

Analysis and elimination of disturbing flowrates deviations between a 24" ANSI 600 ultrasonic meter and vortex meter in a natural gas meter station.

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1 INTRODUCTION

The VNG is operating an approx. 4.500 miles long pipe network for natural gas (Fig. 1) in the eastern part of Germany. One of the most significant stations of this network is the Steinitz gas transfer station which is located about 40 miles north of Magdeburg. Since its commencement of operation, the station is equipped with five measuring lines G4000 (max. 6.500 m³/h where each line consists of a permanent series arrangement of turbine meter (TRZ) and vortex meter (WBZ).

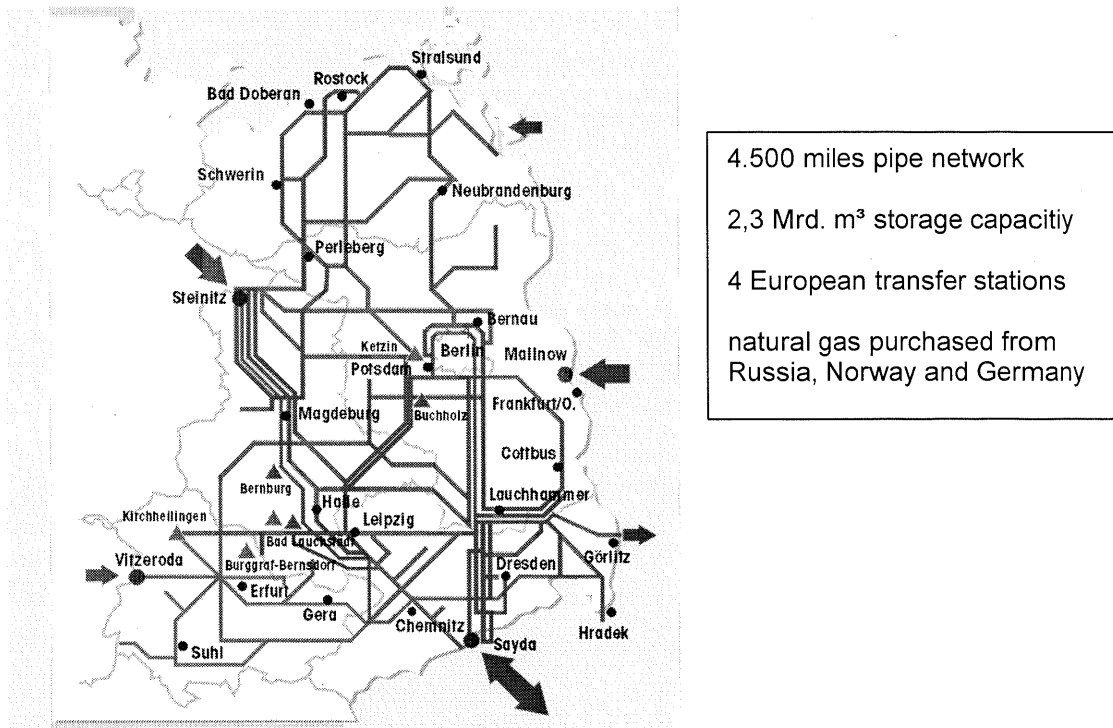


Fig. 1: Location of the „Steinitz“ station in the natural gas network of the VNG-Verbundnetz Gas AG in the eastern part of Germany.

From the viewpoint of system planning, it became necessary as from the year 2000 to substantially expand the transfer capacity of the station. For this purpose, there was a variant in the additional erection of three further measuring lines similar in design. For reasons involving costs and due to the more convenient handling, preference was given to the new construction of a 24" ANSI 600 measuring line consisting of a permanent series arrangement of an ultrasonic meter (USZ) and a G25000 WBZ (max. 40.000 m³/h) as well as a control valve located downstream. In order to realise a shorter construction length, it was planned to arrange the USZ in the inlet zone of the WBZ – according to a recommendation of the VNG. The permits for the USZ as well as for the WBZ had to be changed accordingly.

In addition to the evident advantages of this solution (no moving mechanical parts and, subsequently, high overload safety, long-term stability, large throughput line, diagnostics options of the USZ, short construction length), the ultrasonic emissions of the control unit to be installed were regarded as critical from the very beginning with reference to the USZ. In order to obtain planning safety for the new installation, the influence of various structural designs of control valves on the USZ in a 12" ANSI 600 natural gas measuring section in Sayda was therefore examined. In this case, the control ball valves proved to be the most favourable variant. At the same time, the control ball valves indicated significantly smaller pressure losses in the full load range compared with other armatures. For this reason, the installation of a control ball valve for Steinitz was envisaged (Fig. 2).

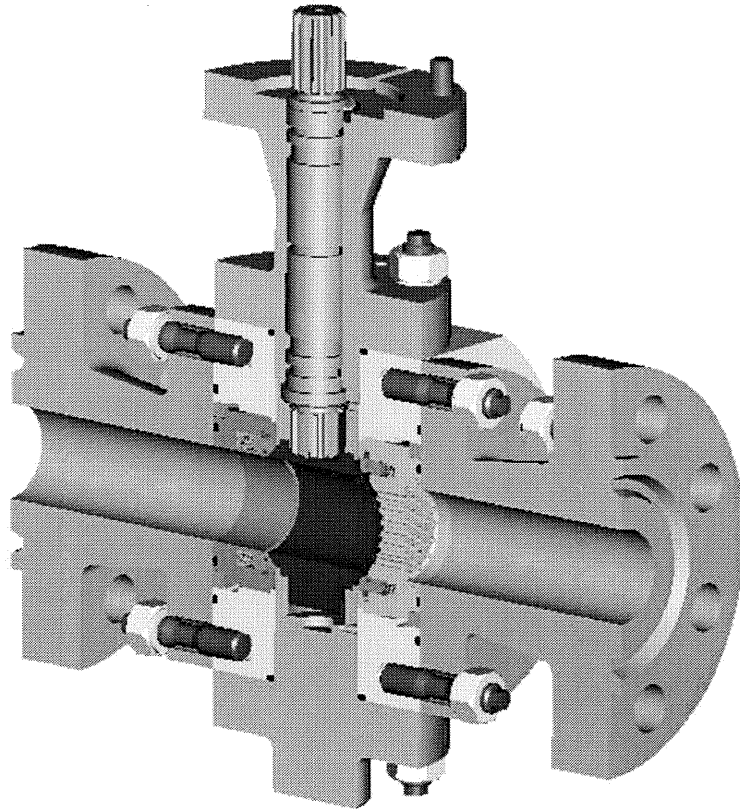


Fig. 2: ARTEC control ball valve with lower ultrasonic emissions and pressure losses at full load.

2 PRELIMINARY EXAMINATIONS

The new measuring section went into operation in November 1998. However, even at low level volume flows (flow velocity approx. 3 m/s), a total failure of the ultrasonic meter occurred as a result of ultrasonic disturbance noise levels. The source of these noise levels was not the control ball valve but rather the additionally installed ultrasonic silencer. This disturbance was quickly eliminated by removing and returning the ultrasonic silencer.

Furthermore, a considerable synchronism deviation was detected between the USZ and the WBZ of approx. 1,3 % during the startup phase. This fact was incomprehensible because, during the high pressure test, both meters had a max. deviation of 0,5% from each other and this difference was even corrected in the flow computers.

In order to eliminate the synchronism deviation, various measures were tested and realised before a second high pressure test (HP-test) as well as an extension of the inlet zone by 40 D were implemented. Whereas the WBZ again found its HP-curve approximately during a repeated high pressure test, a systematic shift of 0,5% was discovered at the USZ. It has not been possible up to the present day to clarify the cause of this shift.

During the startup of the reconstructed measuring section, it was discovered that only the renewed high pressure test had produced a reduction of the shift to now 0,8%. The extension of the inlet had no influence on the synchronism quality of the meters. This condition remained unsatisfactory for an accounting measurement. For this reason, the third measuring device installed was a G16.000 turbine meter (TRZ) (max. 25.000 m³/h). By comparing the meters, it was possible to identify the WBZ as a primary source of the shift. Subsequently, it was recognised as a fact that the plant influences the WBZ.

In order to analyse the physical reason for this influence, pulsation measurements were carried out by the manufacturer of the meter in a first step. In this case, there were no critical values whatsoever for the WBZ. Following this, and by means of repeated rebuild operations, further plant-related influences (inlet disturbances, function of the flow computers, pressure and temperature transmitter) were ruled out, so that the last possible cause was the control ball valve about 30 meters downstream (approx. 50 x D). In order to examine this influence variable, a sophisticated test was carried out where the differential pressure over the station was lowered for a brief period, so that the opening angle of the control ball valve could be increased from 20 % to 80 %. The change of the measuring behaviour of the WBZ with reference to the USZ is illustrated in Fig. 3.

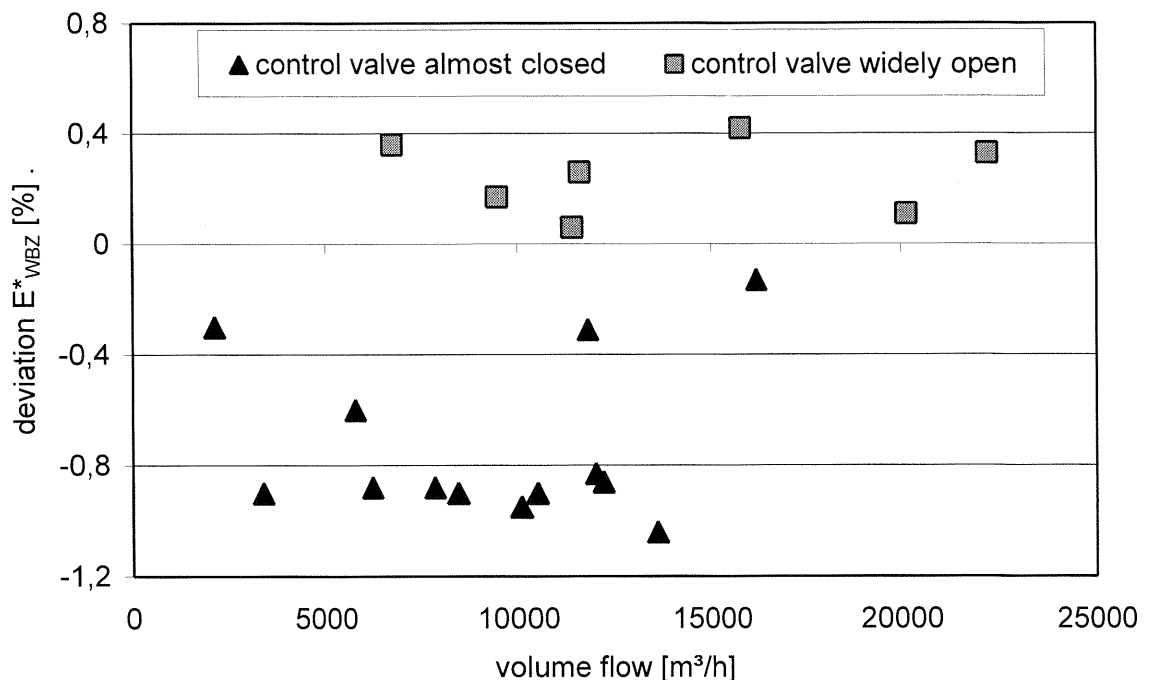


Fig. 3: Deviation of the corrected standard volume flows E^*_{WBZ} between the ultrasonic and the vortex meters over the operating volume flow for various positions of the control ball valve.

In the result, the WBZ and the USZ showed only a synchronism deviation of approx. 0,3% in various working points. An shift of approx. 1% resulted. Subsequently, the following questions arose for solving the problem “synchronism difference”:

How can a control valve located 50 x D upstream influence a vortex meter?

What technical alterations are necessary in order to reduce the synchronism deviation?

3 PULSATION AND VIBRATION MEASUREMENT

In order to clarify these points, KÖTTER Consulting Engineers (KCE) was involved. They carried out a comprehensive measurement-technical examination at the measuring section (Fig. 4). In this case, the pressure fluctuations in the natural gas were recorded at various locations simultaneously with the structure vibrations at the WBZ and the sound pressure levels next to the measuring section. At the same time, the wanted signals of the flow meters as well as further PLS-data were recorded. The measurements were carried out at different volume flows and differential pressures across the control ball valve at practically constant static pressure within the measuring section.

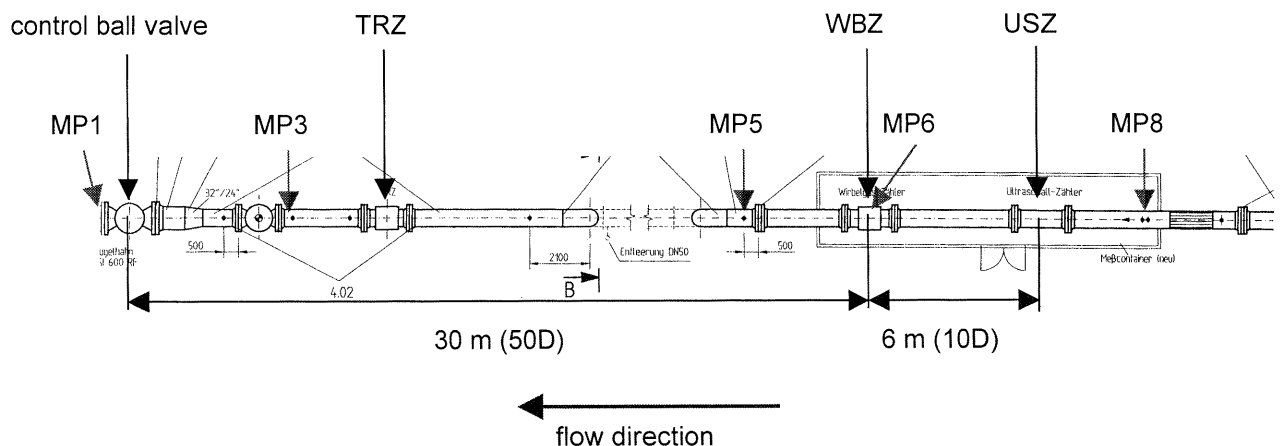


Fig. 4: Arrangement of the 24" ANSI 600 measuring section as well as location and designation of the pressure measuring points.

- (TRZ Turbine meter)
- (WBZ Vortex meter)
- (USZ Ultrasonic meter)

Then, the operating volume flows are determined for each meter from the measured rectangular impulses. By way of the relationship

$$E_{WBZ} [\%] = \frac{\dot{V}_{WBZ} - \dot{V}_{USZ}}{\dot{V}_{USZ}} \cdot 100 \quad (1)$$

the deviation E_{WBZ} results, which is plotted in Fig. 5 for various standard volume flows via the differential pressure. Due to the missing consideration of reference pressures and temperatures, a comparison of the illustrated curves of different standard volume flows is not directly possible.

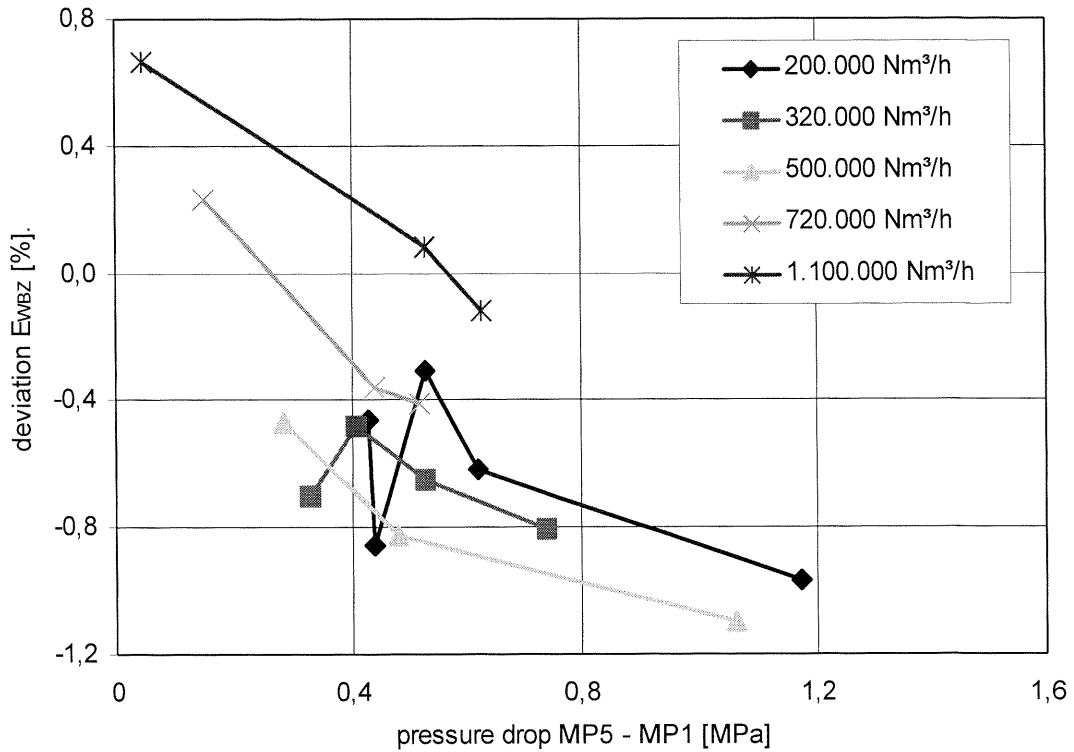


Fig. 5: Percentage deviation of the operating volume flows between the vortex and ultrasonic meters over the differential pressure for various standard volume flows.

An existing systematic correlation for each standard volume flow between the deviation E_{WBZ} and the differential pressure across the control ball valve is conspicuous. With increasing differential pressure the vortex meter indicates an increasingly smaller operating volume flow compared with the ultrasonic meter. This synchronism change of up to 0,8% is clearly caused by the control ball valve because, at constant standard volume flow and static pressure, no further influence parameters (e.g., current flow profile, twist) are changed.

In addition, the effective pressure fluctuations show a systematic correlation between the volume flow and the differential pressure (Fig. 6). They become stronger with increasing throughput and differential pressure.

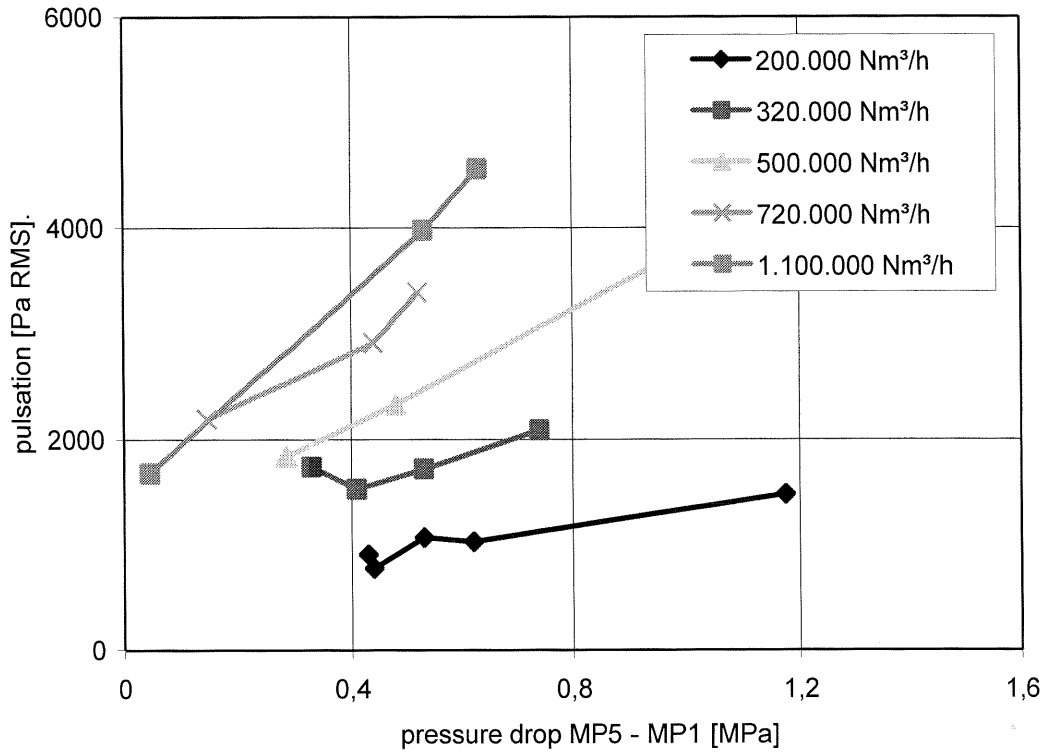


Fig. 6: Effective values of the pressure fluctuations (2 Hz - 1.500 Hz) at the measuring point MP8 over the differential pressure for different standard volume flows (including nozzle resonances).

There is evidently an inner correlation between the synchronism quality and the pressure fluctuations in the natural gas flow. For further analysis and for this reason, it was examined to see if relevant acoustical resonances (plain waves or transverse modes) establish themselves in the measuring section. These resonances are known for the fact that they primarily lead to substandard indications in vortex meters. By comparing the pressure signals measured simultaneously at different positions, this cause was clearly ruled out (Fig. 7). A periodic pressure fluctuation can be recognised only at the measuring point MP6 at approx. 32 Hz which is caused by the vortex shedding at the disturbance body of the vortex meter.

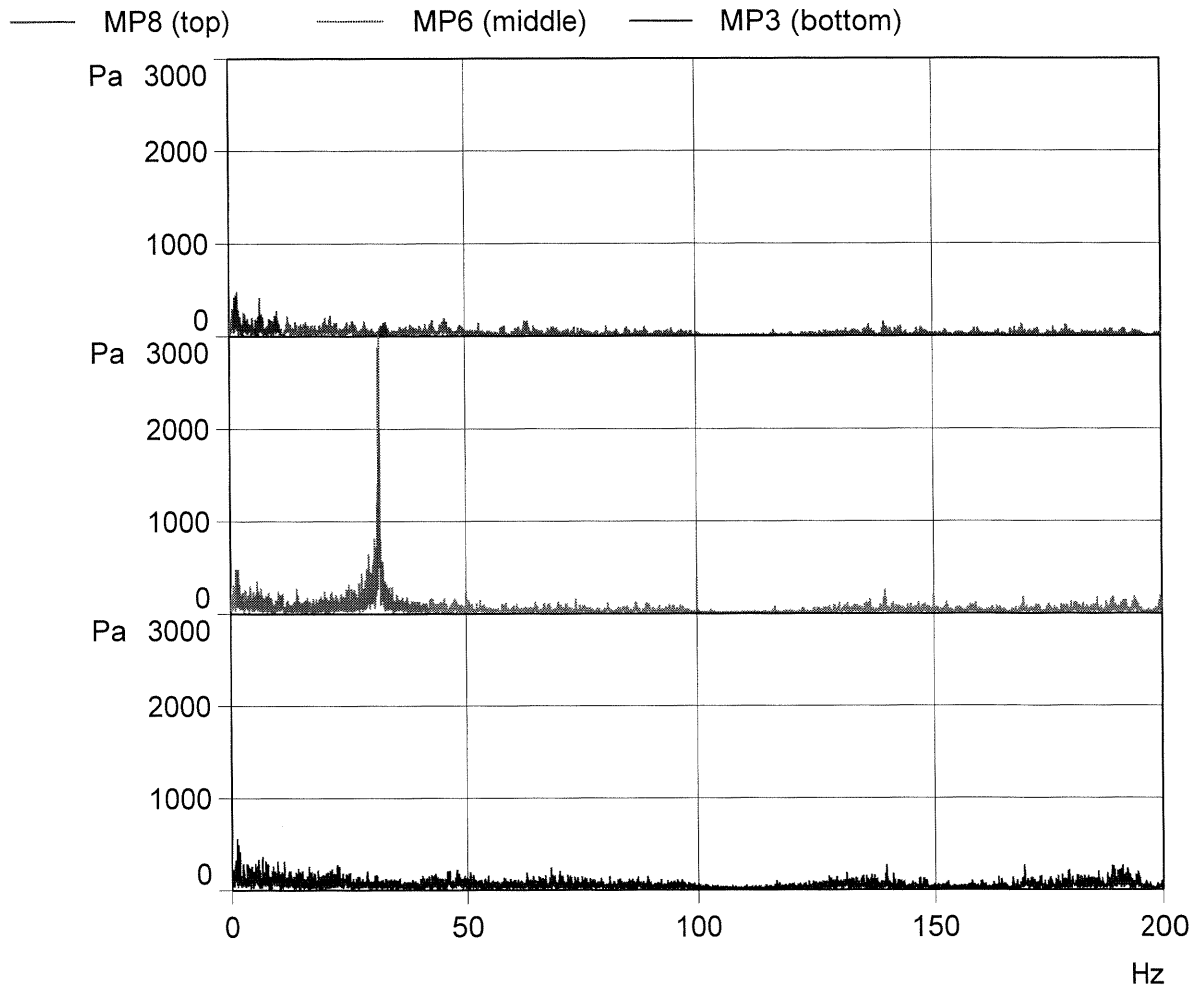


Fig. 7: Amplitude spectrums of the simultaneously measured pressure fluctuations at the measuring points MP8, MP6 and MP3 at a standard volume flow of 1.100.000 Nm³/h and a differential pressure MP5 – MP1 of 0,53 MPa.

The effective values of the pressure fluctuations are rather dominated by a broadband noise and the individual nozzle resonances (MP8 approx. 1.100 Hz) (Fig. 8). Above 200 Hz, the sound pressure levels increase with the differential pressure. The control ball valve, in this frequency range and with increasing differential pressure, emits a higher sound output which propagates in the downstream direction as well as in the upstream direction – meaning, in the direction of the measuring section.

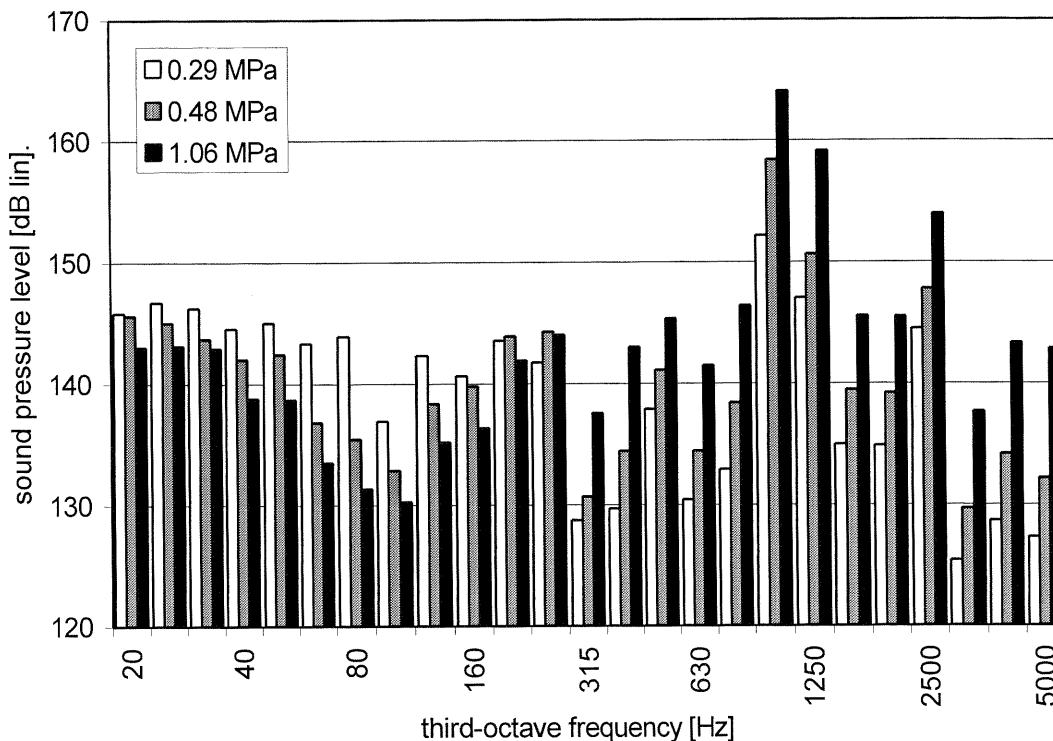


Fig. 8: Sound pressure level at measuring point MP8 over the third-octave frequencies for various differential pressures MP5 – MP1 for a standard volume flow 500.000 Nm³/h (incl. nozzle resonances).

No further systematic correlations whatsoever were detected between the positional setting of the control ball valve and the synchronism between WBZ and USZ. Therefore, there was a strong inclination to assume that the WBZ is influenced by the stochastic pressure fluctuations and/or the according velocity fluctuations. Following specialised research in literature, it was possible to corroborate this thesis [1 – 5]. As verified by wind tunnel analyses, the vortex shedding frequency (Strouhal number) is not only a function of the Reynold's number, but is also a factor of the turbulence degree of the flow and the related coherence length of the turbulence (Fig. 9) [5]. With increasing turbulence the Strouhal number decreases. At constant mean flow velocity, the volume flow indicated by the WBZ becomes subsequently smaller with increasing turbulence within the gas flow. In the present case, this corresponds to the observed behaviour of the WBZ.

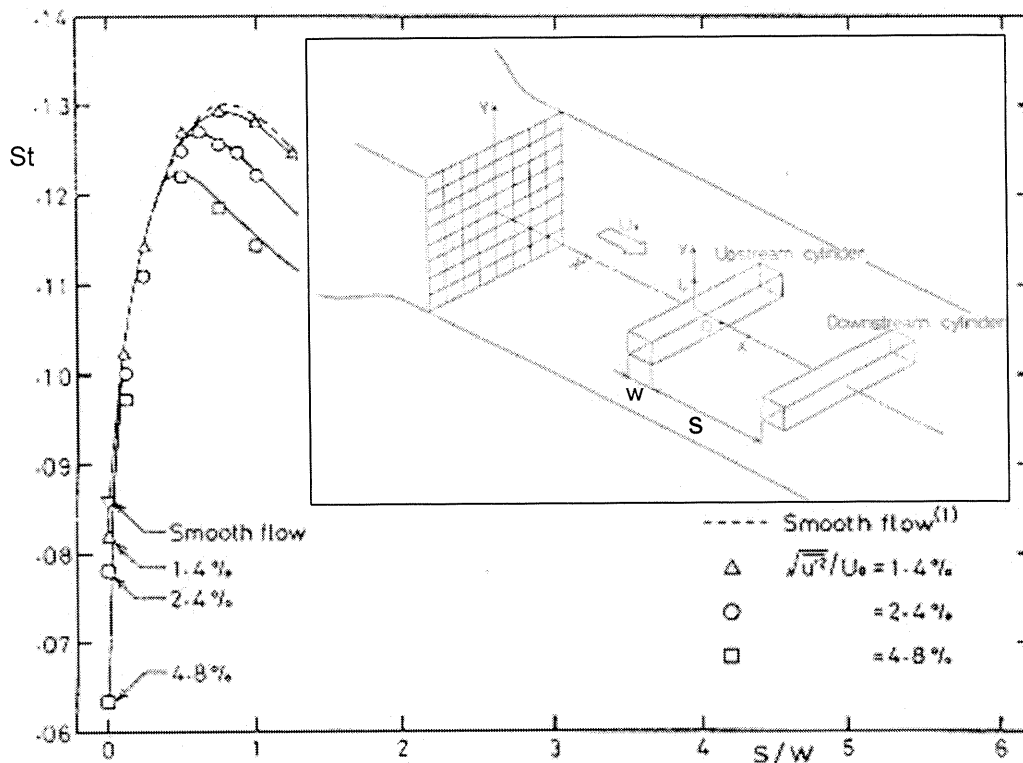


Fig. 9: Experimental setup and measured Strouhal numbers (St) over the distance of two prisms for various turbulence degrees and coherence lengths within the wind tunnel flow [5].

4 REMEDIAL ACTIONS

The cause for the influencing of the synchronism between the WBZ and the USZ by the control ball valve is therefore to be seen in an increase of the sound pressure level and assumably also the turbulence. With increasing turbulence, the vortex shedding frequency decreases at unchanged mean flow velocity (Reynold's number). Accordingly, the volume flow indicated by the WBZ is too small.

Remedial actions in this case must therefore be aimed at a reduction of the sound output and/or turbulences existing within the measuring section. Unfortunately the required attenuation could not be named. For this purpose, the sound and/or turbulence situation would have had to be documented during the high pressure testing.

As possible remedial actions, the installation

- of an absorption silencer
- of alternative control valves
- of sound reducing measures for the control ball valve

was compared and evaluated by KCE. Parallel to this, the possible sound reduction action for the control ball valve was processed. This consists of a replacement of the control disc immediately on the control ball by two specially designed multi-hole discs (Fig. 10) [6 – 8]. When the control ball valve enters the opening phase, no longer only one gap is released for the flow, but instead an increasing number of boreholes on the inlet and outlet sides. At the same time, the bore diameter gets larger with increasing opening. In this way, the remaining pressure loss of the control ball valve in the fully open position could be kept on a furthermore acceptable level.

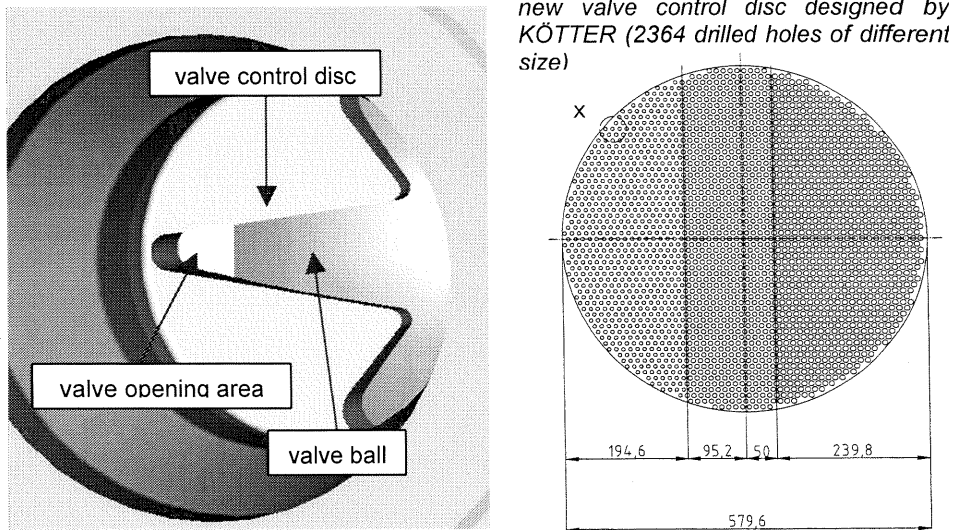


Fig. 10: Sketch of the control ball valve in the position 25° open, as well as the specially designed control disc for minimising the sound and turbulence emissions of the control ball valve.

After good effectiveness of this sound reduction remedial action on a smaller control ball valve had been verified, it was decided to rebuild the 24" ANSI 600 control ball valve. In May 2001, the line with installed multi-hole discs went into operation. In an exemplary manner, the effect of the modification with regard to the sound pressure levels inside natural gas is illustrated in Fig. 11.

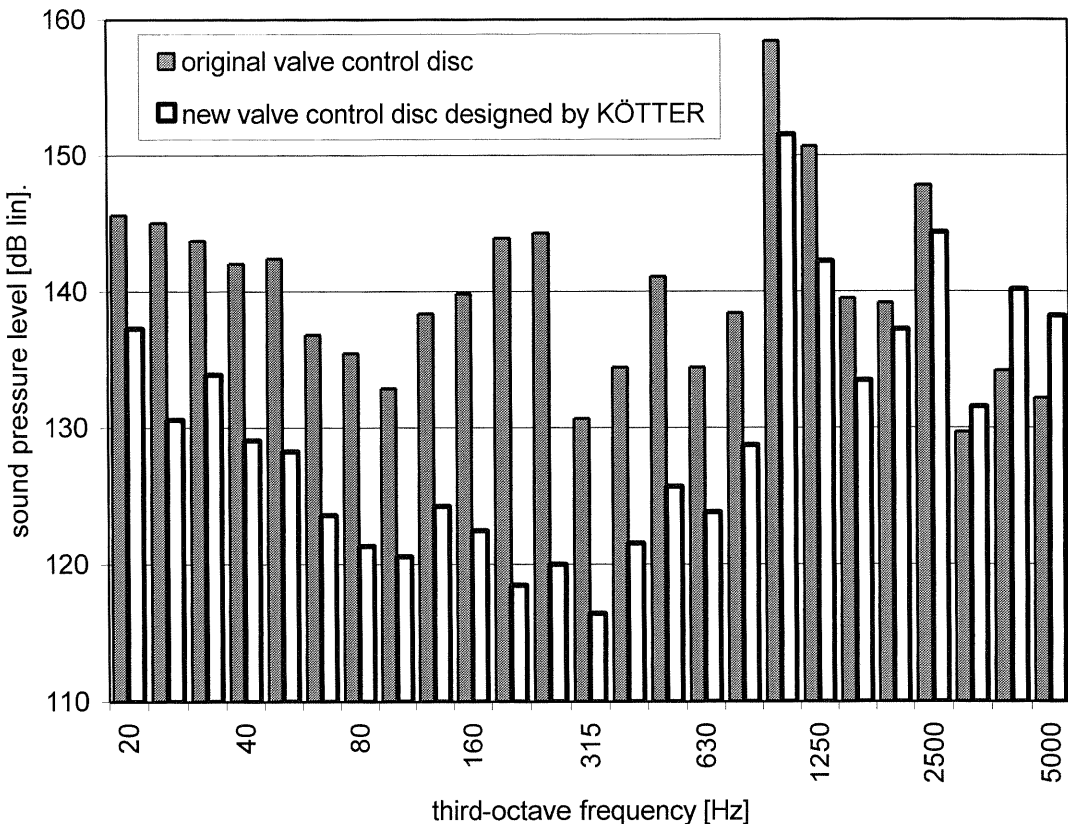


Fig. 11: Sound pressure level at the measuring point MP8 over the third-octave frequencies for the original execution and the specially designed control discs (multi-hole discs) for a standard volume flow of 500.000 Nm³/h and a differential pressure of 0,5 MPa (incl. nozzle resonances).

The cumulative level is reduced by approx. 8 dB with the use of the multi-hole discs. The sound power level of the control ball valve including the surrounding pipe sections decreased to about 89 dB(A) at a standard volume flow of 720.000 Nm³/h and a differential pressure of 0,36 MPa. The reduction is made up of an increase of the pressure fluctuations above and a strong level decrease below of approx. 3 kHz. As expected, the multi-hole discs therefore led to an increase of the frequency of the maximum sound emissions.

The remedial action also has a decisive influence on the synchronism of WBZ and USZ. The reduction of the pressure and flow fluctuations leads to a significant shift of the operational volume flows as indicated by the WBZ (Fig. 12).

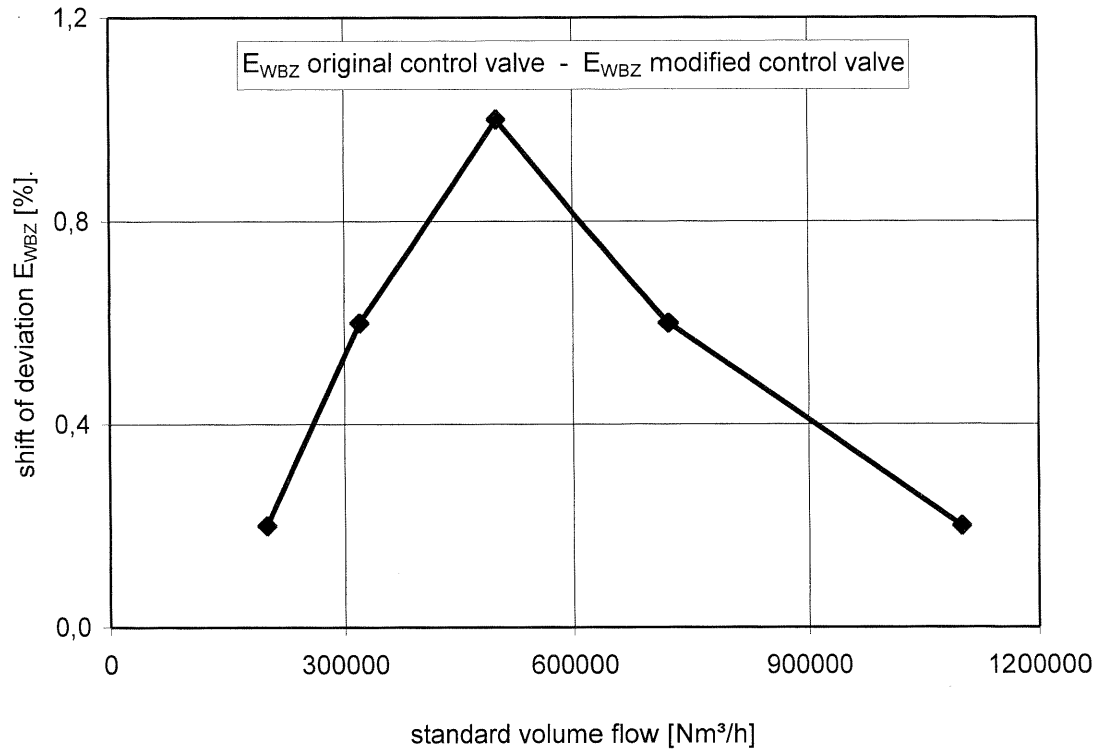


Fig. 12: Shift of the deviation of the operational volume flows between vortex and ultrasonic meter E_{WBZ} following replacement of the original control disc of the control ball valve with the multi-hole discs.

Considering the meter characteristic lines from the HP-tests as well as the temperature and pressure compensation, an acceptable synchronism was finally established to the satisfaction of all parties concerned (Fig. 13).

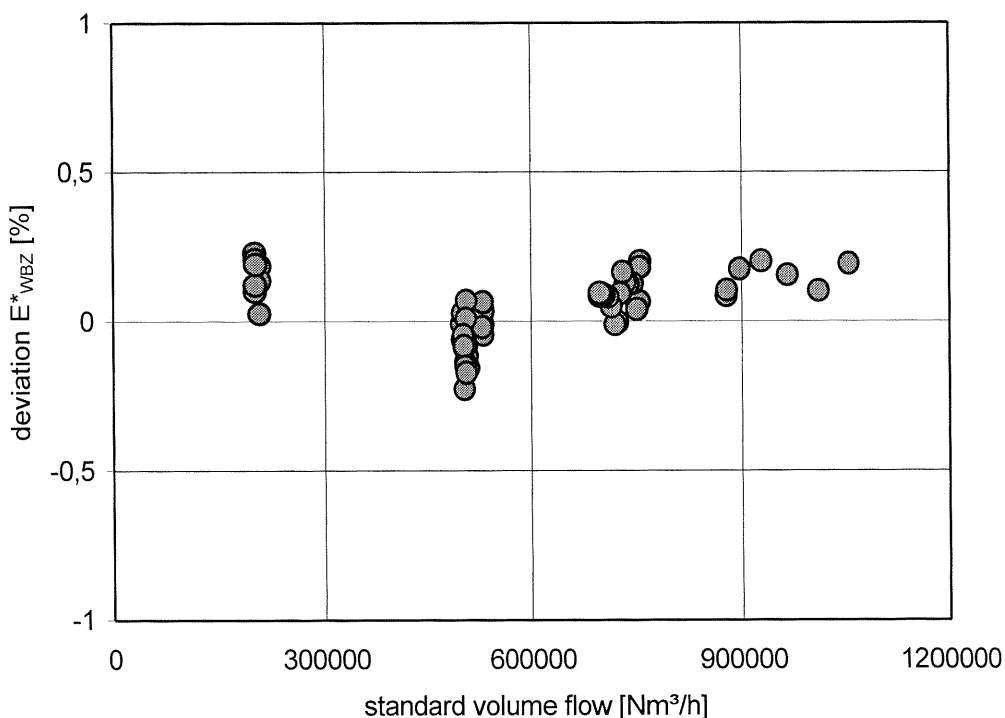


Fig. 13: Percentage deviation of the standard volume flows between vortex meter and ultrasonic meter including all corrections (high pressure test, pressure, temperature) E^*_{WBZ} over the standard volume flow for different differential pressures across the control ball valve.

5 SUMMARY

During the startup phase of a newly erected meter station for natural gas, considerable synchronism deviations were discovered between the ultrasonic and vortex meters arranged in series. In order to eliminate the difference, the inlet zone of the meters was extended by 40 D, among other things, and a second high pressure test was carried out for both meters. The renewed high pressure test showed for the ultrasonic meter a shift of 0,5% for which there is no explanation up to the present day, and this leads to a corresponding reduction of the synchronism difference. The extension of the inlet failed to produce any improvement. The synchronism quality of the measuring devices continued to be unacceptable.

With the additional installation of a turbine meter, the vortex meter was positively identified as being the primary source of the shift. At the same time, a dependence of the synchronism on the position of the control ball valve located approx. 50 D downstream was determined. As verified by a detailed pulsation measurement, there is a systematic correlation between the differential pressure across the control ball valve, the stochastic pressure and velocity fluctuations within the measuring section as well as the synchronism deviation between the ultrasonic and vortex meters. Evidently, an increase of the flow turbulence at the vortex meter at constant volume flow led to a reduced indication. The vortex shedding frequencies (Strouhal number) decrease at constant Reynold's number with increasing turbulence (intensity and coherence length, respectively).

As a remedial action, the control ball valve was equipped with two multi-hole discs so that the natural gas for expansion no longer has to flow through one cross-section but rather through a multitude of boreholes. In this case, the number of boreholes as well as the borehole diameters increase in amount and size with the increasing opening phase of the control ball valve. With this remedial action, the stochastic fluctuations in the natural gas flow were reduced significantly. At the same time, the synchronism between the vortex meter and the ultrasonic meter was improved significantly and was subsequently accepted by all participants.

6 NOTATION

D	pipe diameter
E_{WBZ}	deviation of operating volume flow between ultrasonic and vortex meter (equation (1))
E^*_{WBZ}	deviation of corrected standard volume flow between ultrasonic and vortex meter
\dot{V}_{WBZ}	operating volume flow of vortex meter
\dot{V}_{USZ}	operating volume flow of ultrasonic meter
TRZ	turbine meter
USZ	ultrasonic meter
WBZ	vortex meter

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