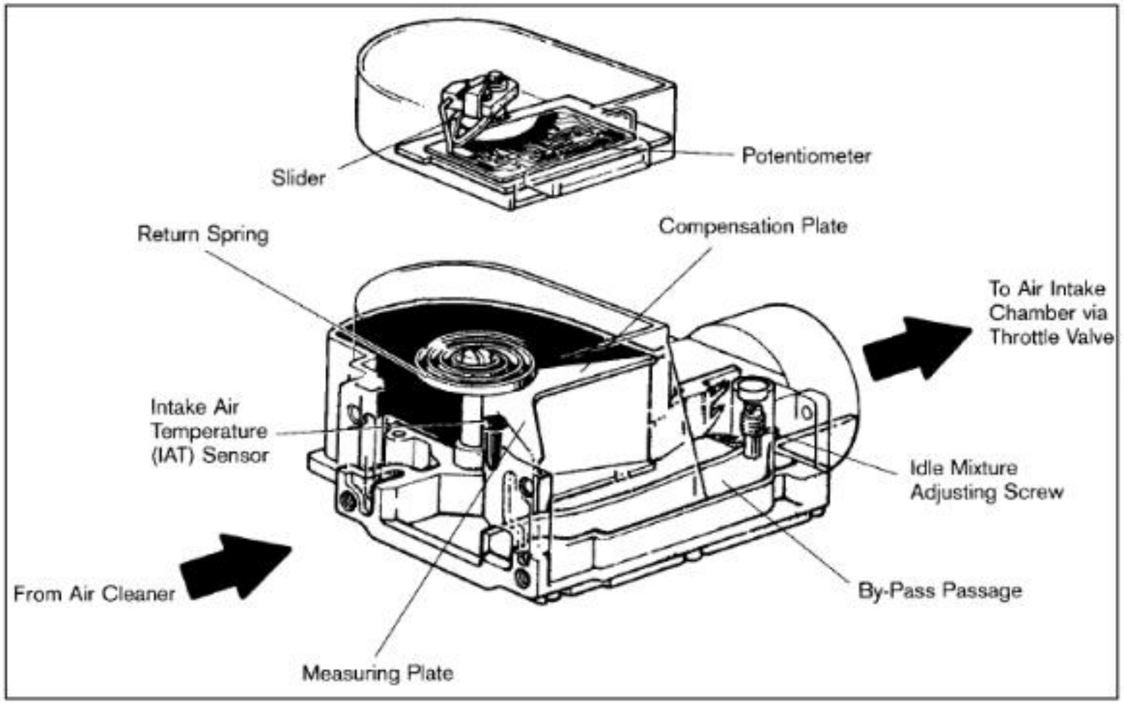
1 Diverting edge
2 Partial-flow measuring passage (first duct)
3 Sensor element
4 Air outlet
5 Second passage
6 Particulate and water outlet

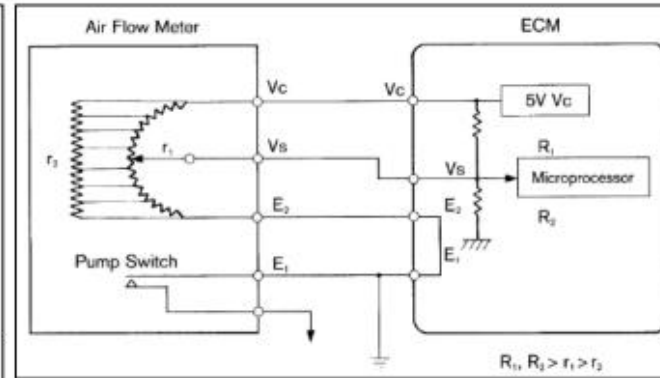
## Primeri senzora protoka na motornim vozilima





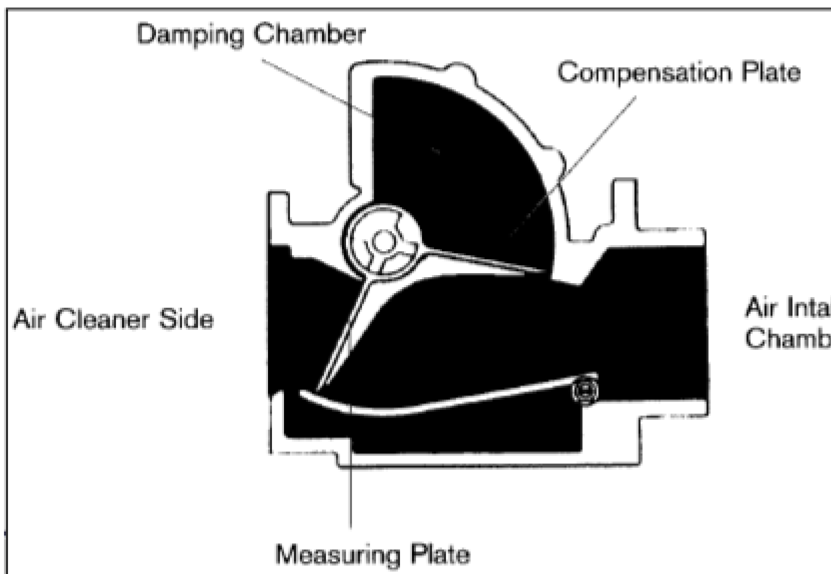




fig. 2-4

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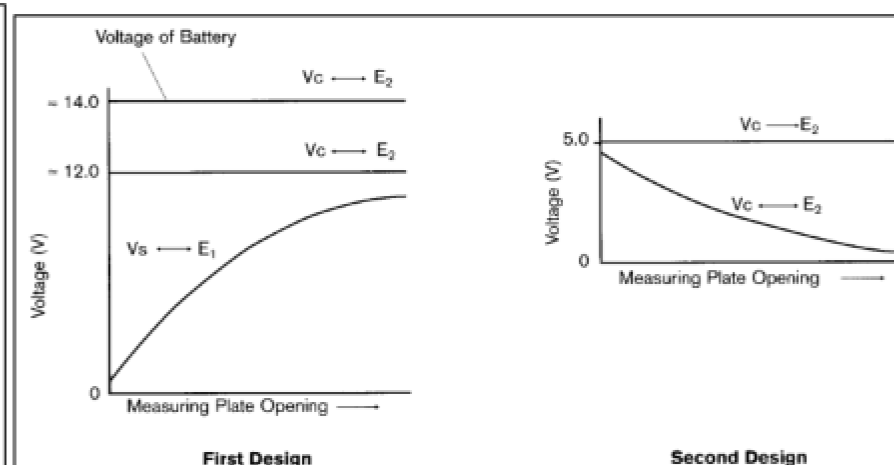


## Hot-film air-mass meter, type HFM 2

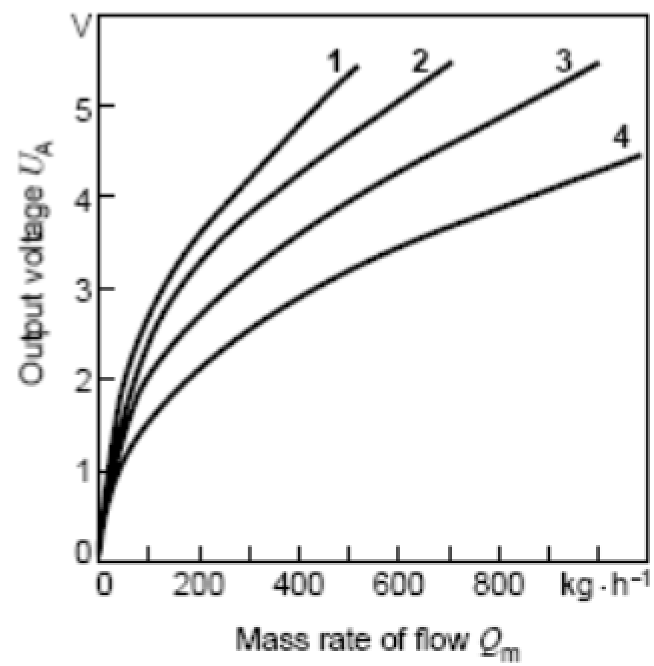
Measurement of air-mass throughflow up to 1080 kg/h

### Technical data / Range

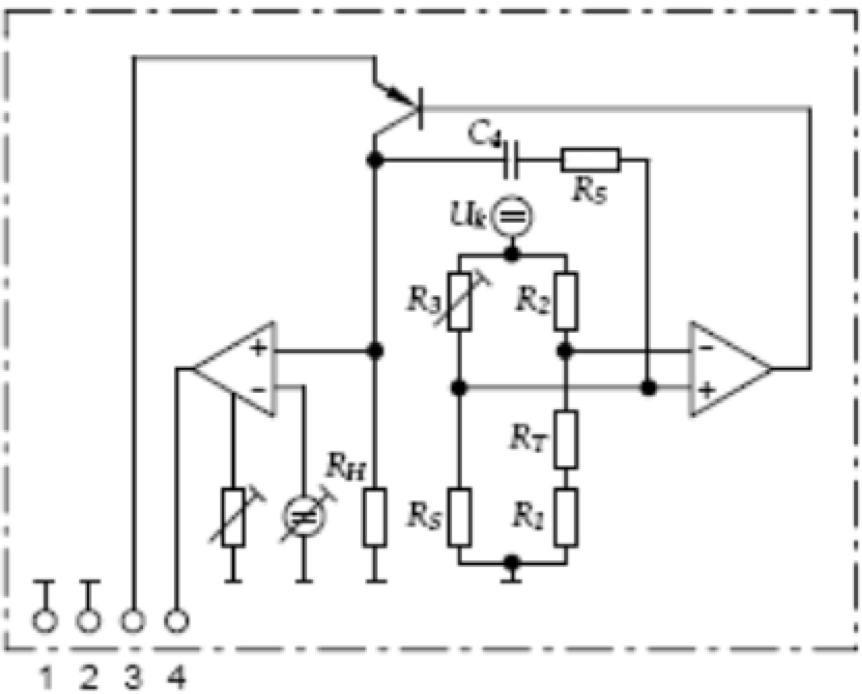
| | | | | | |
|---|---|---|---|---|---|
| Part number | | 0 280 217 102 | 0 280 217 120<br>0 280 217 107 | 0 280 217 519 | 0 280 217 801 |
| Characteristic curve | | 1 | 2 | 3 | 4 |
| Installation length L | mm | 130 | 130<br>96 | 130 | 130 |
| Air-flow measuring range | $kg \cdot h^{-1}$ | 10...350 | 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 $kg \cdot h^{-1}$ | A | ≤ 0,25 | ≤ 0,25 | ≤ 0,25 | ≤ 0,25 |
| at $Q_{m\ nom.}$ | 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 | mbar | <15 | <15 | <15 | <15 |
| Vibration acceleration max. | $m \cdot s^{-2}$ | 150 | 150 | 150 | 150 |

[1]) In case of sudden increase of the air-mass flow from 10 $kg \cdot h^{-1}$ auf 0.7 $Q_{m\ nominal}$, 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**

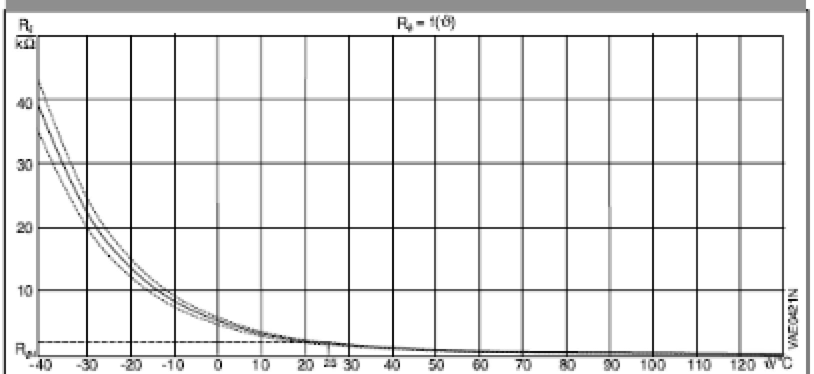
| | |
|---|---|
| $\dot{m}_N$ | Air mass throughput |
| $\Delta\dot{m}$ | Absolute accuracy |
| $\Delta\dot{m}/\dot{m}$ | Relative accuracy |
| $\tau\Delta$ | Time until measurement error <5 % |
| $\tau_{63}$ | Time for 63 % measured value change |

## Technical data

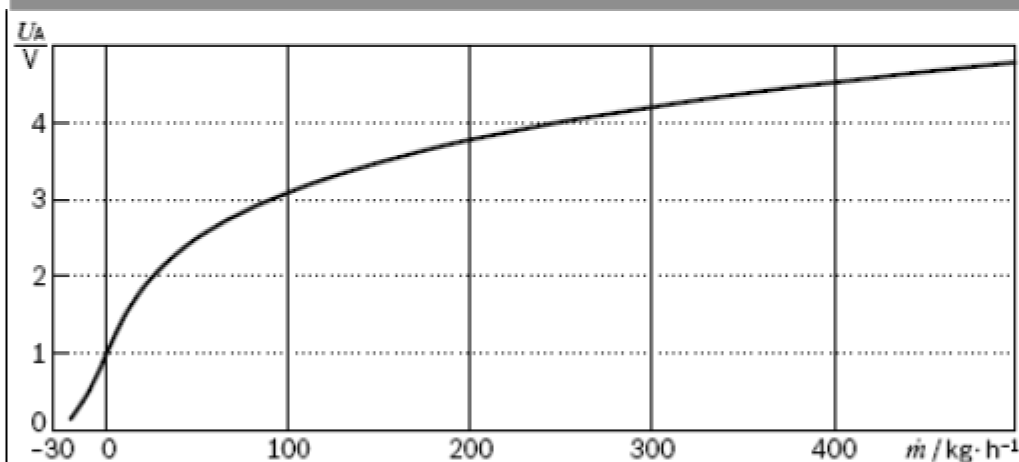
| | | |
|---|---|---|
| Rated supply voltage | $U_N$ | 14V |
| Supply-voltage range | $U_V$ | 8 … 17 V |
| Accuracy | $\Delta\dot{m}/\dot{m}$ | ≤ 3 % |
| Pressure drop at $\dot{m}_N$[1]) | $\Delta p$ | < 15 hPa |
| Output voltage | $U_A$ | 0 … 5 V |
| Current input | $I_V$ | < 0,1 A |
| Permissible vibration acceleration | $a_v$ | ≤ 150 m/s² |
| Time constant $\tau_{63}$[2]) | | ≤ 15 ms |
| Time constant $\tau\Delta$[3]) | | ≤ 30 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 $|\Delta\dot{m}/\dot{m}| \le 5$ %.
[4]) Up to 130 °C for brief periods (≤ 3 min.).

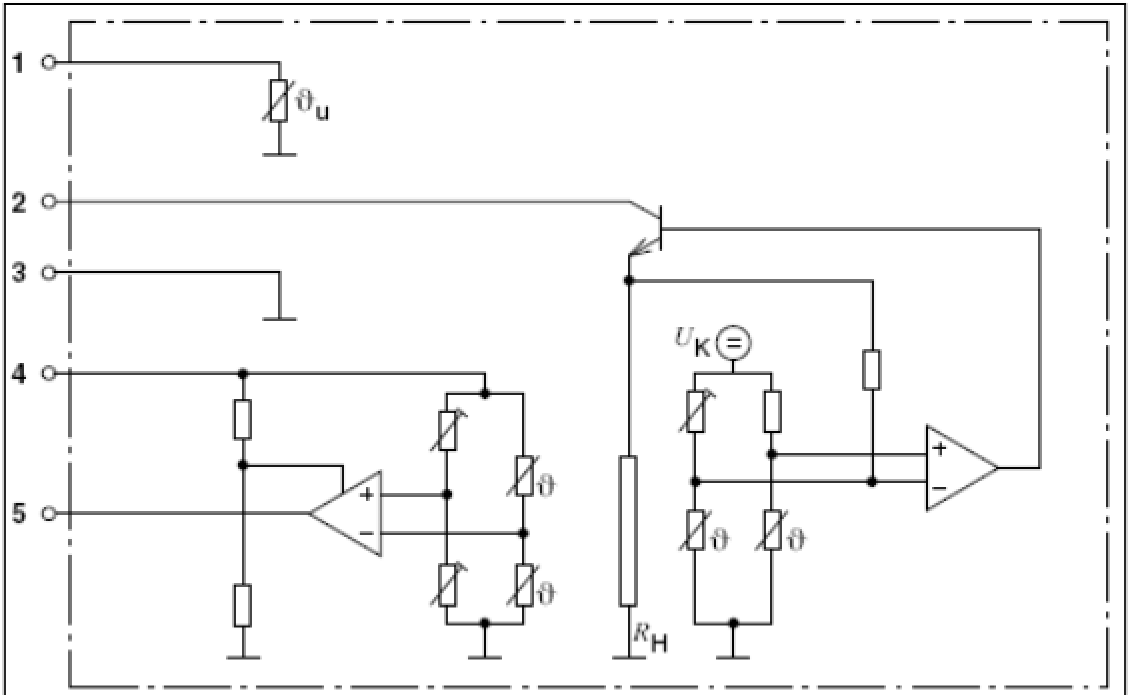
## Resistance profile of temperature sensor




## Air-mass characteristic curve at ambient temperature

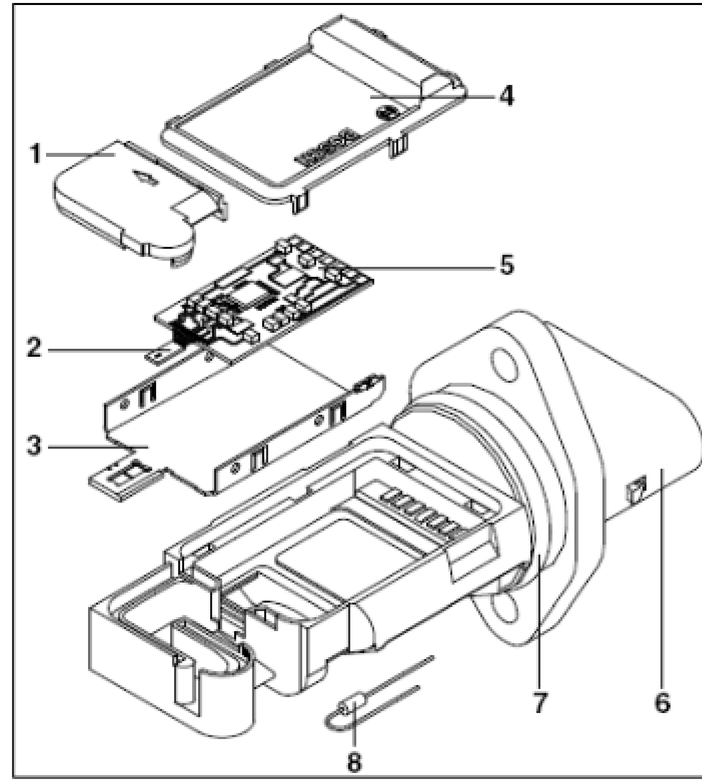



| | | |
|---|---|---|
| **0 280 218 119** | $\dot{m}_N$ | -15 … 480 kg/h |




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

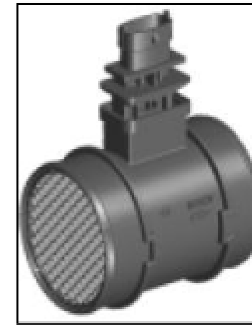
| | | |
|---|---|---|
| **0 280 218 113** | $\dot{m}_N$ | 10 … 480 kg/h |
| **0 280 218 087** | $\dot{m}_N$ | -30 … 850 kg/h |
| **0 280 218 089** | $\dot{m}_N$ | -50 … 1100 kg/h |




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

# Hot-film air-mass meter, type HFM 6

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

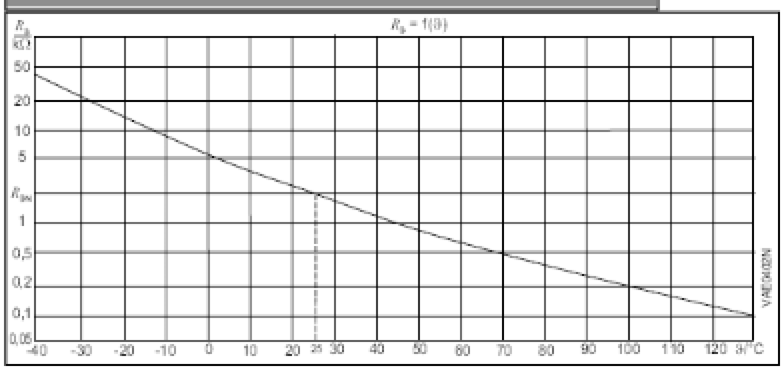


## Technical data

| | | |
|---|---|---|
| Rated supply voltage | $U_N$ | 14V |
| Supply-voltage range | $U_V$ | 7,5 ... 17 V |
| Relative accuracy[1]) | $\Delta\dot{m}/\dot{m}$ | ± 2 % |
| Temperature range[2]) | | -40 ... 120 °C |
| Pressure drop at $\dot{m}_N$ | $\Delta p$ | < 18 hPa |
| Current input | $I_V$ | < 0,06 A |
| Vibration acceleration | $a_v$ | ≤ 180 m/s² |
| Time constant $\tau_{63}$[3]) | | ≤ 10 ms |
| Time constant $\tau_{\Delta}$[4]) | | ≤ 30 ms |

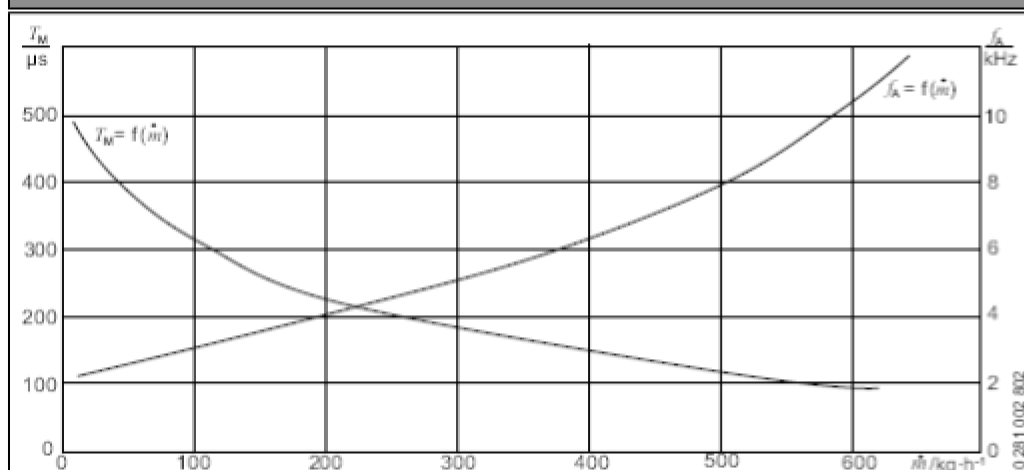
[1]) For $0.04 \le \dot{m}/\dot{m}_N \le 1.3$
[2]) Up to 130 °C for brief periods (≤ 3 min.).
[3]) Time required for step response of output voltage to 63 % of final value given an abrupt change in air mass from 10 kg/h to 310 kg/h.
[4]) Delay on switch-on and after any change in flow rate until the output voltage has attained the relative measurement deviation $|\Delta\dot{m}/\dot{m}| \le 5$ %

## 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 |