Main Index

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DESIGN AND SUGGESTIONS TO REDUCE THE VOS EFFECT FOR GAS DENSITY MEASUREMENT

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Northsea Flowmetering Workshop

Design and suggestions to reduce the VoS effect for gas density measurement

Summary

The requirements on readout accuracy of gas densitometers have been increased during the last few years. It is desirable to gain an accuracy of field instruments close to that of the lab standards.
Different ways direct to that target like modifications and changes in the instrument's design or by using additional mathematical equations based on the velocity of sound offset model.

1. Introduction to Bopp & Reuther Densitometers type DIMB 104.2.

Applicable field instruments for gas density measurement were introduced in the 60's. Different types were based on different working principles. Finally the most successful instruments with highest accuracy use a vibrating sensor. These sensors are operated at their resonance frequencies where a certain (1)
amount of energy is introduced into the vibration system only to overcome the friction. The frequency itself depends on fix parameters of the vibrator like mass, shape, elasticity of material and on the density next to the sensor. Usually the sensor is exposed to the gas and the design is in a way a maximum of (2)
surrounding gas is effected by the vibrating element to gain highest resolution.

If the sensor is operated at vaccum conditions there is no reaction of a gas and the sensor may vibrate at its' base frequency. Now the sensor is exposed to a gas of a certain density, so it has to move an additional mass and the resonance frequency will drop.
If the sensor is a tuning fork type the fundamental equation that describes the relation of the frequency versus density is:

$$f = C\sqrt{\frac{E}{\rho_{st} + K_1 \cdot \rho_G}}$$

where f = frequency
E = elasticity of sensor material
ρ st = density of sensor material
ρ_G = density of gas
C, K_1 = coefficients

As far as the computer receives the frequency and may calculate the density the new equation is:

$$\rho_G = K\left(\left(\frac{B}{f}\right)^2 - 1\right)$$

where K, B = coefficients

In the earlier generation of our Bopp & Reuther computers this equation was established. At present time all available computers (3)
work on the base of an approximation curve as:

$$\rho = A + B \cdot \frac{1}{f} + C \cdot \frac{1}{f^2} \quad \text{or}$$

$$\rho = A + B \cdot \tau + C \cdot \tau^2$$

where ρ = density
f = frequency
τ = periodic time
A,B,C = coefficients

Within the operating range the square curve very well covers the attitude of the densitometer. Surprisingly the square curve provides better results for lower densities.

The sensor of the densitometer type DIMB 104.2 is designed as a tuning fork with paddles at the end of each branch. These (4)
paddles provide a better ratio of $\frac{\Delta f}{f}$ vs. density variations by connecting a higher volume respectively a higher mass of the sample gas to the tuning fork sensor.
The tuning fork is integrated into a closed loop with an amplifier that introduces energy only in a special way to overcome the frictions, but lets the sensor operate freely at its resonance frequency. So the resonance frequency depends on the sensor alone and the additional mass of the sample gas that is connected to it by the paddles.
Most applications of gas densitometers is in mass flow conversion. As one easily can see a misreading of the densitometer directly leads to an offset of all conversion results, as far as mass = $\text{volume}_{(\text{service})} * \text{density}_{(\text{service})}$.

The installation of a densitometer in a meter run has to be executed in a way that provides highest accuracy. (5)
For example a thermal insulation is required as far as gas changes it's density on temperature changes. The feed pressure of the sample gas must not differ from that of the pressure tap. The sample flow rate has to be chosen under respect of the time delay after a change of the composition of the gas (Tests showed a time delay up to more than one hour depending on the installation of the sample pipework and caused by a low sample flow rate).
On standard applications the density range varies at 10 kg/m³ to 80 or 90 kg/m³, but the densities of liquid and solid particles is dramatically higher. This means all vibrating sensors for density measurement, independent on their design, must be (6)
protected as far as a contamination of the sensor will lead to an offset with higher density reading.
All these problems can be solved by proper installation and maintenance of the instrument itself and the accessories. (7)

2. Influence of different gas types on the read out of the densitometer type DIMB

All densitometers based on a vibrating sensor depend on the reaction of the gas next to that sensor. As soon as the sensor starts its vibrations the gas column is forced to vibrate too at the frequency of the sensor system.
Sound waves are emitted and travel along through the sample gas at the speed of sound.

Moments later these waves hit the surfaces of different parts inside the densitometer such as the guide tube or the bottom of the housing. The reflected waves now hit the sensor, in our case the tuning fork, and obviously strike back. It is a known fact, for example, that the distance between the tuning fork and the bottom of the housing is responsible for some misreading as soon as this distance is too short.
The tuning fork itself is located in the center of the guide tube and all radially emitted sound waves will return to that focus. Depending on the travel time the returning waves will hit the tuning fork sensor during a certain phase of its motion. If now the velocity of sound changes the sound waves will hit the sensor at a different phase angle and the introduced energy probably will have its influence on the attitude of the sensor and on its resonance frequency and on the read out result respectively.

Here now my private opinion: We do have to modify the densitometer and especially the parts around the sensor in a certain way to reduce reflections. Probably some sintered metal parts or other materials can absorbe the energy of the original sound waves and reduce the reaction of reflected waves to the sensor.
At present time I am not able to provide test results already, they do not yet exist as far as this was one of the latest modifications of one of our densitometers.
The tuning fork itself is machined with sharp edges and while in
motion the gas is forced to move forth and back. Next to the sharp (8)
edges of the sensor some shear will appear and the forces to overcome the friction depend on the viscosity of the fluid.
If the shear zones could be reduced by a modified sensor the influence of different viscosities of the sample gas on the sensor also would be reduced.
We designed a tuning fork sensor where the paddles no longer are machined with such a long line of sharp edges but they are made of two tubes now. High shear zones do exist on the end of these tubes only, between and around the tubes there is a moderate shear only and no shear within the tubes.
The densitometers equipped with this type of sensor is named
DIMB 200. It's base frequency differs to that of the standard (9)
type DIMB 104.2
If the DIMB 200 is calibrated by using methane and it is applied to natural gas the offset to be expected is within a range of approx. + 0.1 to zero percents.
On the other hand its' ratio of $\frac{\Delta f}{f}$ vs. density is lower compared
to the standard version. This is a reason why we recommend an
application of the DIMB 200 for densities. (10)
The VoS-offset caused by other gases like nitrogen or ethylene is lower too by the same ratio but another attitude.

Other known effects with an influence on the readout is the attitude of the adhesion of the gas to the surface of the sensor. Another known effect is the capability of some gases to penetrate the metal of the sensor.
The best of all examples is given by the Ekofisk gas, where all our previous experiences were turned upside down. After the (11)
instruments were exposed to the gas, there a permanent drift occured until a saturation was reached. The same thing happened in the opposite direction. When removed from Ekofisk gas and check with methane within a short time period there was a tremendous offset but after a few days the situation and results were back to normal. Similar offsets are known to the gas from Sibiria.

Some attempts were done to reduce these effects. The best idea was to have the tuning fork teflon-coated or gold plated. The results in our and other labs and on field tests showed, that a coating of the tuning fork sensor can reduce the effects like mentioned above but other problems occur. As we found out the sensors react (4)
on different thickness of the coating and change their attitude on accuracy vs. density, but cannot prevent the so-called VoS-offset. The improvement of the readout was not as high as expected. So we can say a coating of a tuning fork sensor more or less will be useful for protection against aggressive gases.

Bopp & Reuther does not only manufacture gas densito-meters, but also provides instruments for liquid density measurement. These instruments are named DIMF 1.2.
The sensor of these instruments are vibrating tuning forks again but their design is different. The sensors of the gas densitometers (8)
are submerged into the sample gas while the liquid sample of the DIMF 1.2 remains within the hollow tuning fork. This tuning fork is machined out of a single piece of metal with special bores inside. This design works very well for liquid density and so we put it on our gas density test rig and found some interesting results. As far as the sample gas remains within the sensor and the gas next to it is air and will not change, there is no or almost no shear of the sample gas. Sound emitted from the sensor is by air only under almost constant conditions. So after some development is done and some improvements are installed this instrument might be applied for gas measurement too. At present time it's a little too early to specify the instrument's limits and qualities, but we are still optimistic and will continue the tests.

3. Correction of the VoS-offset by conventional means.
All attempts to overcome the VoS-offset by means of design and modification of the sensors or the instruments themselves have some incouraging results but the acceptance in the field is still low. Some of the first instruments delivered for field testing could not fulfill the expectations, had to be redesigned or improved in any way. As we think the DIMF 200 is ready now for field installations within the given limits. On the other hand there are systems of equationsdevelopped by the Ruhrgas Company and meanwhile approved by our authorities. These mathematical corrections gain the same accuracy for our standard instruments of $\pm$ 0.1 percents and are based on the velocity of sound model. These equations require to know the velocity of sound of the sample gas where two ways exist to gain them.

The first way is to calculate the velocity of sound from some known or measured parameters like temperature, pressure, specific gravity and other information on the composition of the gas. The second way is to measure the velocity of sound as a live value by instrument.
Now we can look back the last few years where everyone was happy to gain an accuracy of 0.5 percent but now the requirements are to meet the 0.1 percent limit. So these requirements meet the lab test accuracy levels.

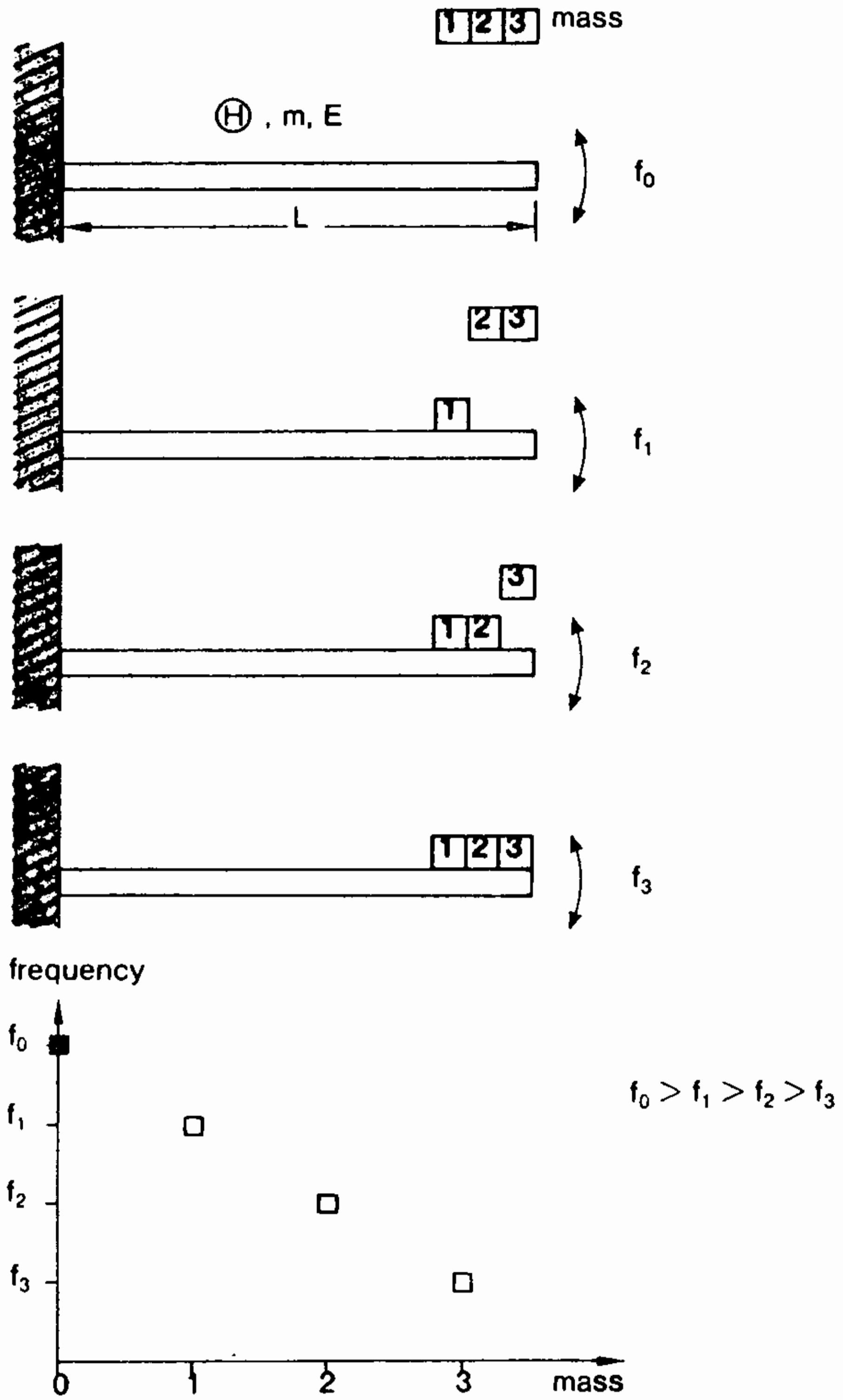
Quellennachweis

J. Hennig - Ein Gerät zur Berücksichtigung der Dichte bei Gasmengenmessung
"Gas Wärme International" Bd. 22 Nr. 11 Nov. '73

D. Ceelen - Dichte- und Normdichtemessung mit schwingenden mechanischen Strukturen
Lehrgang Nr. 8707/41.140 TA Esslingen '86

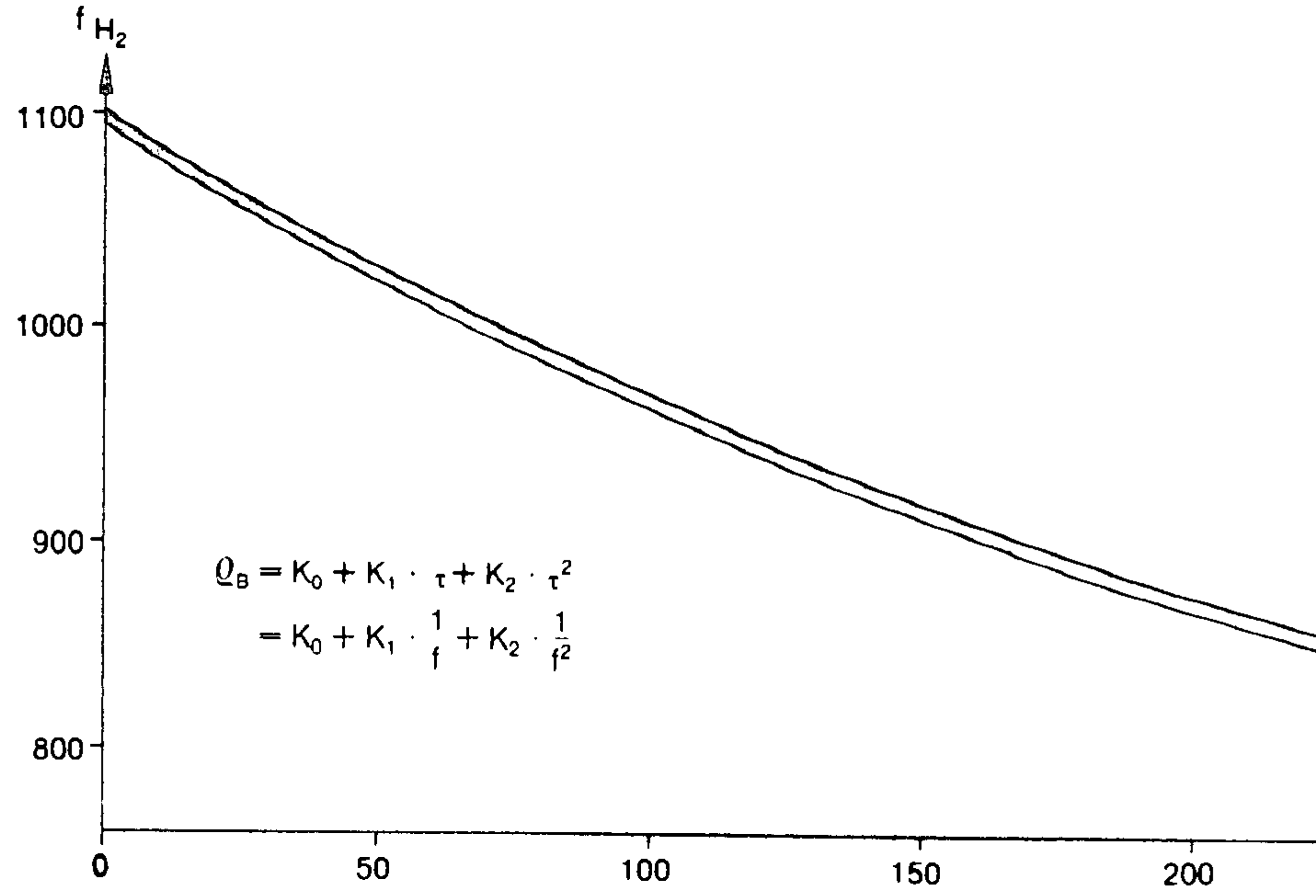
M. Jaeschke,
H.-M. Hinze - Using densitometers in gas metering
Hydrocarbon Processing, June '87

Internal reports of Bopp & Reuther GmbH



Titel:	Density Measurement by Vibrating Sensor

Abb.:		Datum:
1	Marketing/ Unternehmensplanung	8.87



Titel: Frequency vs. Density of DIMB 104.2

Abb.: 2

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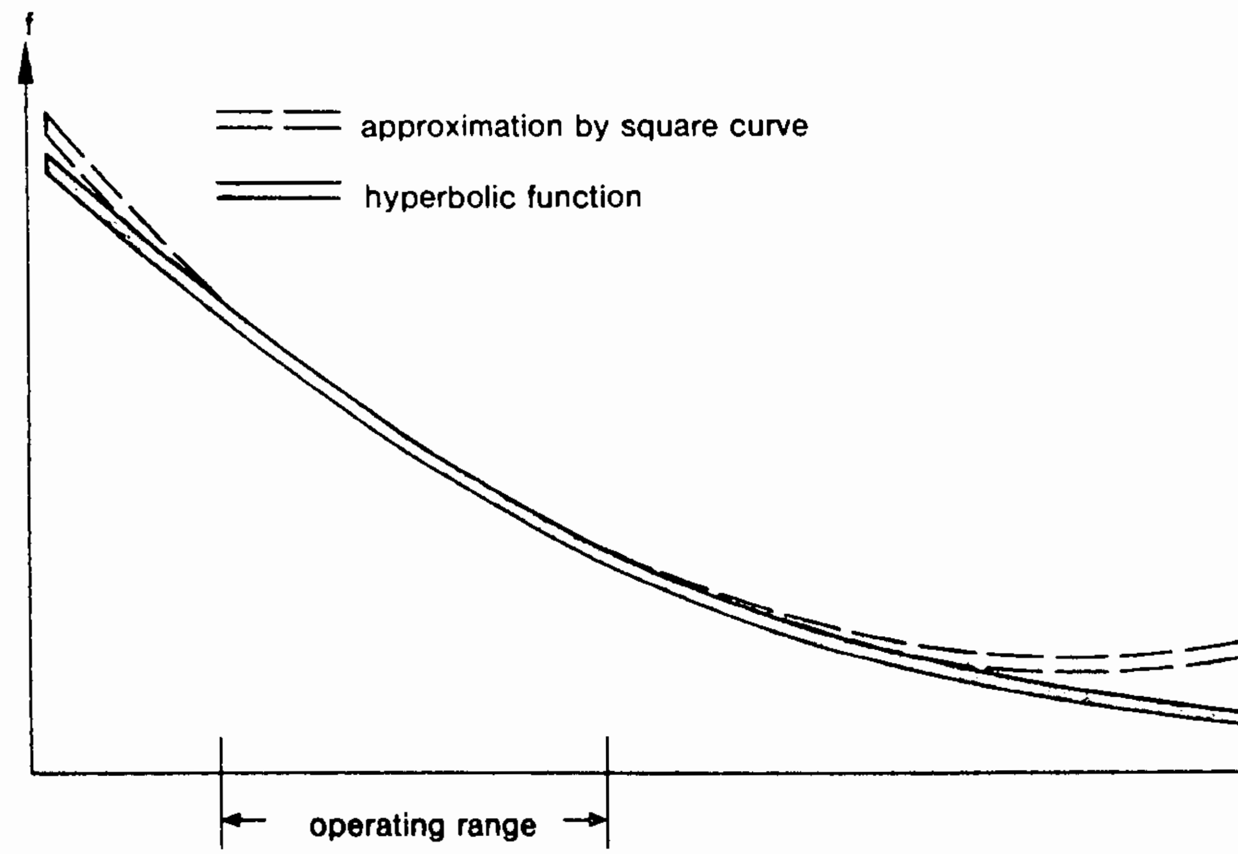
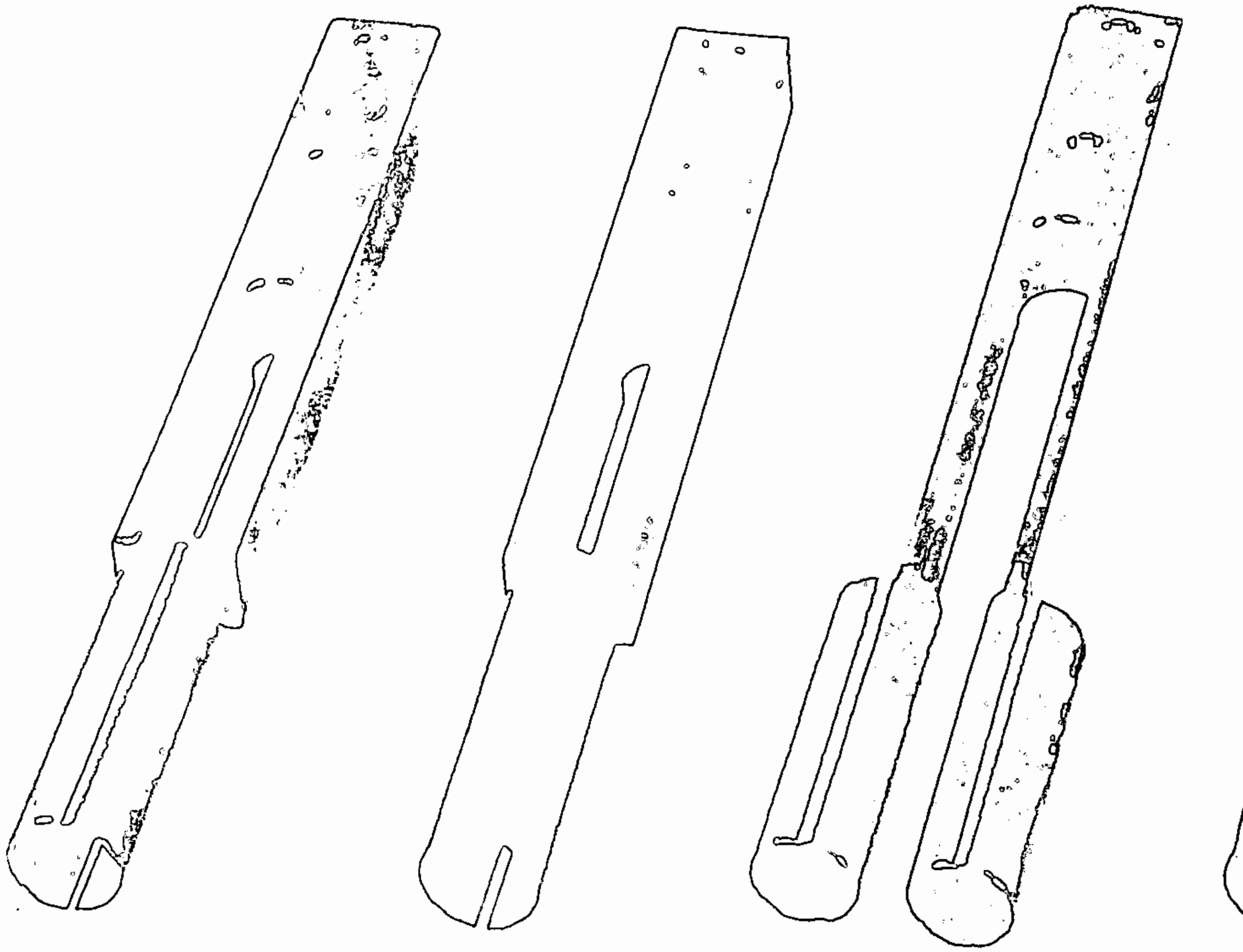


Titel: Attitude of resonance frequency of tuning fork compared to approximation by square curve

Abb.: 3

Unter



Tital:
Different Designs of Tuning Fork Sensors

Abb.: 4 a

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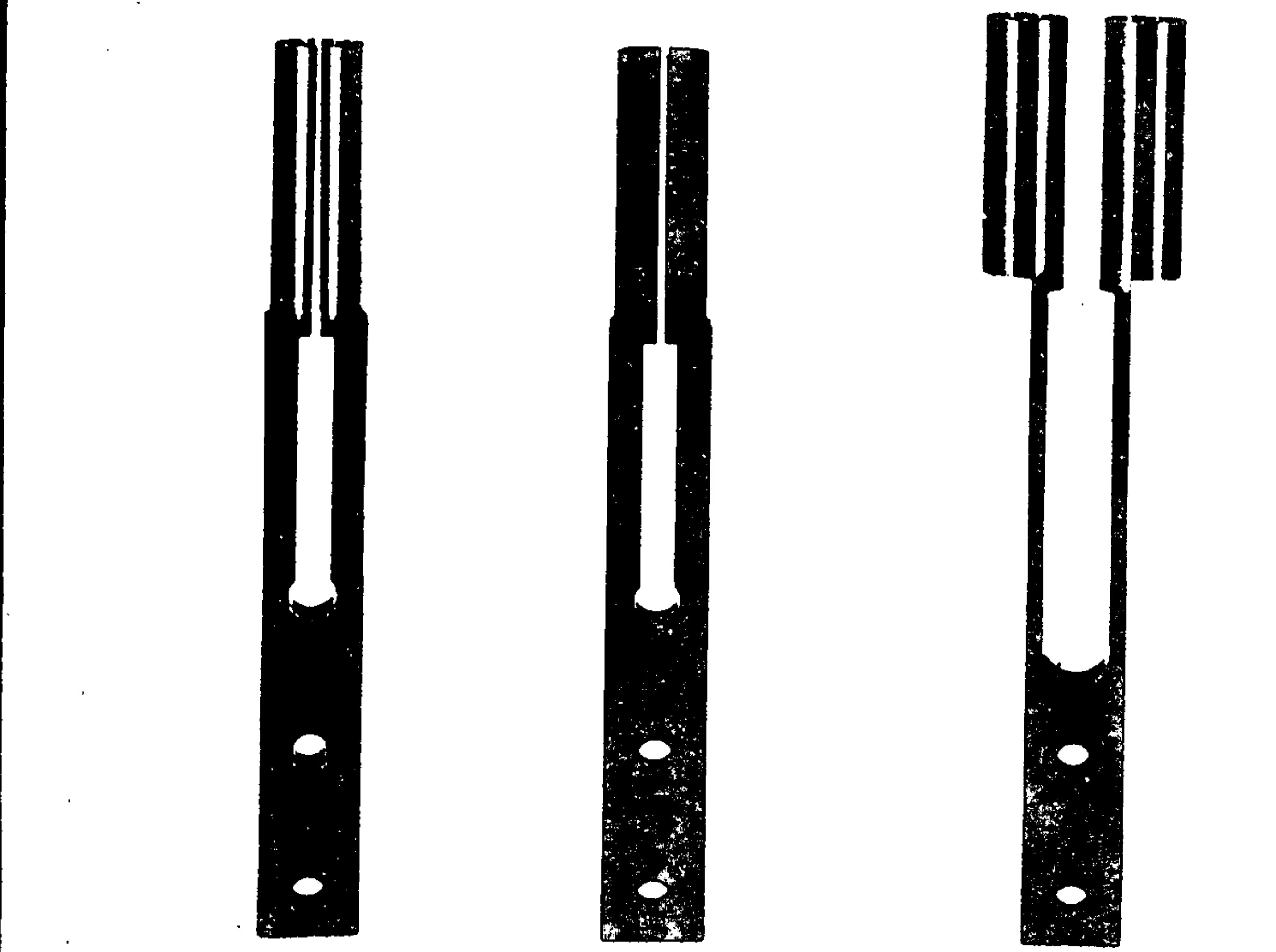

Titel:

Different Designs of Tuning Fork Sensors

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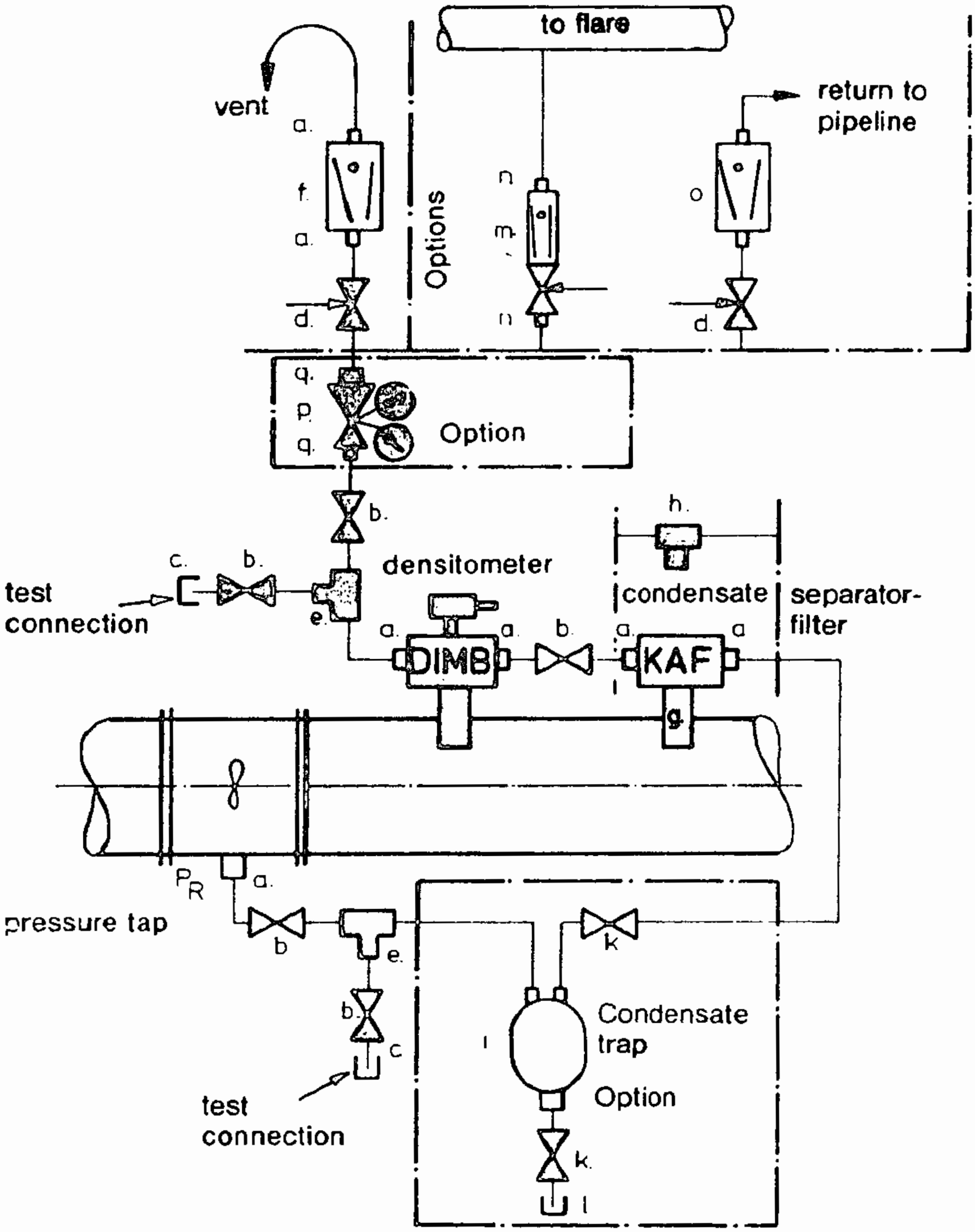
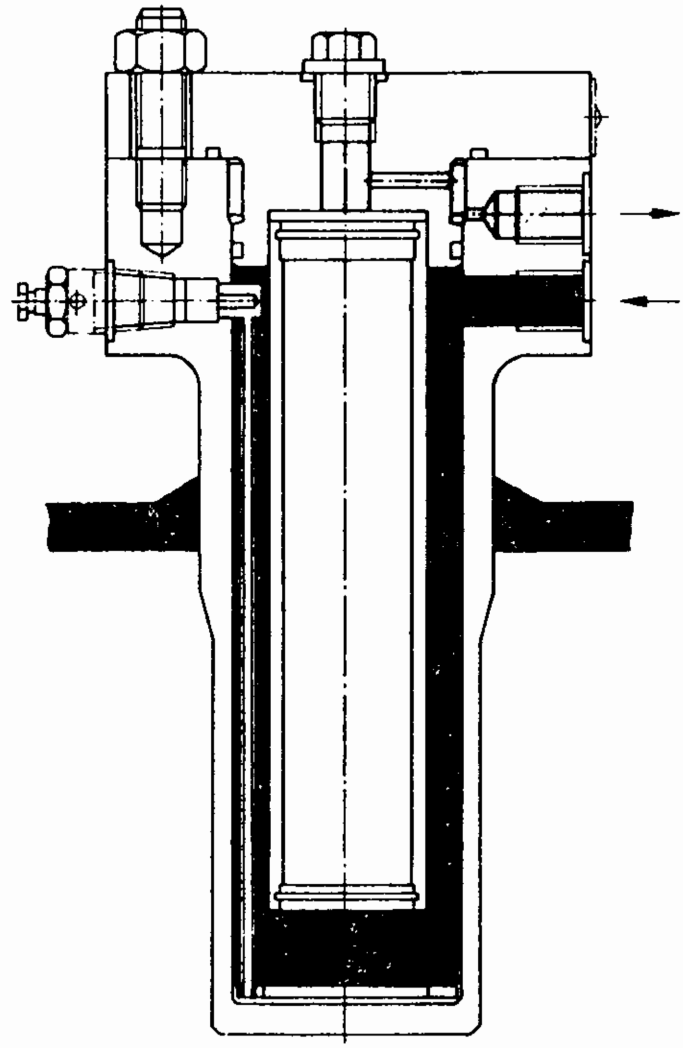


Titel:
Accessories and piping for installation of gas densitometer

Abb.:		Datum:
5	Marketing/ Unternehmensplanung	8.87



Titel: Condensate Separator – Filter Type KAF		
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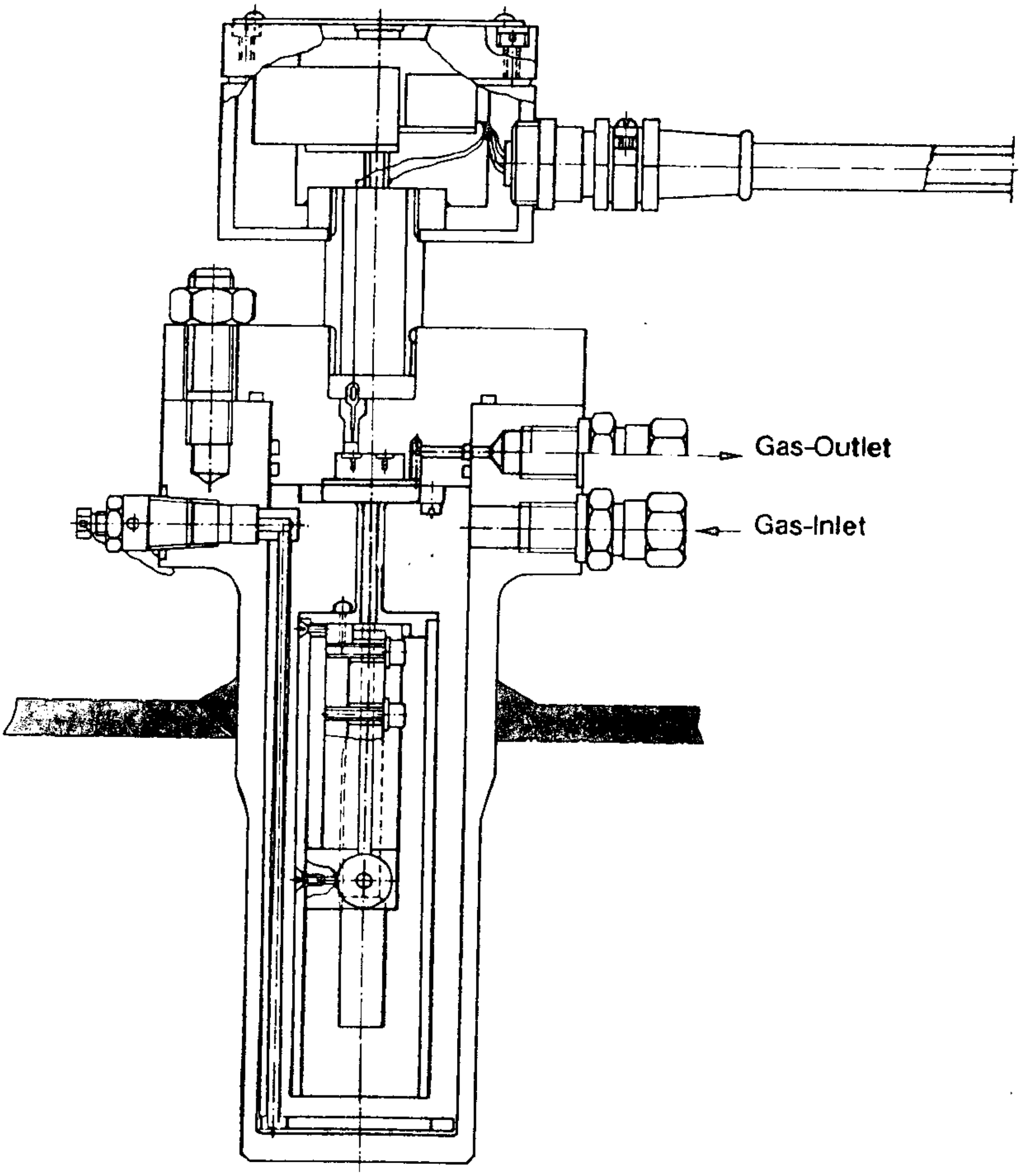

Titel: Gas Densitometer Type DIMB 104.2		
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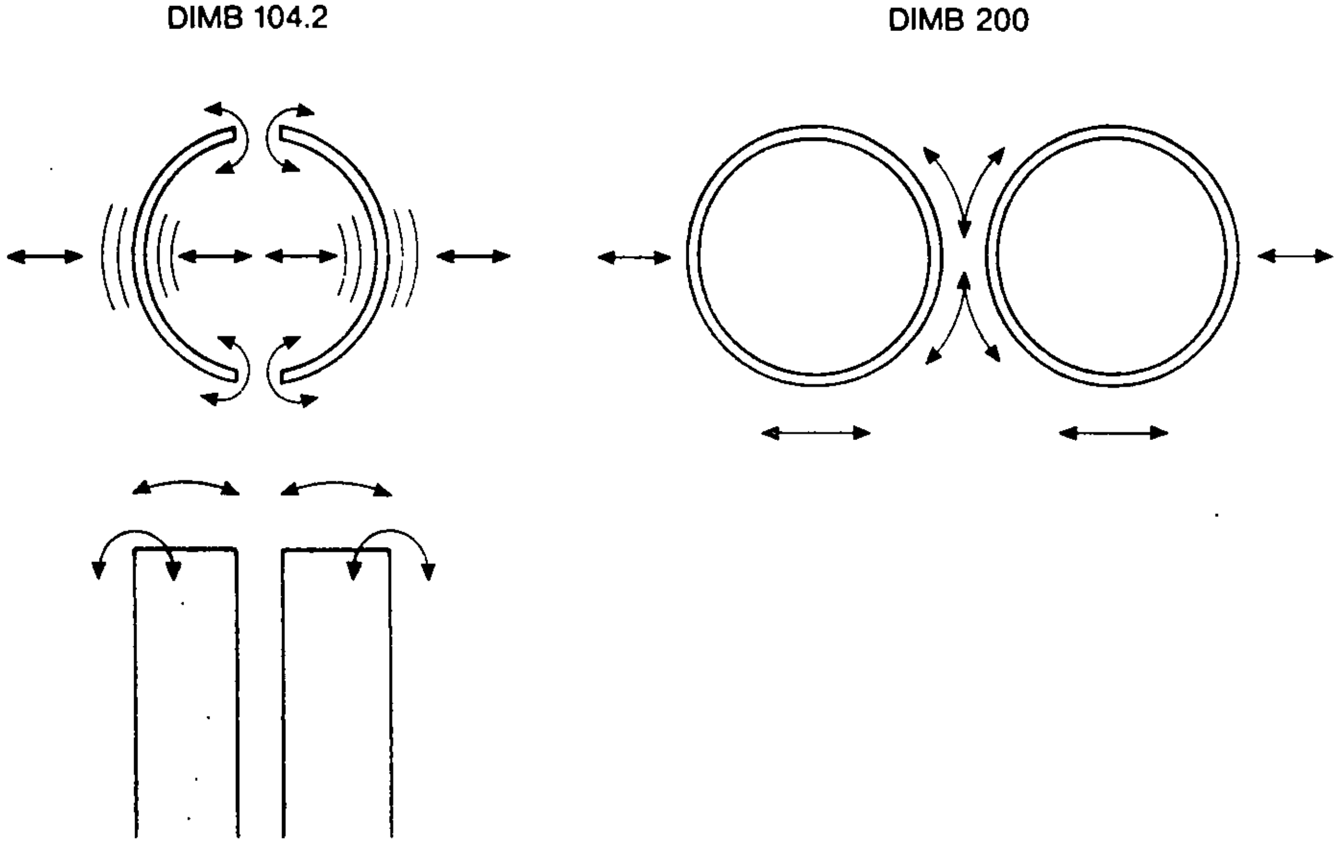
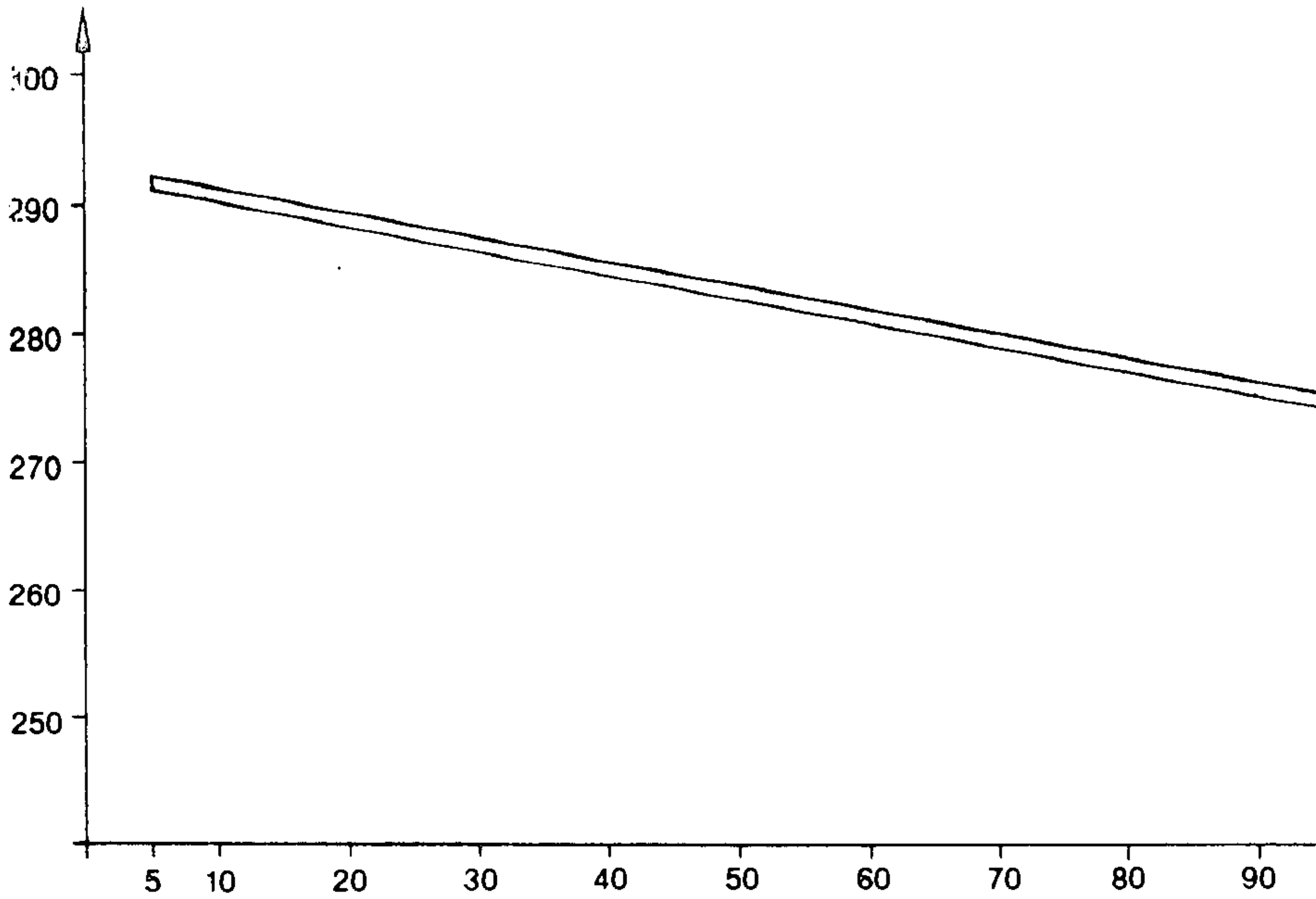


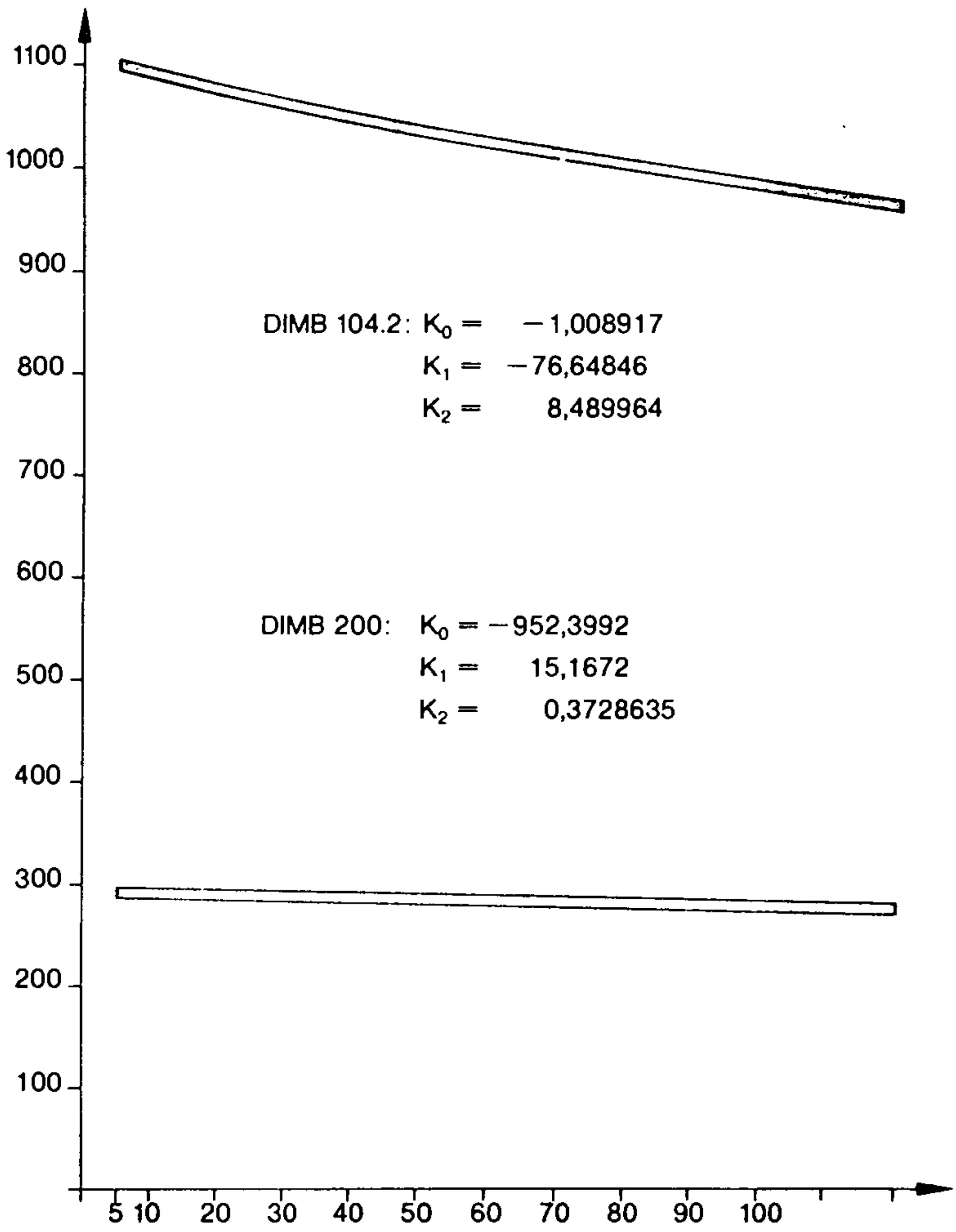
Titel:
Shears and Motions of Gas close to the Tuning Fork

Abb.: 8

M
Unterne



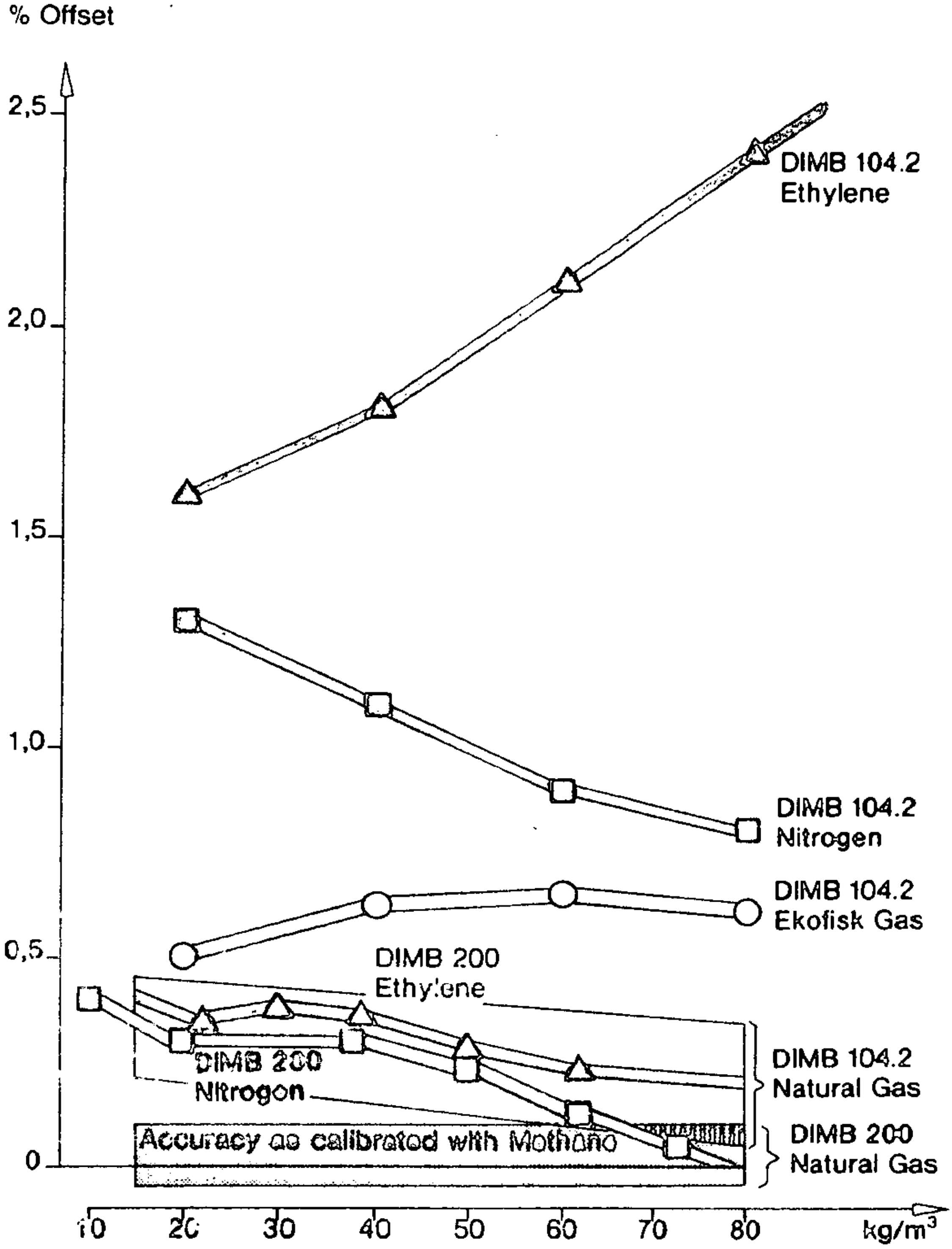
Titel:	Abb.:	
Frequency vs. Density of DIMB 200	9	Untern



Titel:

Frequency Relations of DIMB 104.2 and 200

Abb.: 10	Marketing/ Unternehmensplanung	Datum: 8.87



Titel: Velocity of Sound offset caused by different gases

Marketing/ Unternehmensplanung

Datum: 8.87

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.