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Electronic Gasflowmeters for High Energy Physics

by

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ELECTRONIC GASFLOWMETERS FOR HIGH ENERGY PHYSICS

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DESY - B2 -

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Electronic Gas Flowmeters for High Energy Physics

1. Why do we need electronic flowmeters?

Detectors consist of many assorted types of components. They comprise steel constructions, lead and iron shielding, liquid argon systems together with their associated electronic and high voltage systems. Not least they contain large volumes which are largely filled with various gas mixtures, some of which are highly combustible. These are the drift chambers, proportional chambers, and so on, which are used for tracking the particles, and which, for this reason are mechanically very delicate structures. They cannot be tested for leaks by the usual methods, pressure and vacuum, because they cannot withstand the forces involved. The only remaining alternative is then to try to establish that the difference between input and output flow rates of each module is so low that one can be certain that no dangerous build up of combustible gasses can occur in the experimental halls. Now we know why flowmeters are necessary, paragraph 3 explains why electronic flowmeters offer the best solution.

2. Comparison of the technical possibilities for measuring small gas flows.

It is possible to measure gas flows to an accuracy of 1-5%. It therefore follows that if input and output flow rates are compared, losses due to leaks can only be detected when the leak rate exceeds 1-5% of the total flowrate. Usually the gas for a detector is supplied from a single source and then close to the chambers is distributed to the individual modules, the outputs from which are then reunited and returned to the gas system. By measuring the rates in common flow and return lines, with a typical flow rate of, say, 5,000nl/h it is possible to detect leaks of ≥50nl/h. This is inadequate for combustible gasses. If we measure the flows in the individual channels the same accuracy levels, 1-5%, are achievable, and so it can be seen that by measuring the flows to the individual modules, after distribution, one can get down to a leak rate of the order of <0.01% of the total flow. This is an acceptable level.

3. Which measuring technique?

In many cases flow rates can be measured at the input and output of a chamber by observing the height to which a body rises in a tapered tube due to the gas flowing past it, the so-called "Rotameter". If a pressure drop of 1-3mbar can be tolerated then this is a solution. Rotameters and many electronic flowmeters cause a pressure drop of 1 - 5mbar and for the pressure sensitivity of the chambers under discussion this, on the output side, is already too much. An electronic flowmeter with a practically negligible ($\delta p \leq 0.05$mbar) pressure drop can, however, be built. A further advantage of electronic flowmeters is that readout by a computer enables continuous monitoring and recording, and furthermore, alarm levels can be set which means that human assistance need only be called when the situation demands it. In choosing a measuring system the requirements of negligible pressure drop together with automatic readout were considered to be particularly important. One particular electronic transducer fulfills both of these requirements simultaneously.

4. Principle of operation.

Right from the start it was decided to look for a commercially available system which, in collaboration with the manufacturer, could be modified for this particular application. A search through the catalogues revealed an electronic anemometer* which works on the principle of dependence of heat loss with air speed. It uses two very small temperature dependent resistors, (thermistors, $d \approx 0.5mm$), both of which sit in the air stream. One of these measures the air temperature while the other is maintained at a constant elevated temperature with respect to it. The heat loss of the warm thermistor is then a function of the rate of flow of air over it. The heat transfer coefficient is described by the following equation:

$$\alpha = \text{Constant} \cdot (w \cdot c_p)^{0.786} \cdot \lambda^{0.214} \cdot d^{0.16}$$

Where α = heat transfer coefficient; w = air speed; c_p = specific heat of air; λ = thermal conductivity of air and d = diameter of the heated thermistor. The heat transfer from the heated thermistor is then seen to be proportional to $w^{0.786}$. The heating energy is measured, and as the airspeed increases so the energy required to maintain a constant elevated temperature must increase.

5. Temperature compensation

By using a second unheated thermistor of the same type, mounted in the air stream close to the heated one, a constant temperature difference of say 100°C is held, and so the heat loss is a function of air speed and independent of ambient temperature. This results in a temperature compensated measurement over a sufficiently wide range.

6. Application of the anemometer to other gasses

This principle of operation is clearly not restricted to air, but by appropriate calibration can be used for other gasses since the heat loss a is a function of the conductivity λ, other things staying constant. The commercially available anemometer from the company Prosser in Ipswich, England, works on the principle discussed above and is intended for air velocities in two ranges of 0.1 to 3m/sec and 1 to 30m/sec.

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* Air velocity meter AVM 501 TH from Prosser Scientific Instruments, Hadleigh, Suffolk, GB.

7. Limitations affecting accuracy and setting of alarm levels

A temporary difference between input and output flow rates does not necessarily mean that there is a leak. This can occur when temperatures and pressures in the chamber are not held constant. A typical example of an apparent "leak" is caused when the barometric pressure changes, and is dependent on the volume, (V_x) of the individual chamber modules and the rate of change of barometric pressure, (db/dt). In Hamburg, in extreme cases db/dt can reach ± 5 mbar/h, and value of ± 2mbar/h are common and can last for quite long times (6 - 20 h). Such atmospheric pressure increases cause apparent leaks in the chamber of about 0.2% of its volume/h. In determining the gas flow in a chamber one must allow for such temperature and pressure gradients and set it high enough to cover both eventualities. A gas flow of at least 4% of the chamber volume per hour therefore should be chosen.

8. Technical specification of the flowmeter

The technical specification of an electronic flow meter system becomes clear from the previous discussion.

a. The pressure drop of the transducer in its working range must be $\leq$ 0.05mbar.
b. The measuring system must be capable of tripping alarms at preset levels.
c. Automatic monitoring by means of a multiplexed switching system together with a computer or other data logger must be possible.
d. An accuracy of ± 2.5% must be achieved.

9. Optimum operating range

For air speeds between 0.05 and 0.45 m/sec the measured value increases linearly with air velocity, and therefore this is the optimum range, but the system can be used up to 30m/sec. Above 0.45m/sec the ratio of increasing signal to increasing speed, dU/dw, decreases with increasing air velocity until at 30m/sec. its value becomes zero. Increasing the flowrate beyond this point causes no change in the signal. The specific pressure drop, δp in a pipe of length 1m, is proportional to w^n. The index n varies between 1.7 and 2 according to geometry and air speed. Assuming the conditions that $\delta p < 0.05$mbar for a smooth pipe of length 1m and that the sensor causes negligible pressure drop, for argon (20 °C and 1bar), the following table shows the relationship between maximum flow rate V and speed of gas w as a function of pipe diameter:

d_1 = 4mm $\dot{V}$ = 5,0 nl/h w = 0,11 m/sec
d_1 = 5mm $\dot{V}$ = 12,0 nl/h w = 0,17 m/sec
d_1 = 6mm $\dot{V}$ = 25,2 nl/h w = 0,25 m/sec
d_1 = 8mm $\dot{V}$ = 78 nl/h w = 0,43 m/sec
d_1 = 10mm $\dot{V}$ = 192 nl/h w = 0,68 m/sec
d_1 = 13mm $\dot{V}$ = 552 nl/h w = 1,40 m/sec

After many years of experience it has been found that a flow rate of 10nl/h per channel is typical and so the system was designed with d_1 = 5mm. If larger flowrates are required then the existing construction allows modification to d_1 = 6mm without alteration of the external dimensions.

10. Positioning of the transducer in the pipe

It is well known that the distribution of velocities across a section of a pipe under laminar flow conditions is parabolic, while in turbulent flow, outside the boundary layer it is flat. In figure 1 it may be seen that there is a point at which the two curves cross, and it is therefore sensible to align the two thermistors such that the heated one lies exactly at this radius. In this position the transition from laminar to turbulent flow does not cause a step-function in the measurement. Failure to take such details into account would cause irregularities, at least hysteresis, in the measurements particularly in the transition region, i.e. it would be practically useless in the Reynolds number range 1,600 to 2,300. In order to achieve high accuracy the gas stream around the transducer must be uniform, and this means choosing the longest practicable staight section for the measurement channel. On the other hand this is limited by the requirement to install 6 to 8 crates each with 20 units in a standard 19" electronic rack.

11. Constructional details of the DESY/PROSSER flowmeter

Figure 2 shows that the mechanical construction is a compromise between the longest possible measurement channel and the minimum height of a unit. The individual tubes of 5mm internal diameter are 45mm long. A transistor header with three hermetically sealed, electrically insulated pins has been chosen as a carrier for the two thermistors. They have the additional advantage of being cheap and readily available. The electronic printed circuit board is soldered directly onto this header obviating the need for an additional connector between the electronics and the actual transducer. The distance between the two thermistors should be as big as possible in order to achieve a good zero stability. The heated thermistor must also be positioned in the measurement tube as described in 10 above and illustrated in fig.2. Details of the transistor header with the thermistors are shown in fig.3.
20 such dual measuring systems are mounted on a single aluminium chassis to which the supply and return connectors are fixed together with the individual flow control valves (Kuhnke Type No. SP 747.0129). Together with its power supply and multiplexed system for automatic readout of the individual flow and return rates for 20 chamber channels this crate only takes up 268mm of height in a 19"standard rack. The aluminium chassis and the measurement tube units are so designed that they can be economically and accurately produced on numerically controlled machines. In general the screw fittings, seals and valves are standard items in the business of hydraulics and pneumatics and are therefore produced in large numbers which makes them cheap.The Prosser electronic unit requires 50mA at ±15 volts D.C. per channel. Since there are clear advantages in having a local analogue display on the crate it has been equipped with a "Bar Graph Indicator"

12. Evaluation of the results measured on the prototype

It was necessary to know what flowrates are possible using the Kuhnke control valves SP 747.0129 and so an experiment was performed using a soap bubble counter to measure flowrates of argon, helium, CO_2 and air, dependent on supply pressure at the valve and number of turns of the valve spindle. The values in the following table are averaged, since individual valves have shown measurable differences fom one another; 0,0 turns means the valve is fully closed. At a supply pressure of 1,5 bar absolute the following flowrates were measured for argon:

1,0 turns	$\dot{V}$ = 0,4 nl/min	or	24 nl/h
2,0 turns	$\dot{V}$ = 1,2 nl/min	or	72 nl/h
3,0 turns	$\dot{V}$ = 2,2 nl/min	or	132 nl/h
4,0 turns	$\dot{V}$ = 3,2 nl/min	or	192 nl/h
5,0 turns	$\dot{V}$ = 4,5 nl/min	or	270 nl/h
6,0 turns	$\dot{V}$ = 5,8 nl/min	or	348 nl/h
7,0 turns	$\dot{V}$ = 7,2 nl/min	or	432 nl/h
8,0 turns	$\dot{V}$ = 8,3 nl/min	or	498 nl/h
9,0 turns	$\dot{V}$ = 9,8 nl/min	or	588 nl/h

The effect of doubling the supply pressure to 3 bar absolute was, to a first approximation, to double the flowrate.
If, for example, the system is calibrated for a maximum flow of 30nl/h argon then the signal voltage and flowrate are almost linearly related. A second important result of the tests was that, regardless of whether a given flow is achieved by increasing or decreasing the flowrate from the last value, the DESY/PROSSER flowmeter exhibits no hysteresis, as may be seen in figs. 5 - 8. Changing the gas in use, e.g. from argon to CO_2 causes the constant of proportionality to change by about a factor of two, and shifts the origin. This means that a change from argon to CO_2 at about half the flowrate can be made without the need for recalibration. This is illustrated in fig. 9. The electronics developed by Prosser allows for adjustment to suit various gasses. The largest differences are seen in hydrogen and helium, (see figs. 10 - 13), since they have much greater thermal conductivities than air. As can be seen from the results, when changing from one gas to another it is not absolutely necessary to recalibrate the instruments. From a safety point of view it is the difference in input and output flowrates which count and not their absolute values. After changing gasses it takes a while to flush a chamber completely and, of course, until the input and output flowmeters are measuring the same gas or gas mixture one must accept this difference. A similar effect is seen, as already discussed, if there is a change in atmospheric pressure or chamber temperature.

13. Prices and costs of the system

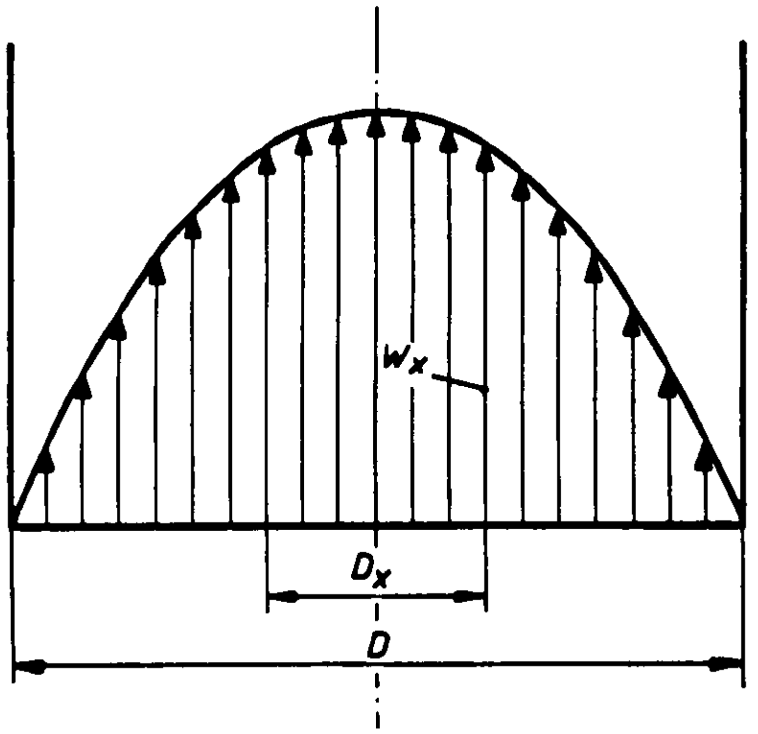
Commercially available instruments working on this principle are very expensive. They cost between DM 2.000,- and DM 3.000,-. This was the reason for starting this collaboration with the manufacturer of the anemometer, Prosser Scientific Instruments, to try to find a way of producing a realistically priced multichannel electronic flowmeter where every channel needs two measurement systems. Now that 42 prototypes have been produced an accurate estimate of the costs can be stated to be close to DM 600,- per channel. This includes all mechanical components, the dual measurement channels together with their thermistors and electronics, the needle valves, bargraphs, alarm indicators and the screw connectors for the tubes to and from the chamber. Additionally 1/20th of the cost of the aluminium chassis, the power supply and wiring is taken into account. What is not included is the interface between this crate and the computer where the signals are digitised and automatically read out.

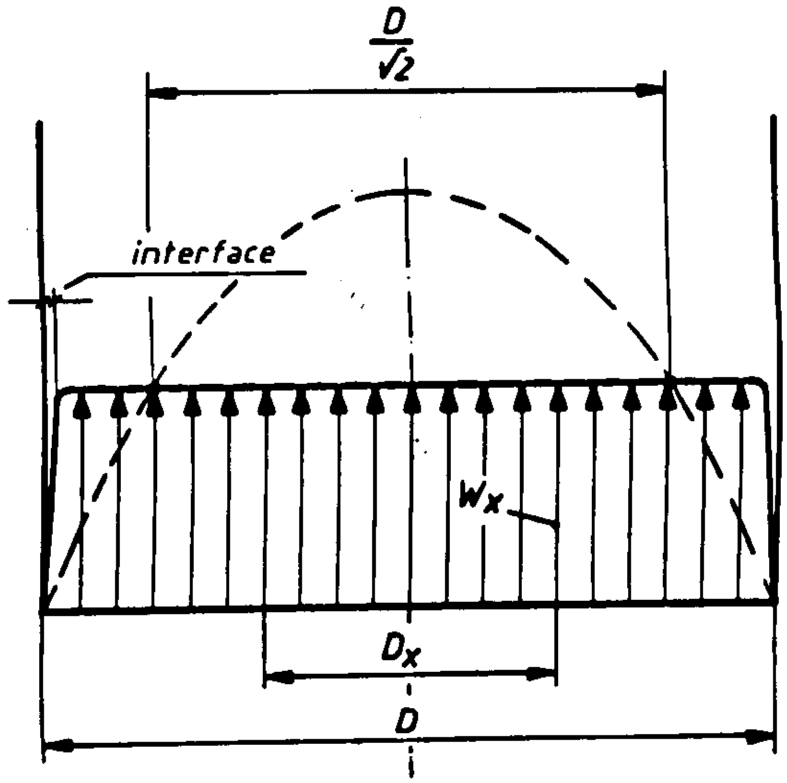
14. Acknowledgements

In particular I am indebted to Dr. Jeremy Prosser and David C. Jessop of Prosser Ltd. who together with their encouragement have also brought the wealth of their experience in this field to the project. Next I would like to thank my colleagues in the groups B2, H1, ZEUS and F56 who by discussion and enthusiasm contributed to working out and developing the DESY/PROSSER flowmeter and bringing it to fruition. Particular thanks are due to Frau Christine Kretschmann, -B2-, for preparing the engineering drawings and her valuable help in the construction. Then I would like to express my gratitude to Herr Wolfgang von Schröder, also from B2, who carried out the prototype tests and presented the results. Last but not least I want to thank Dr. H. F. Hoffmann, who as head of the "Z" section at DESY made the whole thing possible.
I have to thank exspecially Derek Darvill, who did the English translation.

Figure No. 1

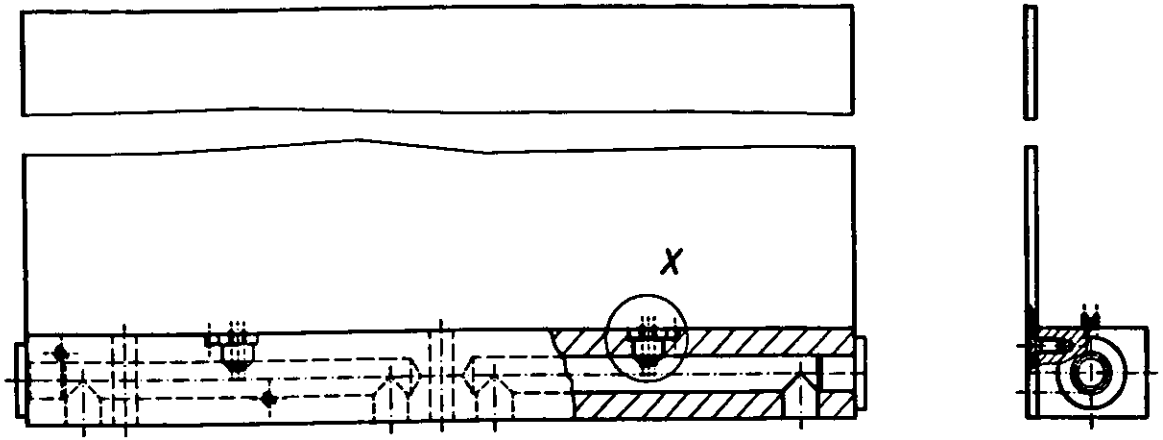
Possible flow profiles for constant flow in the transition range $1600 \leqq Re \leqq 2300$

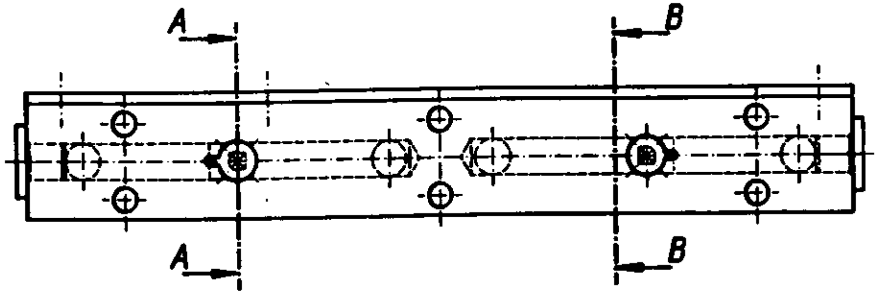




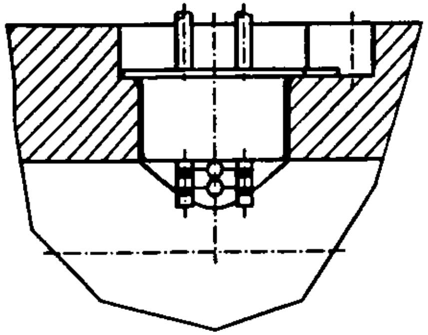
Only on the circumference with the diameter $D_x = \frac{D}{\sqrt{2}}$ the local flowvelocity W_x is not changing. if the laminary flow is changing to turbulent flow.

Figure NO. 2

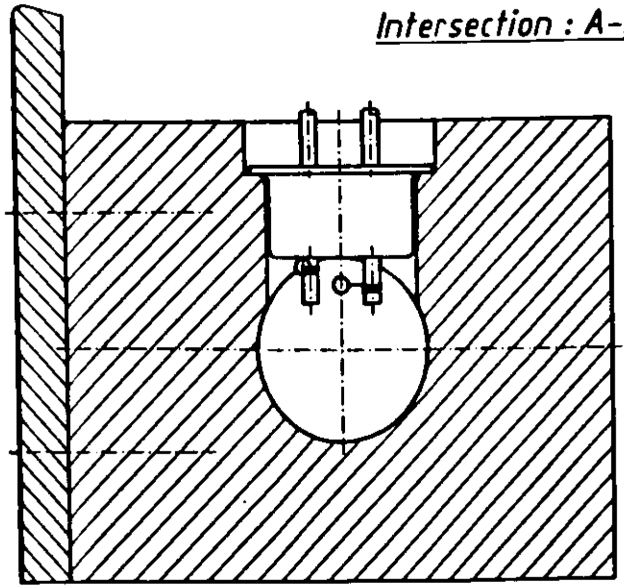




Detail : X



Intersection : A-A



Intersection : B-B

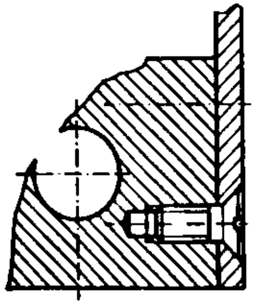
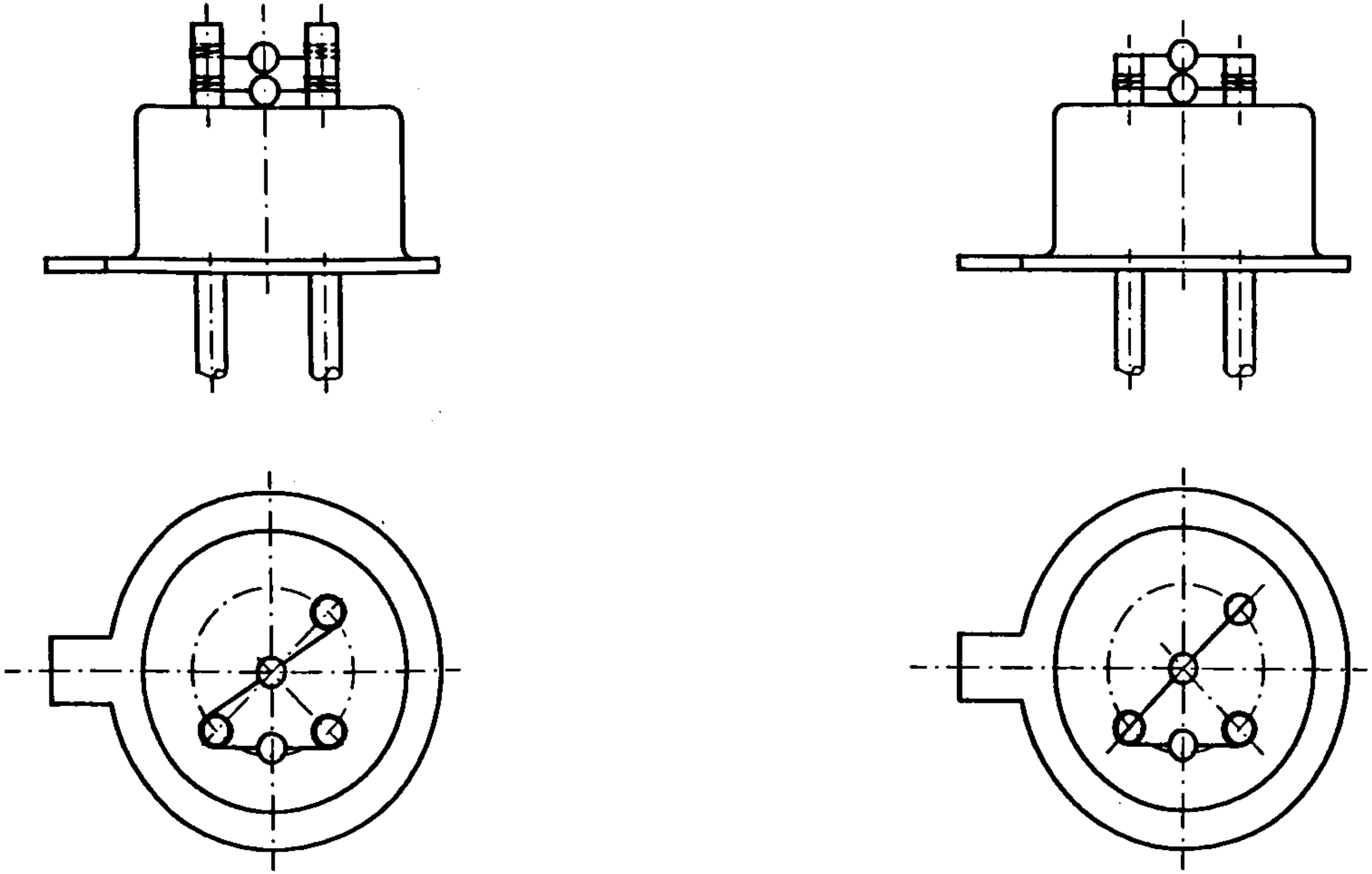
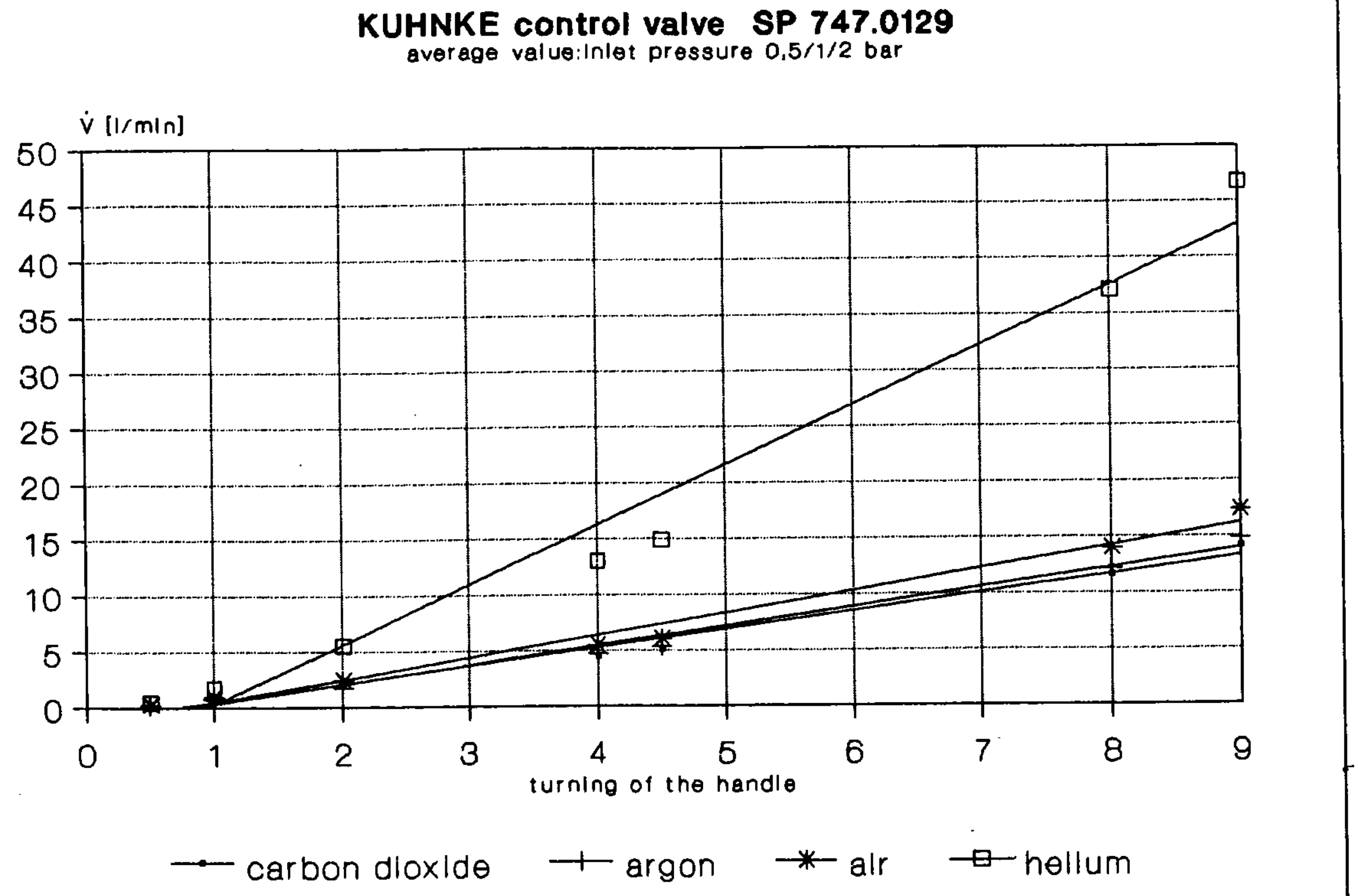


Figure No. 3



The thermistor legs are dot welded to the pins of the transistor header.

Figure NO. 4



KUHNKE control valve SP 747.0129
average value:inlet pressure 0,5/1/2 bar

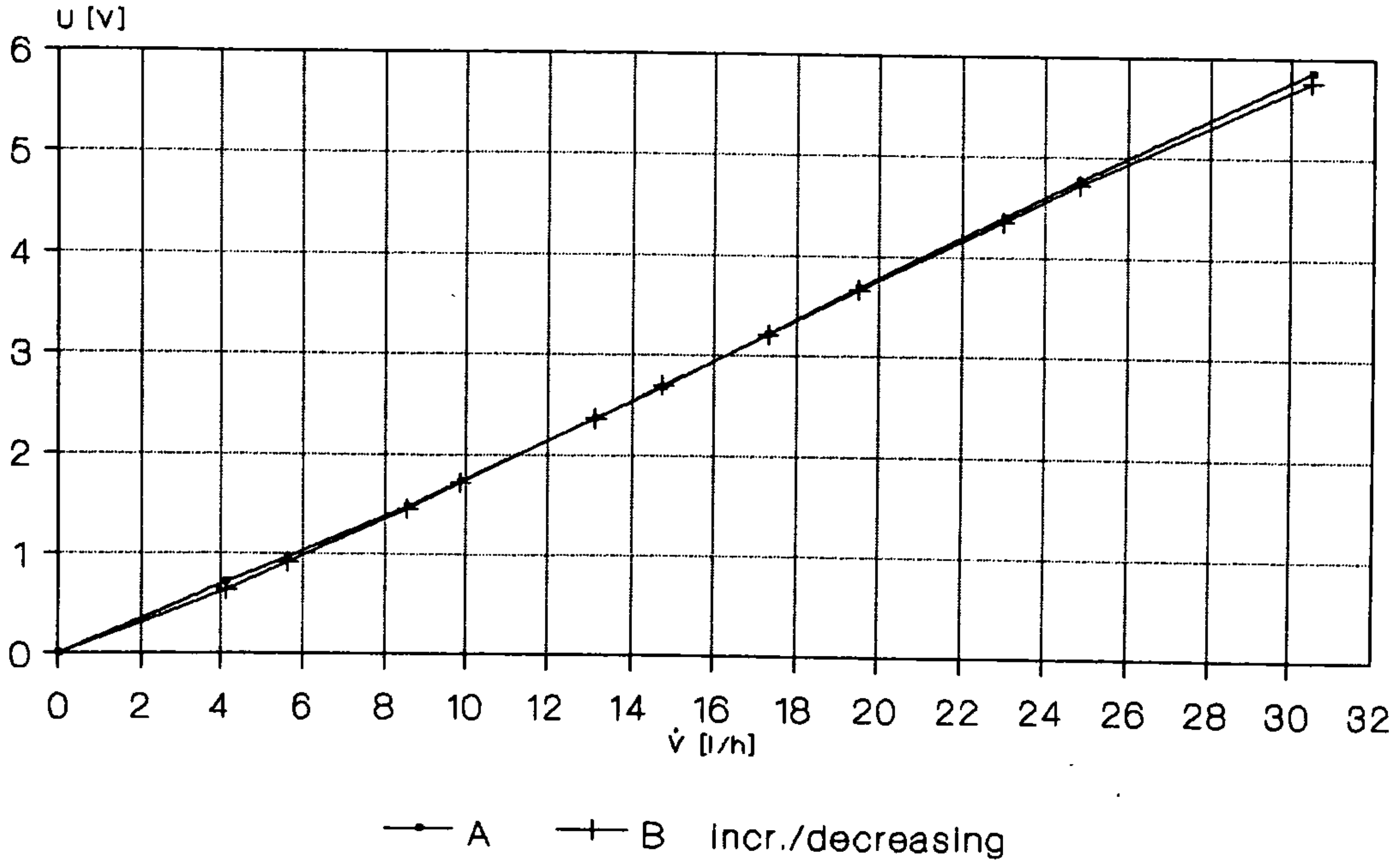
20.2.90
W. v. Schröder - B 2 - 0113

measuring channel d = 5 mm

Figure NO. 5

Electronic flowmeter

medium: air
pressure: 1,0 bar temp.: 20 °C



measuring channel d = 5 mm
A: entrance B: exit

22.2.1990 W. v. Schröder - B 2 - 0101

Figure NO. 6

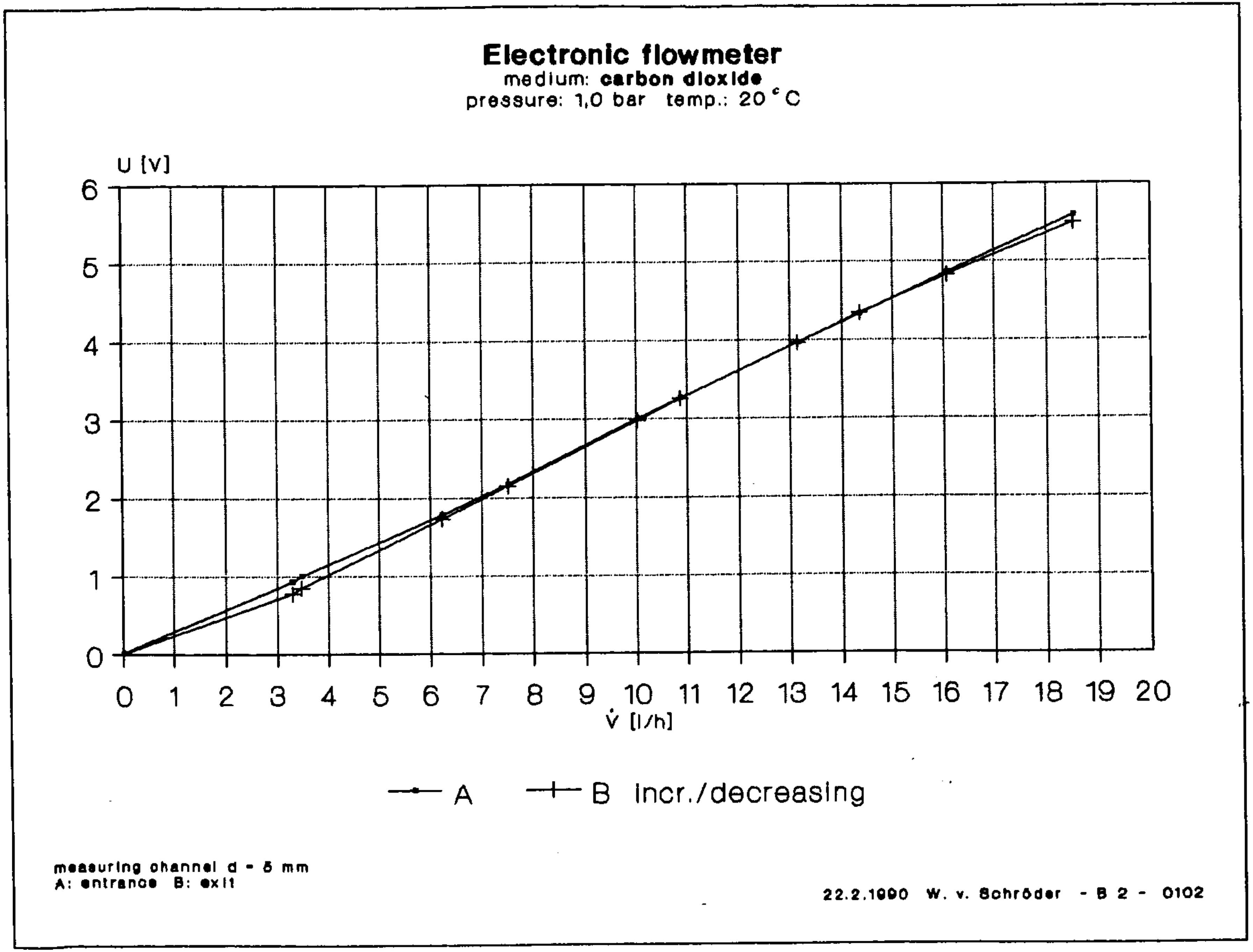
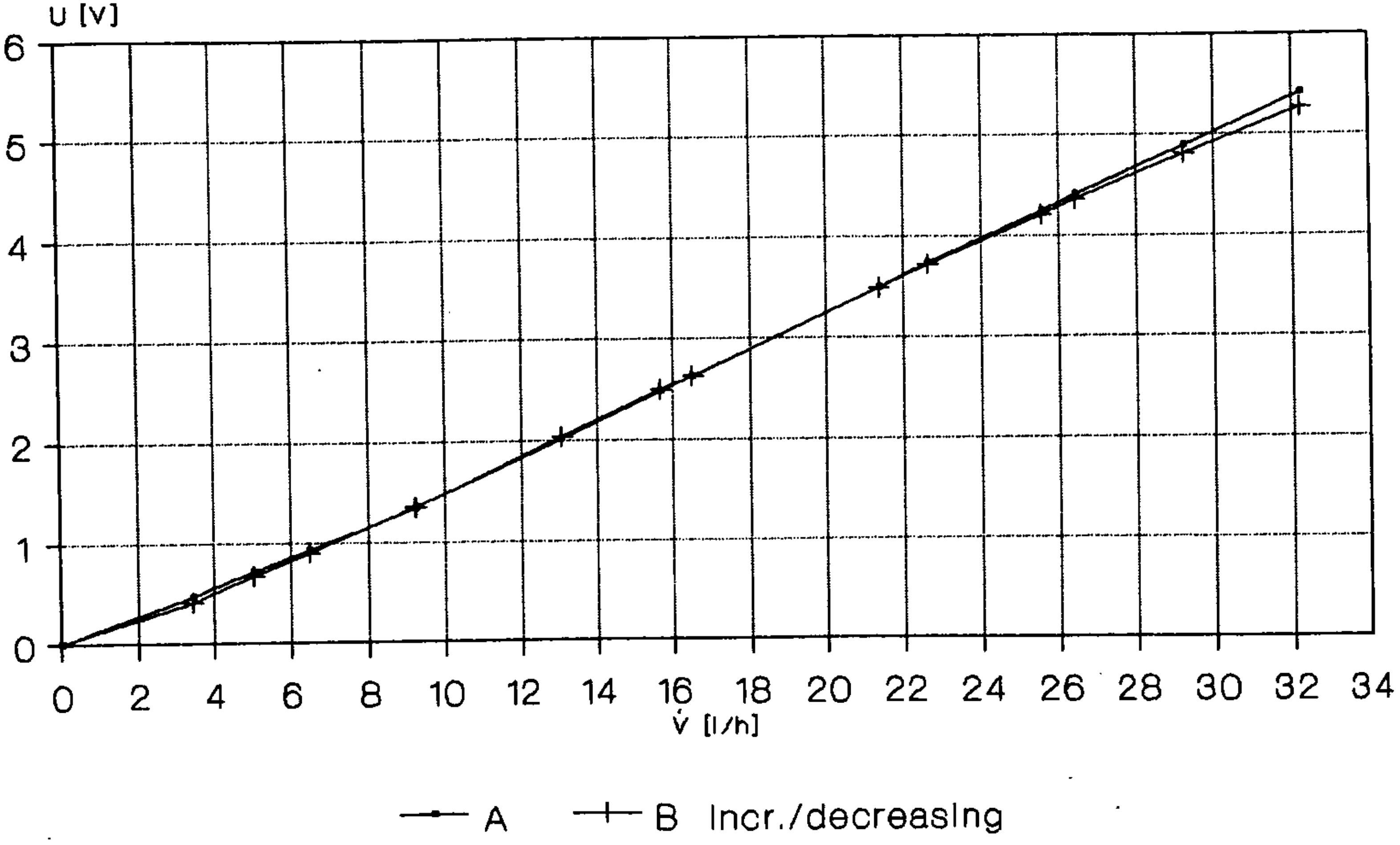

Electronic flowmeter
medium: carbon dioxide
pressure: 1,0 bar temp.: 20 °C
U [V]
0
1
2
3
4
5
6
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
V̇ [l/h]
A
B incr./decreasing
measuring channel d = 5 mm
A: entrance B: exit
22.2.1990 W. v. Schröder - B 2 - 0102

Figure NO. 7

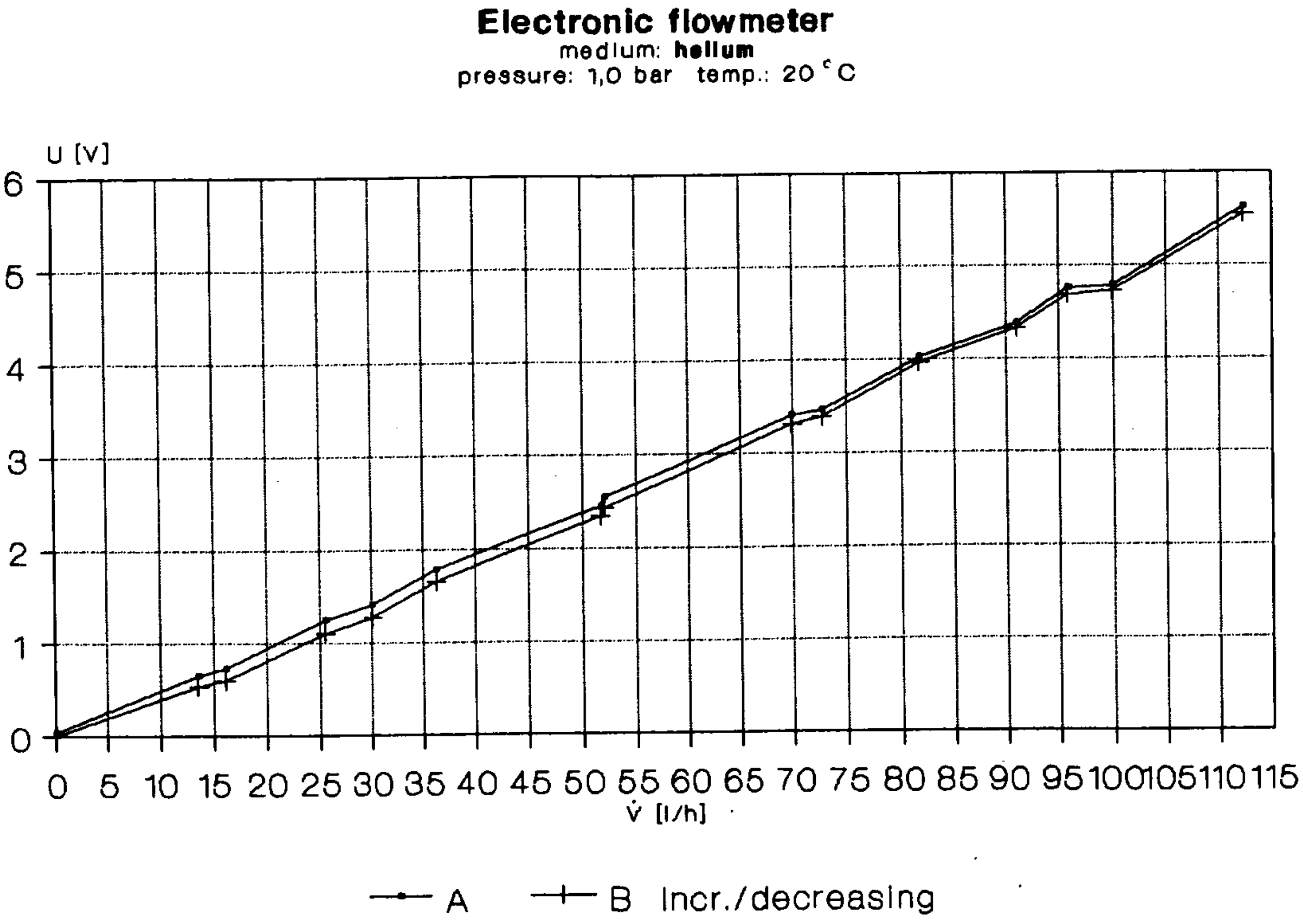
Electronic flowmeter
medium: **argon**
pressure: 1,0 bar temp.: 20 °C



measuring channel d = 5 mm
A: entrance B: exit

22.2.1990 W. v. Schröder - B 2 - 0103

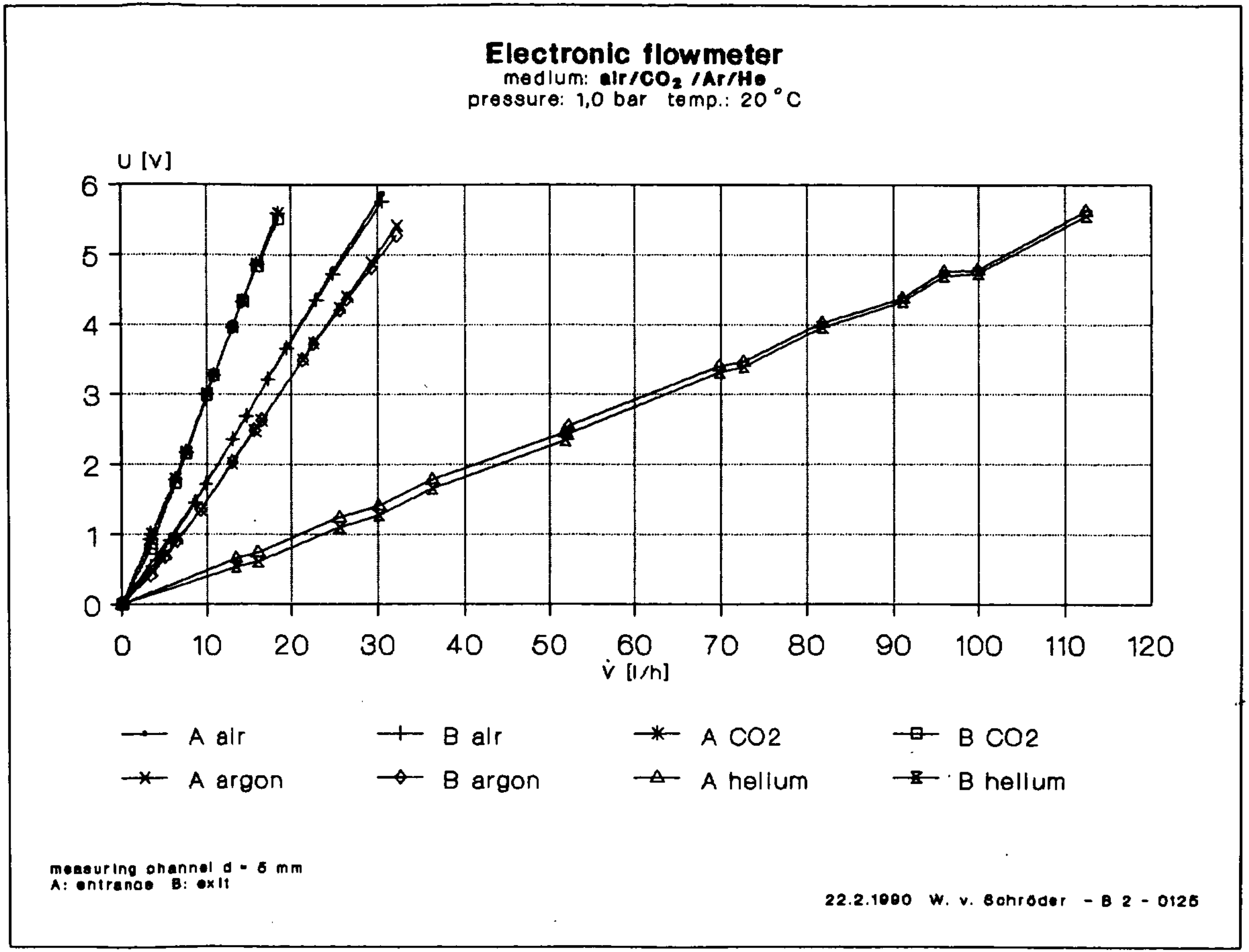
Figure NO. 8



measuring channel d = 5 mm
A: entrance B: exit

22.2.1990 W. v. Schröder - B 2 - 0114

Figure NO. 9



measuring channel d = 5 mm
A: entrance B: exit

22.2.1990 W. v. Schröder - B 2 - 0125

Figure NO. 10

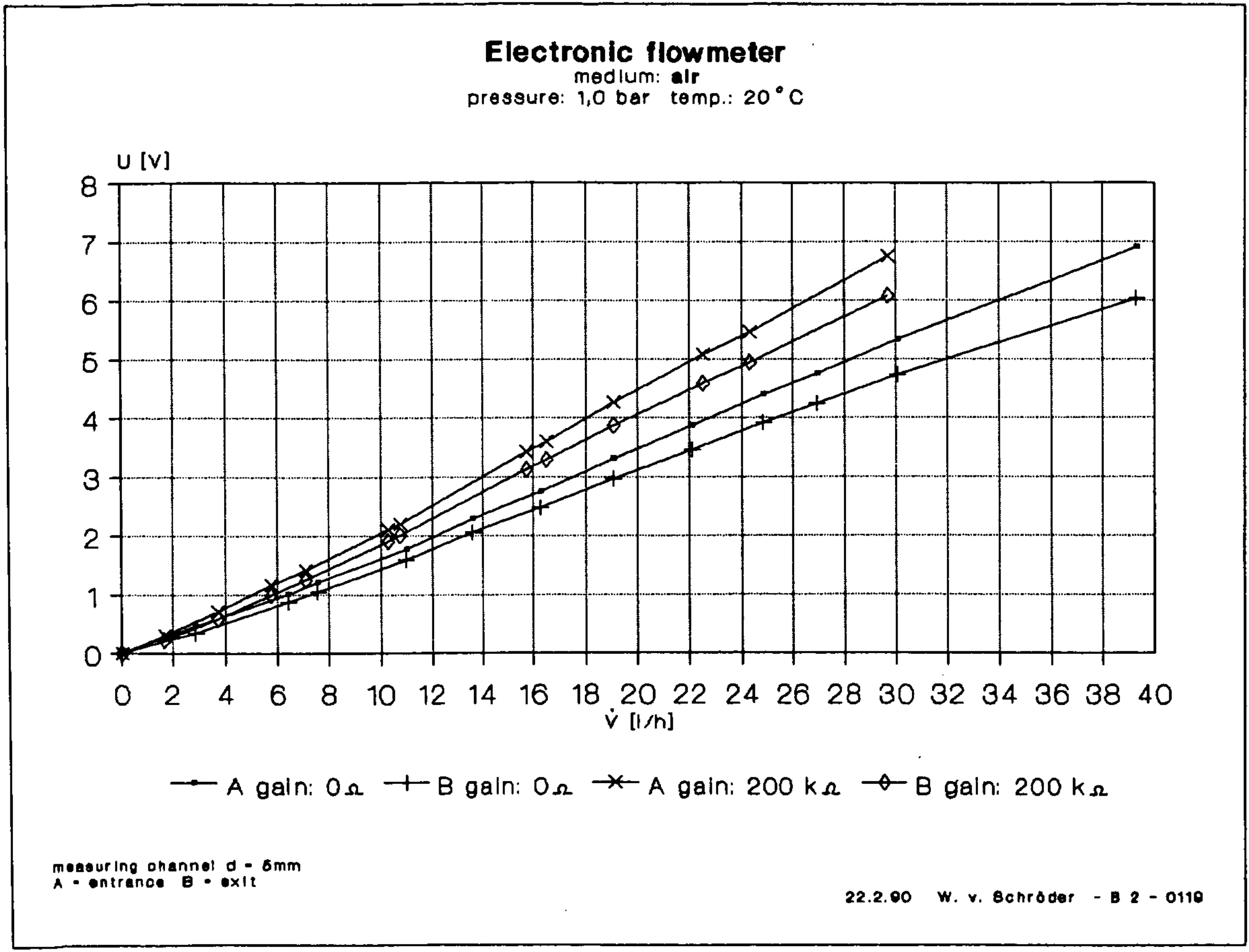
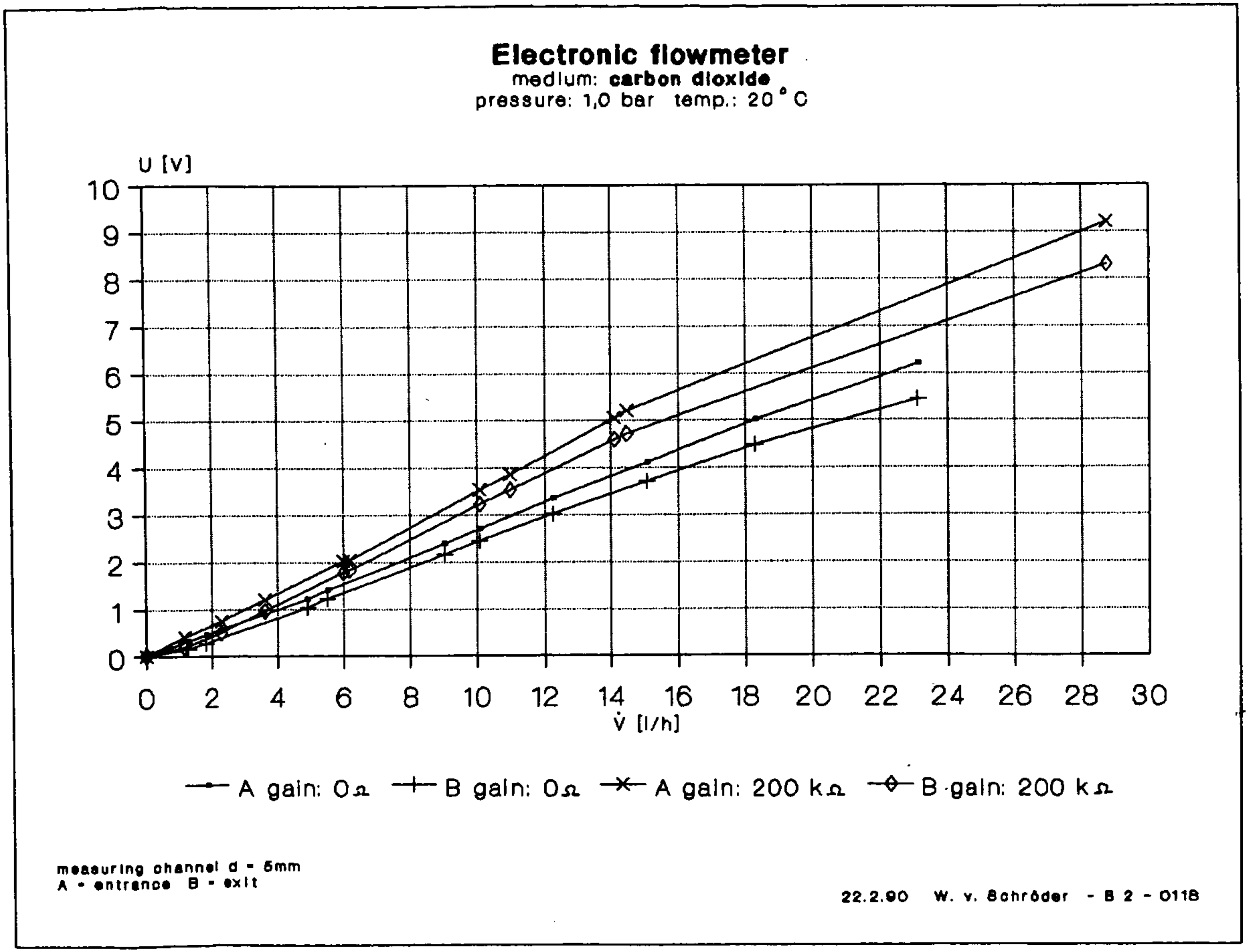

Electronic flowmeter
medium: air
pressure: 1,0 bar temp.: 20 °C
U [V]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
V̇ [l/h]
A gain: 0 Ω
B gain: 0 Ω
A gain: 200 kΩ
B gain: 200 kΩ
measuring channel d = 5mm
A = entrance B = exit
22.2.90 W. v. Schröder - B 2 - 0119

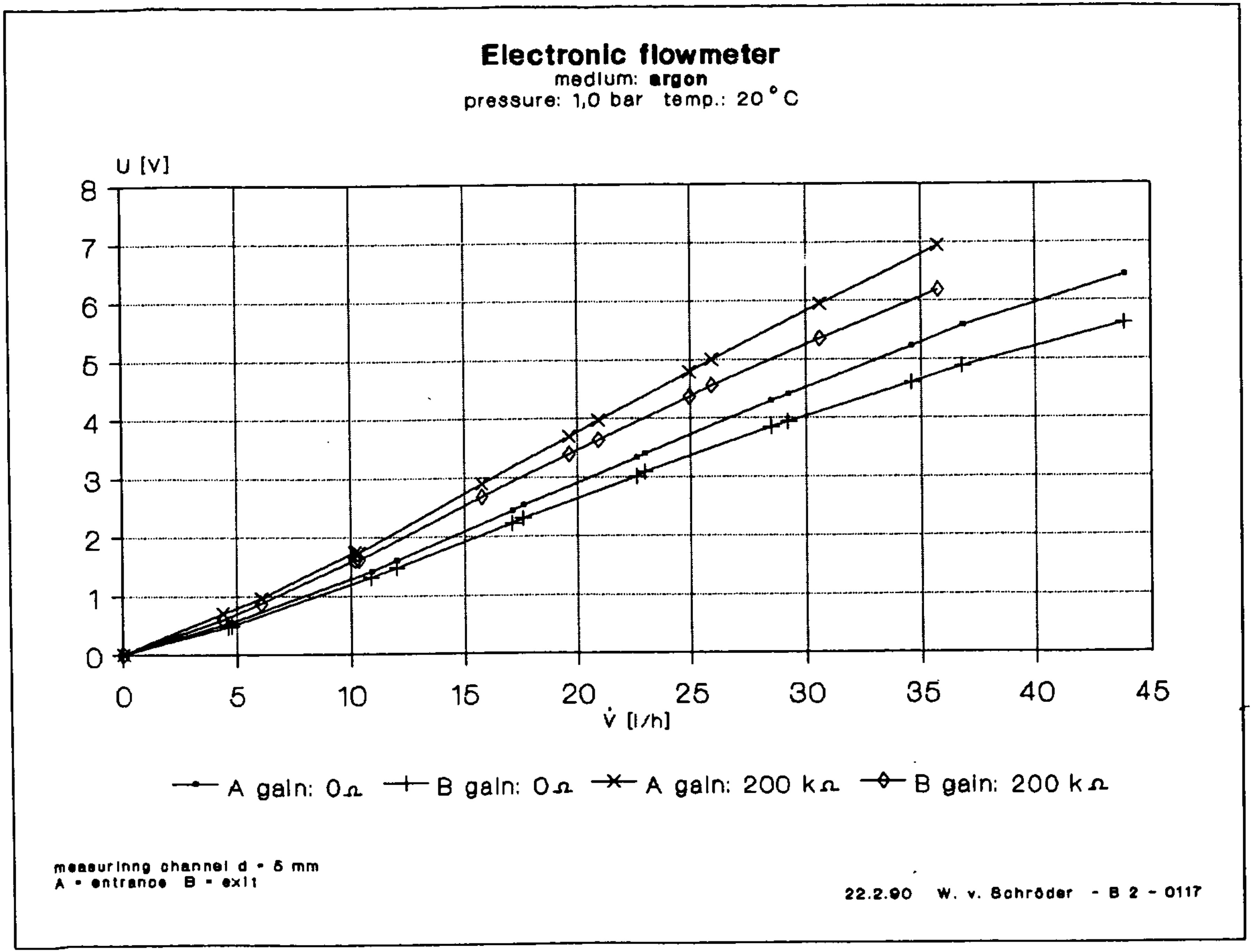
Figure NO. 11



measuring channel d = 5mm
A = entrance B = exit

22.2.90 W. v. Schröder - B 2 - 0118

Figure NO. 12

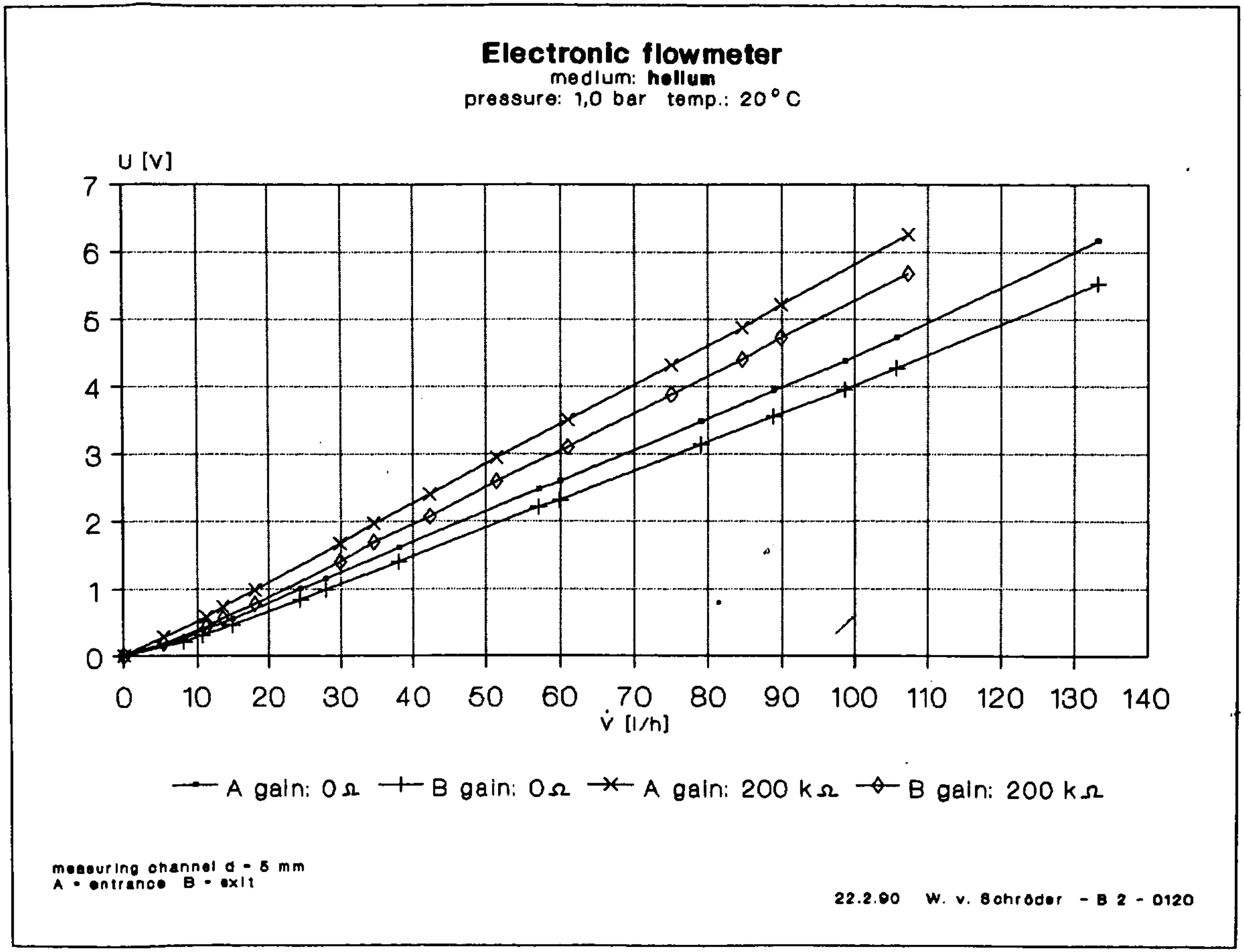


Electronic flowmeter
medium: **argon**
pressure: 1,0 bar temp.: 20 °C

measurinng channel d = 5 mm
A = entrance B = exit

22.2.90 W. v. Schröder - B 2 - 0117

Figure NO. 13



measuring channel d = 5 mm
A = entrance B = exit

22.2.90 W. v. Schröder - B 2 - 0120

Figure No. 14

Chassis with 20 dual flowmeters