WHISTLING FLOW STRAIGHTENERS AND THEIR INFLUENCE ON US FLOW METER ACCURACY

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1 INTRODUCTION

Last year it was reported, that acoustic resonance phenomena ("whistling") occurred in bi-directional metering run setups using Laws type flow straighteners, see Ref. [1]. These findings were reported examining the possibility of a bidirectional setup with two US meters and two flow straighteners at an export measuring station. At this location export of Dutch gas as well as an intake of Russian gas is expected. In Ref. [1] it is shown, that in a metering run setup suited for bidirectional measuring, based upon Laws flow straighteners whistling problems occur. Apart from the environmental sound problems due to the whistling, also the US flow meters are showing large measurement errors.

In this paper we address additional findings related to these whistling phenomena. No additional information was available about the frequency, the intensity and the dependency on process parameters (flow, pressure, temperature) of these acoustical phenomena. This information is however needed to be able to address the cause of the whistling and to search for modifications in the setup to eliminate these problems. Furthermore the question has been raised to determine the cause of the US metering deviations. Is it maybe due to large US sound pressure components?

Experiments are described addressing these questions in practice for a number of different flow straightener configurations. Two types of straighteners have been investigated namely the Laws type for which the problems occurred and the Zanker type. Descriptions of the experimental setups used are given in Section 2. The results are described in Section 3.

2 EXPERIMENTAL SETUP

The experiments are performed in two experimental setup lines at Westerbork one full scale (20") and one reduced scale (12") line.

2.1 Full-scale Run (20")

In the full scale experiments besides the normal pressure and temperature only pressure pulsation amplitudes were measured at three different positions.

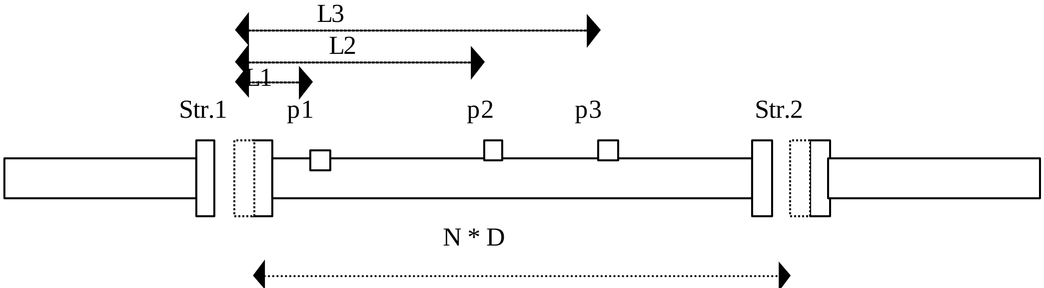


Figure 1 - Schematic layout of the full-scale experiments

The 20” metering run consist of two flow straighteners and pulsation pressure transducers (p1,p2 and p3) in between. Unless otherwise specified the position of the pulsation pressure transducers is L1=2D (100 cm), L2=12D (600 cm), L3=33D-2D (1550 cm). The total distance between the two straighteners is 33D or 1650 cm.

2.2 Reduced Scale Run (12”)

In the reduced scale run besides the pulsation amplitudes the following additional parameters are recorded:

- the ultrasonic sound pressure up to 500 kHz in two probes, mounted in a ring. This ring with two US probes is referred to as USP.
- the total flow and path specific information of a multi-path Instromet US flow meter, placed in between the two flow straighteners. This meter is referred to as USM.

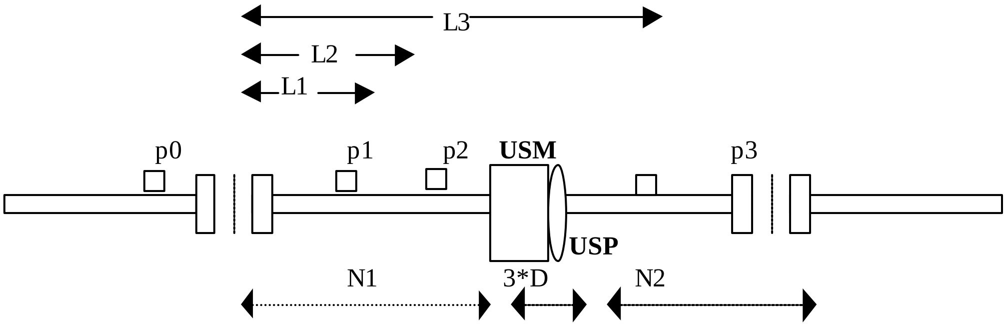


Figure 2 - schematic layout of the reduced scale experiments

2.2 Technical Details

Pulsation Pressure measurements

transducers:	Kistler 7031
charge amplifiers :	Bruel & Kjaer type 2635
Dat recorder:	TEAC RD 200T
spectrum acquisition:	LMS roadrunner
spectrumanalysis:	LMS cada-PC

USP (ultrasonic sound pressure) measurements

pressure transducers:	PCB 132A41 with built-in amplifier
power supply/signal conditioner	PCB F482A
Data-acquisition:	Oscilloscope Nicolette, read-out by HP-VEE computer
Data-analysis:	Matlab code

USP setup

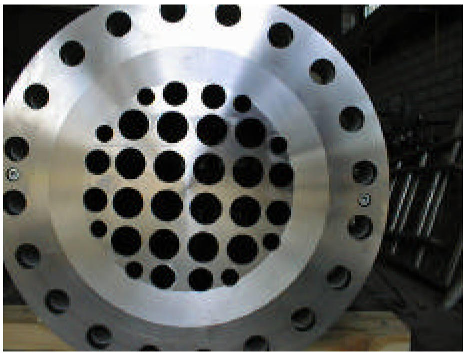
The ultrasonic transducers were mounted inside a ring, which was flanged on the backside of the USM. There were in total two sensors, which were positioned at an angle of 90 degrees relative to one another. The sensors were glued inside specially designed plugs. By using metric thread and seal rings it was ensured that the sensing surfaces were in line with the pipe wall surface. The sensor signal was sampled by the digital oscilloscope with a frequency of 1 μsec. Per measuring event 30.000 samples (in 30 msec) were generated and stored.

During each steady flow situation three such events occurred for each sensor. So in totally six events were recorded and stored. With the FFT technique the digital time data was transferred to frequency data within a range from 35 Hz - 500 kHz.

USM data

type	Instromet type 24 Q.Sonic-5 Series-III QL Meter
software	UNIFORM 1.40c3.0

2.4 The Flow Straighteners



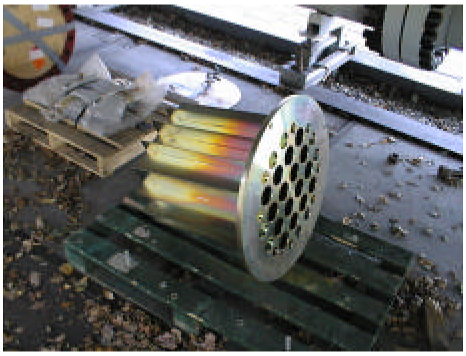


Figure. 3 - Photograpic impression of Zanker straighteners

Zanker

The Zanker flow conditioner is described in the ISO-5167 international standard [2]. It consists of a perforated plate with holes of certain specified sizes followed by a number of channels (one for each hole). The channels, which we refer to as honeycomb, have a length of the order of 1 diameter and are welded against the backside of the plate.

The thickness of the perforated plate of the 20" Zanker is 10 mm. The length of the honeycomb is 50 cm and the wall thickness of the honeycomb channels is 2 mm.

The Zanker is placed in the forward (F) direction if the perforated plate is placed upstream and in the backward (B) direction if the perforated plate is placed downstream.

Figure 4 - Photograpic impression of a positioned Laws straightener

Laws

The Laws flow straightener is a perforated plate with concentric rings of holes, that have three different sizes. It was introduced and patented by E.M.Laws [3].

The thickness of the perforated 20" Laws plate is 0.124 D or 60 mm. The size of the holes is for the central hole 0.195 D or 97 mm, surrounded by a ring of 6 holes with a diameter of 0.1703D or 85 mm and finally a ring of 12 holes with a diameter of 0.147 D or 74 mm.

The Laws has a small upstream chamfer of 1 mm at an angle of 45 degrees. Hence there is a small difference between a normally placed Laws (F = forward) and one which has the chamfer at the downstream position (B = backwards).

2.5 Measurement Configurations

In the full-scale (20") setup the following configurations were measured:

A1. Double Zanker configuration (FB)
A2. Configuration with 1 Zanker (F) and 1 Laws (B)
L1= 2D (100 cm), L2= 12D (600 cm), L3= 33D-2D (1550 cm)
A3. Configuration with 1 Laws (F) and 1 Zanker (B)

A4. Double Laws configuration (FB)
A5 Configuration with one Zanker - F

In the reduced scale (12”) setup the following configurations were measured:

B0B configuration with 1 Laws(B)
B0F configuration with 1 Laws(F)
B1 configuration with 2 Laws (F+B)
B3 configuration with 2 Zankers (F+B) - USM at 19D
B5 configuration with NO straighteners
B6F configuration with 1 Zanker (F)
B6B configuration with 1 Zanker (B)
B7 configuration with 2 Zankers (F+B) - USM at 5D
B8 configuration with 2 Zankers (F+B) - USM at 10D

Table 1 – Scheme of performed measurements in the reduced scale run along with the positions of the pulsation pressure transducers

Run	***Straightener-***	***L0***	***L1***	***L2***	***L3***	***N1***	***N2***	***Remark***
code	*configuration*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	
B0F	1 Laws F	xxx	0,52	3,8	8,9	4,35	4,85	N.B. No US flow-meter installed
B0B	1 Laws B	xxx	0,52	3,8	8,9	4,35	4,85	N.B. No US flow-meter installed
B1	2 Laws	0,54	2,10	3,8	5,4	5,77	2,4	
B3	2 Zanker L=19D	0,92	2,02	5,19	xxx	5,70	3,90	
B5	no straighteners installed	xxx	2,02			xxx	xxx	N.B. No US flow-meter installed
B6F	1 Zanker (F)	0,62	xxx	3,8	8,9			N.B. No US flow-meter installed
B6B	1 Zanker (B)	xxx	-0,91	1,28	2,7	3,05	xxx	
B7	2 Zanker L=5D	xxx	-0,49	0,9	3,6	1,53	5,5	
B8	2 Zanker L=10D	xxx	-0,49	0,9	2,7	3,03	4	

2.6 Process Conditions

The flow was varied during the measurements within a configuration. The static pressure during our measurements amounted about 63 bara. We measured at fixed flows in 8 steps ranging from 2000 m^3/hr (7.5 m/sec) to about 8000 m^3/hr (30 m/sec).

Table 2A – Process conditions during full scale (20”) test runs

Flow (m^3/hr)	Pres. (bar-abs)	Flow (normal m^3/hr)	Gas Celocity (m/s)
15.000	63	1.000.000	20,5
13.500	63	915.000	18,5
12.000	63	809.000	16,4
10.500	63	706.000	14,35
9.000	63	604.000	12,3
7.500	63	500.000	10,25
6.000	63	400.000	8,2

Table 2B – Process conditions during reduced scale (12”) test runs

Flow (in m^3/hr)	Pres. (bar-abs)	Flow (normal m^3/hr)	Gas Velocity (m/s)
	63	540.000	30,0
7200	63	485.000	27,3
6500	63	437.000	24,7
5800	63	390.000	22,0
5000	63	340.000	19,0
4000	63	270.000	15,2
3000	63	200.000	11,4
2000	63	140.000	7,5

3 RESULTS

3.1 Whistling Phenomena (Pulsation Measurements) Using Laws Straighteners

In this Section the results of the measurements of pulsation frequencies and amplitudes are shown. The pulsation amplitudes and frequencies are useful to determine the source and severity of the whistling phenomena.

At first we investigate the configurations in the reduced size run, which only have one Laws straightener (B0B, B0F) either placed in a forward or in a backward direction. For illustration some of the pulsation spectra are shown in Appendix A.1.

In the Table below the pronounced frequencies and amplitudes are shown for the B0F configuration for which the Laws straightener was placed in the forward direction.

Table 3a – Frequency and amplitude of pressure pulsations during run B0F (One Laws straightener placed in the forward direction

Run B0F		*Laws straightener forward directed*				*12"run*			*API-618*
Freq.	*Flow (m3/hr)*	*3000*	*4000*	*5000*	*6000*	*6500*	*7200*	*7900*	
(Hz)	*Velocity (m/s)*	*11,4*	*15,2*	*19*	*22*	*24,7*	*27,3*	*30*	p_{max}
766	pressure(mbar)	0,1	0,23	0,4	0,35	0,7	1	1	22,48
1568	pressure(mbar)	2,5	0,5	0	0	0,8	1,6	0,2	15,71
1709	pressure(mbar)	0	0	1,7	0	0,2	0,3	40	15,05
2137	pressure(mbar)	0,3	6	4	55	1	0,5	0,1	13,46
2487	pressure(mbar)	0,1	0,6	0,6	1	37	3	2	12,48
2575	pressure(mbar)	0,3	0,4	2	1	2	15	1	12,26
2615	pressure(mbar)	0	0	8	1	2	18	1	12,17
2804	pressure(mbar)	0,1	0,3	0,5	0,5	0,6	0,7	40	11,75

The levels found can be compared with the API-618 criterion for maximal pulsation amplitudes p_{max} in mbar-rms near compressor pipework [4]. It can be derived, that this criterion can be written as:

$$p_{\max} = 44{,}4 * \sqrt{\frac{p_d}{d * f}} \qquad (1)$$

It can be seen, that pronounced whistling (at the 2137 Hz frequency) starts around a velocity of 22 m/s and then the amplitudes exceed the API-618 levels at maximum with a factor of 4.

Table 3b – Frequency and amplitude of pressure pulsations during run B0B (One Laws straightener placed in the backward direction

Run B0B	*Laws straightener backwards directed*				*12"run*			
Freq	*flow(m^3/hr)*	*4000*	*5000*	*5800*	*6500*	*7200*	*8000*	*API-618*
(Hz)	*vel(m/s)*	*15,2*	*19*	*22*	*24,7*	*27,3*	*30*	
770	pressure(mbar)	0,7	0,7	1,3	4	45	220	22,4
1245	pressure(mbar)	-	6	30	-	-	0	17,6
1563	pressure(mbar)	20	0,4	8	65	86	2	15,7
1718	pressure(mbar)	0	0	0	0	6	30	15,0
2124	pressure(mbar)	0,3	17	2,5	-	-	42	13,5
2332	pressure(mbar)	-	-	-	3,6	28	23	12,9
2494	pressure(mbar)	-	6	8	5	5	13	12,5
3125	pressure(mbar)	-	-	1	12	22	0	11,1

From Table 3b it can be seen, that in the backward configuration the whistling starts already at a gas velocity of 15 m/s with a frequency of about 1563 Hz; the amplitude is already comparable to the maximum allowed API-618 amplitude for that frequency. The frequency and amplitudes shift. For velocities of ~30 m/s the API-618 maximum has been exceeded by a factor of 10.

In the combined situation -suitable for a bidirectional setup- one Laws is placed in the forward direction and at a distance of about 30 D a second Laws is placed in the backward direction. The whistling phenomena in this setup are comparable to the case with only one Laws straightener in the backward direction, as can be seen from the table below.

Table 3c – Frequency and amplitude of pressure pulsations during run B1 (12”run; two Laws straighteners one in placed forward and one placed in the backward direction)

Run B1	*Laws straightener forward and one backwards directed*				*12"run*				
freq	*flow(M3/hr)*	*3000*	*4000*	*5000*	*5800*	*6500*	*7200*	*8000*	*API-618*
(Hz)	*vel(m/s)*	*11,4*	*15,2*	*19*	*22*	*24,7*	*27,3*	*30*	
775	pressure(mbar)	0,45	0,5	0,6	0,8	4	107	217	22,35
1568	pressure(mbar)	2,5	5	0	0	14,1	18	7	15,71
1706	pressure(mbar)	0	0	1,8	0	0	3,2	18	15,06
2136	pressure(mbar)	0,4	12,8	9	22,5	2,9	0	0	13,46
2200	pressure(mbar)	0,2	0,8	1,6	0	0	5,4	8	13,27
2332	pressure(mbar)	0	0	0	0	12	25	23	12,89
2494	pressure(mbar)	0,35	1	3	0	5,1	7,8	22,9	12,46
2545	pressure(mbar)	0	0	0	0	42,5	0	0	12,33
2800	pressure(mbar)	0,1	0,4	0,6	0	0	0	123	11,76
3125	pressure(mbar)	0	0	0	1	12	22	0	11,13

In the table below the results for a similar setup, but then in the large metering run (20”) are shown.

Table 3d – Frequency and amplitude of pressure pulsations during run A4 (20”run; two Laws straighteners one in placed forward and one placed in the backward direction)

Run A4	*Laws straightener forward and onebackwards directed*				*20"run*				
freq/flow	*flow(M3/hr)*	*6000*	*7500*	*9000*	*10500*	*12000*	*13500*	*15000*	*API-618*
(Hz)	*vel(m/s)*	*8,2*	*10,2*	*12,3*	*14,4*	*16,4*	*18,5*	*20,5*	
480	pressure(mbar)		22	0,9	0,8				22,00
490	pressure(mbar)	0,2		1,2	0,8	1,3	1,5	4	21,77
787	pressure(mbar)					7	60	4	17,18
970	pressure(mbar)	0,2	1,6	27				67	15,48
990	pressure(mbar)	0,2	0,8	15	75	2,7	4		15,32
1070	pressure(mbar)	2,1	5	8,5	17	25	25	55	14,74
1110	pressure(mbar)	0,5	1,5	3	5	6,1	14	9	14,47
1140	pressure(mbar)	0,7	2	2	6	8	12	30	14,28
1335	pressure(mbar)	0,06	0,15			7	10	2	13,19
1572	pressure(mbar)					1,5	9	1,1	12,16
1650	pressure(mbar)			0,8		3,3		3,7	11,87

In the full-scale run the observed frequencies correspond very well with the theoretical radial frequencies. Considering the pipe to be a cylindrical shaped acoustic cavity the radial frequencies are given by (cf. Ref. [4] page 343):

$$f_{jk} = \frac{c}{p}\frac{l_{jk}}{d} \qquad (2)$$

with j=0,1,2,3 the number of nodal diameters
k=0,1,2,3 the number of nodal circles

In the following table the coefficients l_{jk} in ascending order for the full-scale run give rise to the following frequencies (at c= 400 m/s and d=0.4924 m):

k	**j**	l_{jk}	f_{jk} **(Hz)**
k=0;	j=1	1.8412	476
k=0;	j=2	3.0542	790
k=1;	j=0	3.8317	991
k=0;	j=3	4.2012	1086
k=0;	j=4	5.3176	1375
k=1;	j=1	5.3314	1379
k=0;	j=5	6.4156	1659
k=1;	j=2	6.7061	1734

There is in general a remarkable similarity (within 1%) between the observed frequencies in the A4 run in comparison with these theoretical radial modes. The observed frequencies at 1110 and 1140 Hz are only found in the spectrum of one of the three pressure point and must be considered as being generated by reflections in the measuring channel.

On the other hand this similarity is not so straightforward in the reduced scale (12”) metering run.

observed frequency	*theoretical rad.freq*	*difference (%)*
775	776	0.13
1568	1615	3.00
1706	1771	3.81
2136		
2200	2248	2.18
2332		

Whereas for the lowest frequency the correspondence is very good, the differences between the observed and theoretical values are more than 2% for other frequency values. A possible explanation might be the influence of the pipe contraction from 16” to 12” pipe diameter. In contrast to the full scale metering run the reduced scale run does not hold its diameter over a very wide range.

3.2 Whistling Phenomena (Pulsation Measurements) Using Zanker Straighteners

Also for the Zanker straightener configurations pulsation measurements were performed.

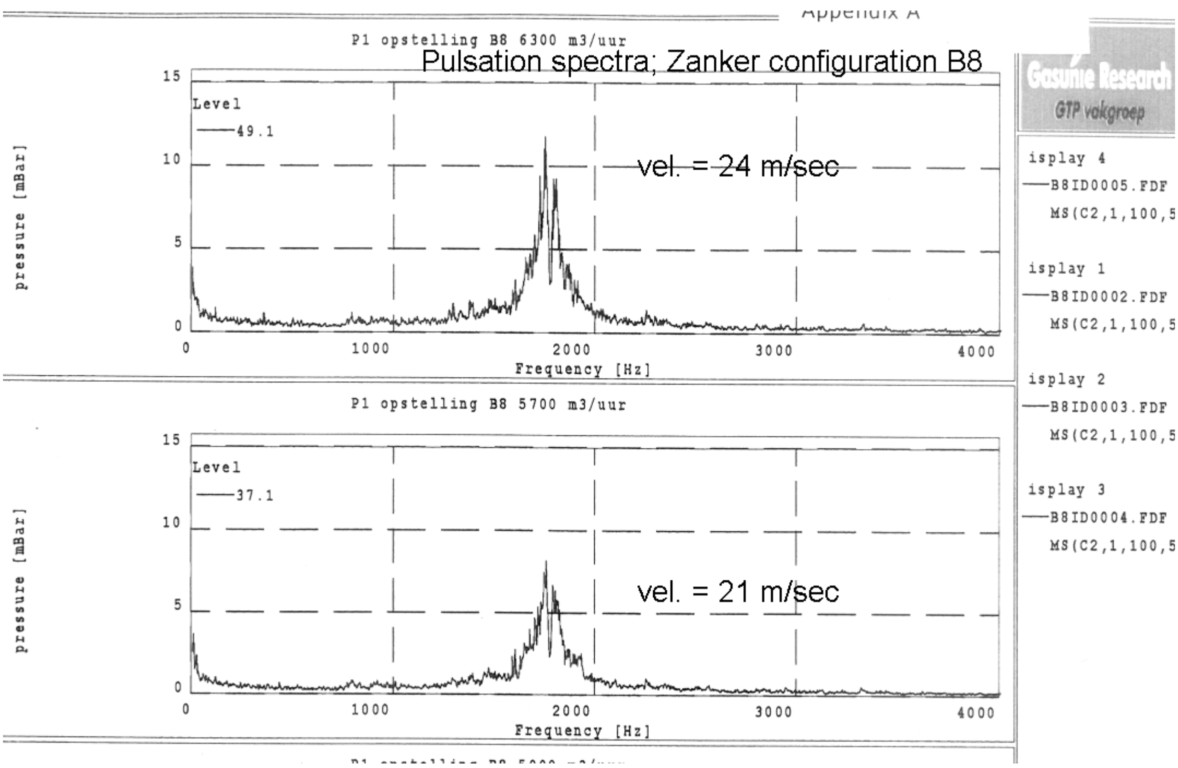


Figure 5 - pulsation spectra Zanker; B8 double Zanker configuration at flow velocity of 24 and 21 m/sec

It turns out, that – in contrast to the Laws straighteners (see e.g. Appendix A.1)- the Zanker straighteners do not produce whistling sound. The spectra shown in Figureure 5 seem to show small resonance bumps, but these are not actually present in the main pipe (measurement reflections).

3.3 USP (Ultra-Sonic-Pressure) Measurements

In this Section the results of the study of ultrasonic pressure USP amplitudes are given. The small-band results are summarized in Appendix A.3

The 1/3 octave band spectra for a number of configurations are shown below.

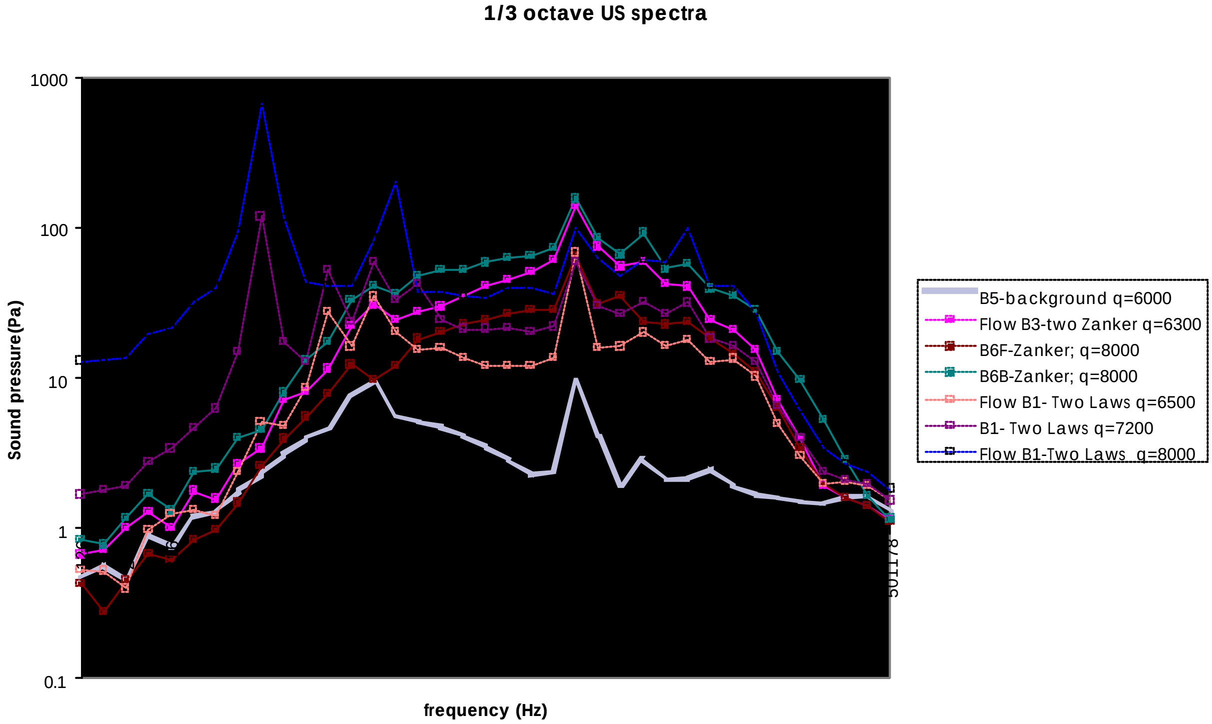


Figure 6 - One-third octave band spectra for configurations with Zanker (solid lines) and Laws straighteners (dashed lines) for different flow values.

It can be seen from Figure 6, that the configurations with Zanker straighteners have a much smaller low frequency component (< 10 kHz), whereas in the midfrequency range (10 kHz-50 kHz) the noise of the Zanker straighteners dominates. The high frequency part of the Zanker results is comparable with that of the Laws results.

On the basis of these trends we conclude, that the US meter error observed in the bidirectional runs with Laws straighteners does NOT originate from a high-frequency US component, but rather is caused by the pipe vibration imposed by the low-frequency noise.

3.4 USM (Utrasonic-Metering) Accuracy Measurements

In this Section the results of the study of USM accuracy are given. We here concentrate on the bidirectional runs, for which the US- flow meter was positioned in between the double Zanker configuration, i.e. the runs B3, B7 and B8. In these runs the distance between flow straightener and meter was respectively 19D, 5D and 10D.

In earlier experiments the measurement errors of the Laws setups were already elaborately investigated [1]. For the sake of comparison we investigated one similar bidirectional run with two Laws straighteners (run B1).

We investigated two aspects, namely the path error logging information in Section 3.4.1 and the flow measuring accuracy in relation with the reference standards in Section 3.4.2.

3.4.1 USM logfiles: path errors

In the logfiles of the US flow meter supplied by Instromet information can be found about the US measurement paths. In this Section we particularly investigate the percentage of no-error scans, since they supply the first indication that measurement errors can occur.

The US meter has a five-path geometry. Path number 1, 3 and 5 are used to calculate the average flow velocity. Path number 2 and path number 4 are oppositely directed swirl paths. These paths are thought to be most sensitive to vibrations and background US noise since they are twice reflected by the wall in contrast to the other paths which consist of only one wall reflection.

We investigate how the error develops as a functions of flow for the different configurations and we compare the different configurations at a similar flow condition.

The flow dependency of the path no-error percentage is shown in the graph below for the configuration B6B, a single Zanker configuration (backwards directed), for which the distance between the Zanker and the US flow meter amounts 10D.

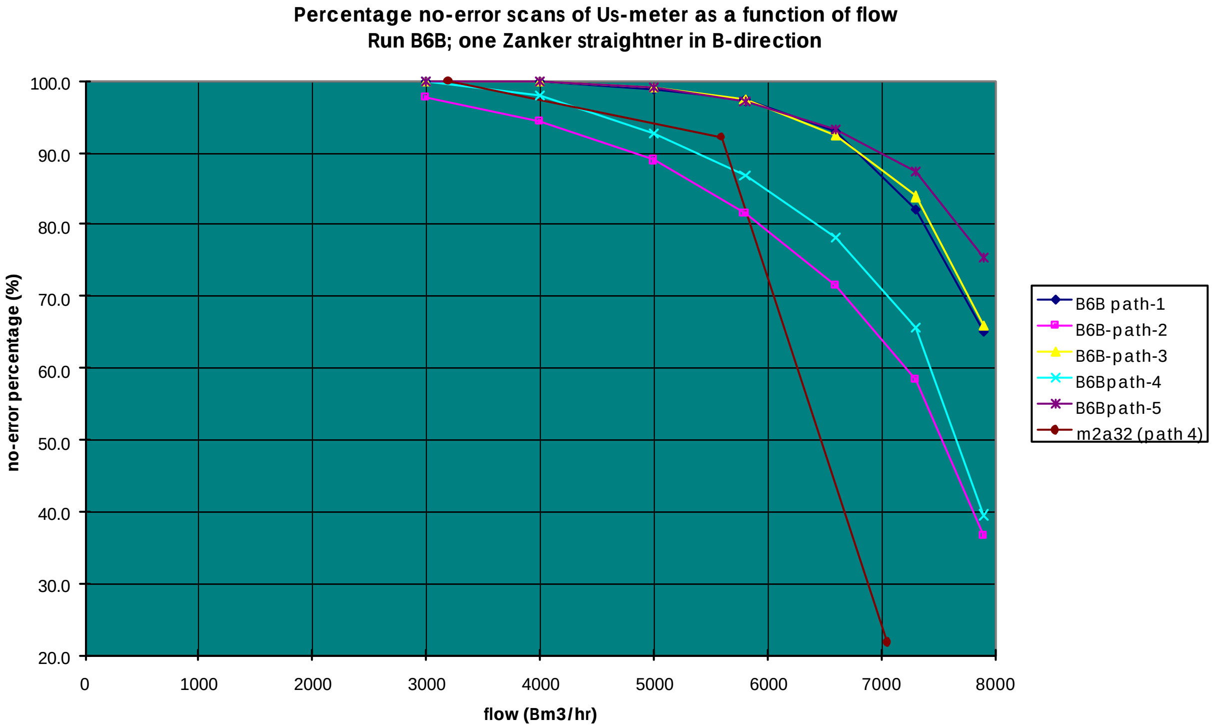


Figure 7 - Flow path accuracy for the different paths as a function of flow conditions. The single Zanker configuration B6B is shown. Other configurations exhibit similar patterns. For comparison the measurement m2a32 (the case with a double Laws configuration where the measurement error amounted 2%) of Ref. [1] has been added.

From Figure 7 it can be seen, that

- Path 2 and 4 (the swirl paths) have a larger error rate than the other paths (1,3 and 5).
- As the flow increases the number of errors increase In general both the (low frequency) sound and vibration as well as the (high frequency) US sound increases with increasing flow and causes the meter to fail once in a while.

From the above it is not clear which of the two possible causes dominates. A difference between the different configurations can shed a light upon this question, since the Zanker straighteners produce a higher US background noise, whereas the Laws straighteners give rise to a higher low frequency noise and vibration.

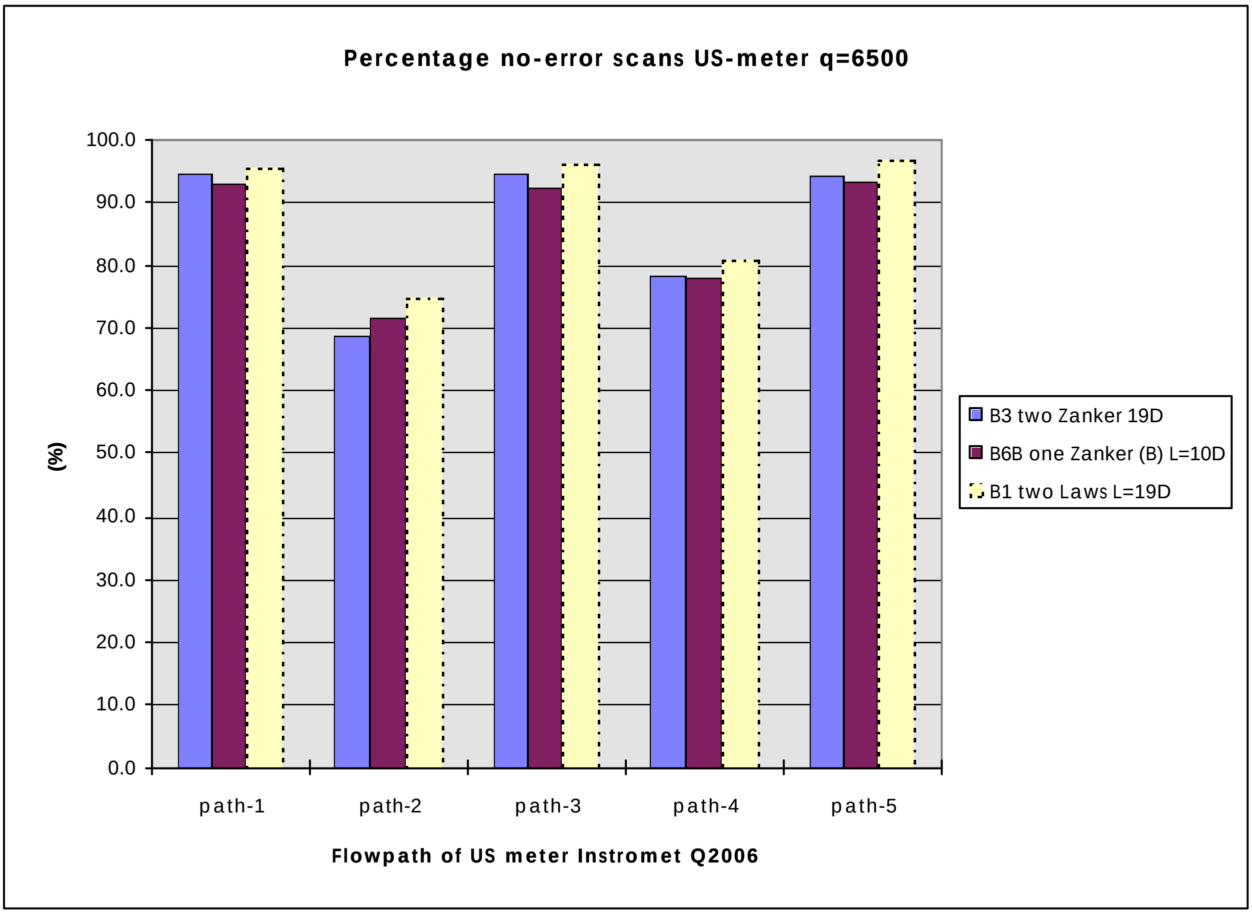


Figure 8 - Flow path accuracy for three different configurations at similar flow conditions. The solid bars are configurations with a Zanker straightener; the dashed line is a configuration with Laws straightener. The gas velocity is about 25 m/s

In Figure 8 the difference between a Laws configuration and a Zanker configuration at similar flow conditions is shown. The Zanker configurations show a higher error rate- which indicates that these type of errors are more sensitive to US background sound levels than to higher vibrational levels.

At a certain stage however at high flow conditions it is observed, that for the Laws configurations -probably due to the high vibrational levels- there is NO good (swirl)path scan at all for many subsequent scans during a long period of time (10 to 20 seconds). This effects has also been seen before in the measurement m2a32 of G.H.Sloet [1] for which the average error in the flow determination was -2%. For certain scans around these periods it appears, that the error can even be greater. On the basis of the measurements of noise and the observed high vibrational levels for the Laws configurations at high velocity these type of errors are probably caused by the vibration of the flow meter.

3.4.2 USM accuracy; measurement errors

Due to the higher pressure drop for the Zanker straightener in comparison with the Laws straighteners the gas flow in the 12” Section was limited to 6300 m^3/hr (gas velocity 24 m/sec).

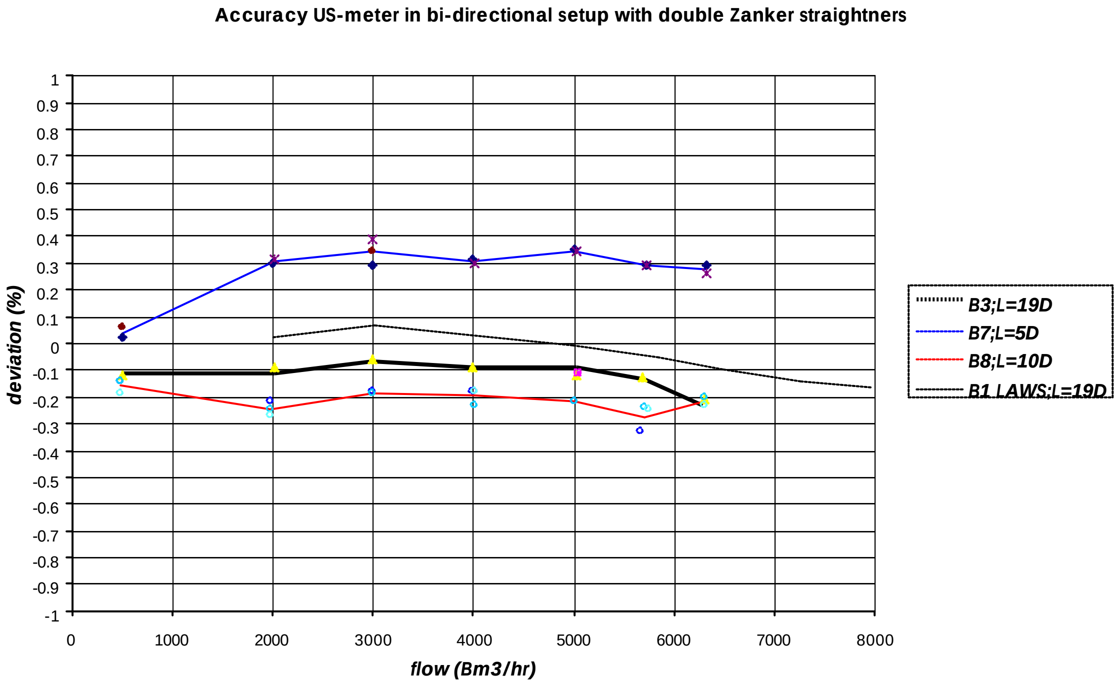


Figure 9 - Calibration curves. The solid lines are bidirectional configurations with a double Zanker straightener at a distance of 5D, 10D and 19D respectively; the dashed line is a bidirectional configuration with Laws straighteners (19D).

In Figure 9 the measurement errors of the US meter in comparison with the reference meters at Westerbork are given for the different runs. It should be noted, that the US meter was not adjusted, so an overall flow difference relative to the reference can be expected.

For reference the calibration curve for the double Laws configuration is also given in Figure 9. The difference between the Laws curve and the Zanker curves probably are due to the high pulsation and vibration levels in the Laws bidirectional case. Moreover the "harmonization" correction was applied to the reference standards at Westerbork during our measurements, which makes the comparison more complicated.

Whereas the deviations become very large for the setup with Laws straighteners [> 2% drop in accuracy when the flow is above 6000 m^3/hr as observed in Ref. [1] Figure 12) in the above cases (with the Zanker straighteners) the deviations remain rather constant. The deviation curves for the Zanker configurations at 10D and at 19D are quite similar and do not differ more than ~0,10 %. This seems quite reasonable since it is within the repeatability range of the installation.

In contrast to the measurements of Ref. [1] in our case B1 (bidirectional setup with Laws straighteners) no large measurement errors are observed up to gas velocity of about 30 m/sec

3.5 Source of Whistling Flow Straighteners and US-Metering Errors

In the above results we found that Laws flow straighteners produce a profound whistling, whereas the Zanker straighteners do not. Moreover we found, that the whistling is more severe for a backward directed Laws straightener, for which the 45 degrees 1 mm chamfer is placed on the downstream size.

Furthermore we observe no whistling of the Zanker type straighteners, which are - apart from the honeycomb structure- also made up of similar diameter perforated plates.

A plausible explanation is to relate the whistling phenomenon to the length scale of the holes in the perforated plate. The length of the Laws straighteners is comparable to the diameter of the holes whereas the Zanker plates are much thinner.

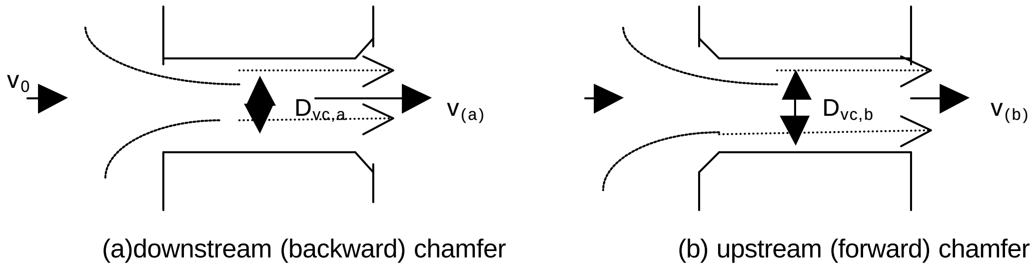


Figure 10 - The chamfer influences the effective diameter of the hole (vena contracta) and hence in the situation with back-ward chamfer (a) the vortex propagation velocity $v_{(a)}$ will be increased in relation to the upstream chamfer situation $v_{(b)}$. This explains why in situation (a) the whistling starts at a lower gas velocity in comparison with the normal situation (b)

The whistling is caused by coupling of the vortex shedding with the acoustical pipe modes. Mainly the radial cross frequency modes appear to be involved in this coupling as can be seen from the close correspondence of the observed frequencies with the theoretical radial frequencies.

A 20” Laws has a hole length of 60 mm, whereas a 20” Zanker has a hole length of only 10 mm. Since the frequency of acoustical phenomena is inversely proportional to the length scale, this explains why the Laws plate produces more audible sound and the Zanker plate produces more US sound

Concerning the metering errors we observe that there are two effects contributing to path errors in a US meter:

1. *High ultrasonic sound background*; an increasing US sound background gives rise to higher path error rates. Due to a higher mid-range US background this affects configurations with Zanker straighteners more than it does with Laws straighteners. However for velocities up to 25 m/s there is no significant flow metering error observed due to this effect.

2. *High vibrational background*; in the case of a high vibrational background there is sometimes NO good (swirl) path scan at all at many subsequent scans for a long period of time (10 to 20 seconds). In this case the resulting flow metering error can be 2% or temporarily even much more. This effect is observed for high-flow Laws straightener configurations only.

Due to the observed large metering errors in the case of the Laws configurations we address these errors to the high vibrational background.

4 SUMMARY AND CONCLUSIONS

In previous studies whistling phenomena have been observed in bidirectional metering run setups using Laws type flow straighteners. Apart from the environmental sound problems due to the whistling, also the US flow meters are experiencing large measurement errors.

Here we report on experiments to investigate the whistling problems in practice for a number of different flow straightener configurations. Two types of straighteners were investigated namely the Laws type for which the problems occurred and the Zanker type.

The experiments have been performed in two experimental setup lines at the Gasunie Bernouilli lab one on full scale (20”) and one on reduced scale (12”).

Concerning the whistling of the Laws straighteners it is observed that:

- For a forward directed Laws straightener pronounced whistling starts around a flow velocity of 22 m/s and then the amplitudes exceed the maximum allowed levels with a factor of 4.
- For a backward directed Laws straightener whistling starts at gas velocity of 15 m/s, its amplitude at that velocity already being comparable to maximum allowed levels.
- In bidirectional setups the observed levels are comparable to those for the single straightener runs. One can hardly observe an additional resonance component due to the interaction between the two straighteners.

The acoustical modes to which the flow through the holes couple mainly have a radial character. No good theoretical basis for the whistling can be addressed at this stage.

Since the maximum (design) velocity of the gas metering runs is usually ~20 m/s the use of Laws straighteners in a normal situation will not endanger the mechanical integrity of the installation.

Concerning the produced ultrasonic sound it is observed, that configurations with Zanker straighteners have a much smaller low frequency component (< 10 kHz), whereas in the midfrequency range (10 kHz-50 kHz) the noise of the Zanker straighteners dominates. The high frequency part of the Zanker runs is comparable to that for the Laws runs.

Concerning the metering errors we observe that there are two effects contributing to path errors in a US meter:

- *High ultrasonic sound background*; an increasing US sound background gives rise to higher path error rates. Due to a higher mid-range US background this affects configurations with Zanker straighteners more than it does with Laws straighteners. However for velocities up to 25 m/s there is no significant flow metering error observed due to this effect.
- *High vibrational background*; In the case of a high vibrational background there is sometimes NO good (swirl) path scan at all at many subsequent scans for a long period of time (10 to 20 seconds). In this case the resulting flow metering error can be 2% or temporarily even much more. This effect is observed for high-flow Laws straightener configurations only.

The experiments present confidence for using Zanker straighteners in bidirectional setups for flow velocities up to at least 25 m/s. There are no great measuring differences (<~0.1%) at distances between straightener and US meter of 10D in comparison with 19D.

5 NOTATION

p_d design pressure (in bar)
c velocity of sound (m/sec)
d diameter op the piping (in m)
f frequency of the pulsation (in Hz)
$f_{j,k}$ pipe resonance frequency of order j,k
l_{jk} mode shape coefficient

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8 APPENDIX

Figure A.1 Pulsation spectra Laws; single Laws in forward direction B0F and backward direction B0B at flow velocity of 30 m/sec

Figure A.2 Small-band USP spectra; spectra of single Laws (B0F) and single Zanker (B6F) configuration for flow velocity of 30, 27 , 25 and 22 m/sec.

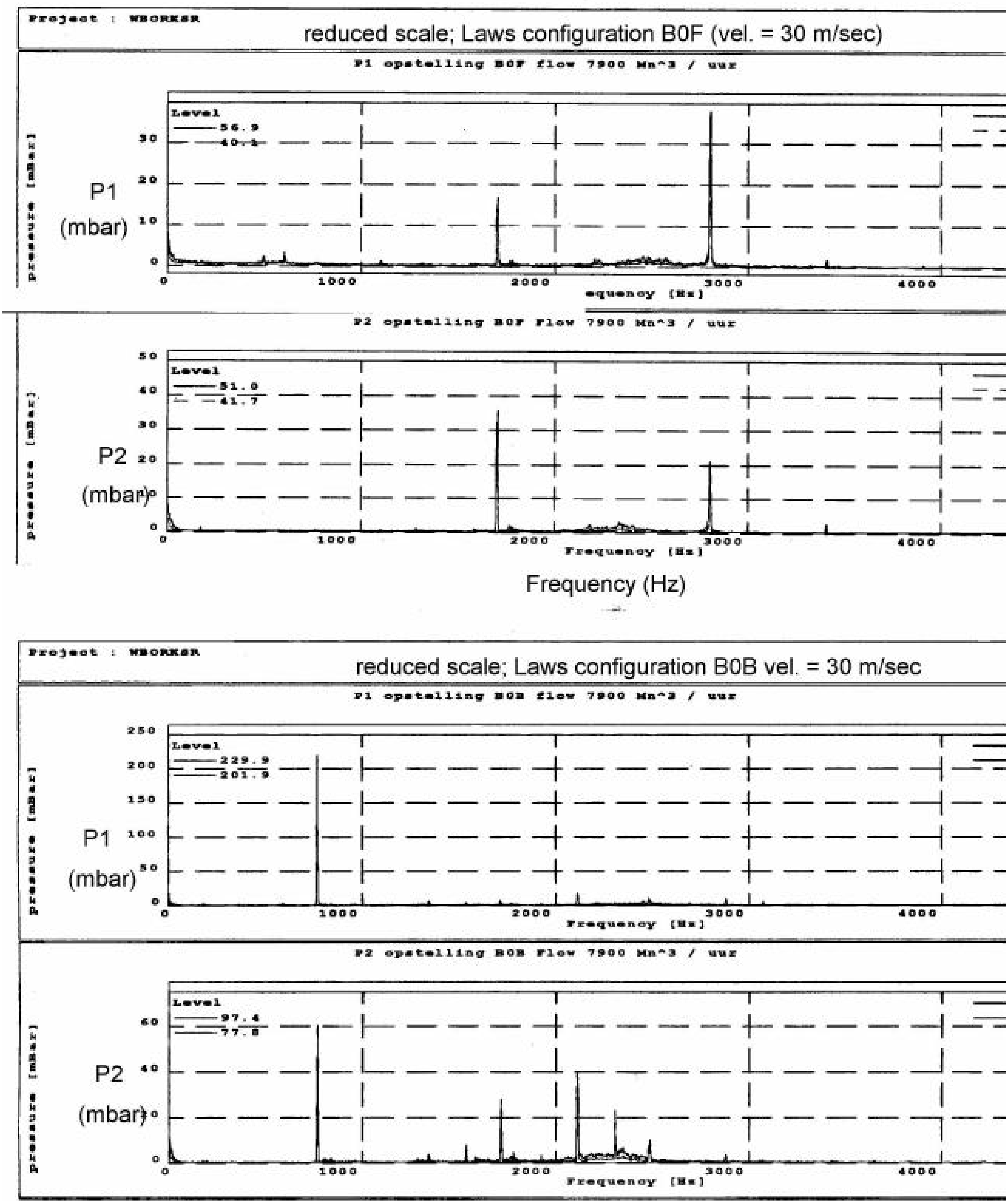

Figure A.1 - Pulsation spectra Laws; single Laws in forward direction B0F and backward direction B0B at flow velocity of 30 m/sec

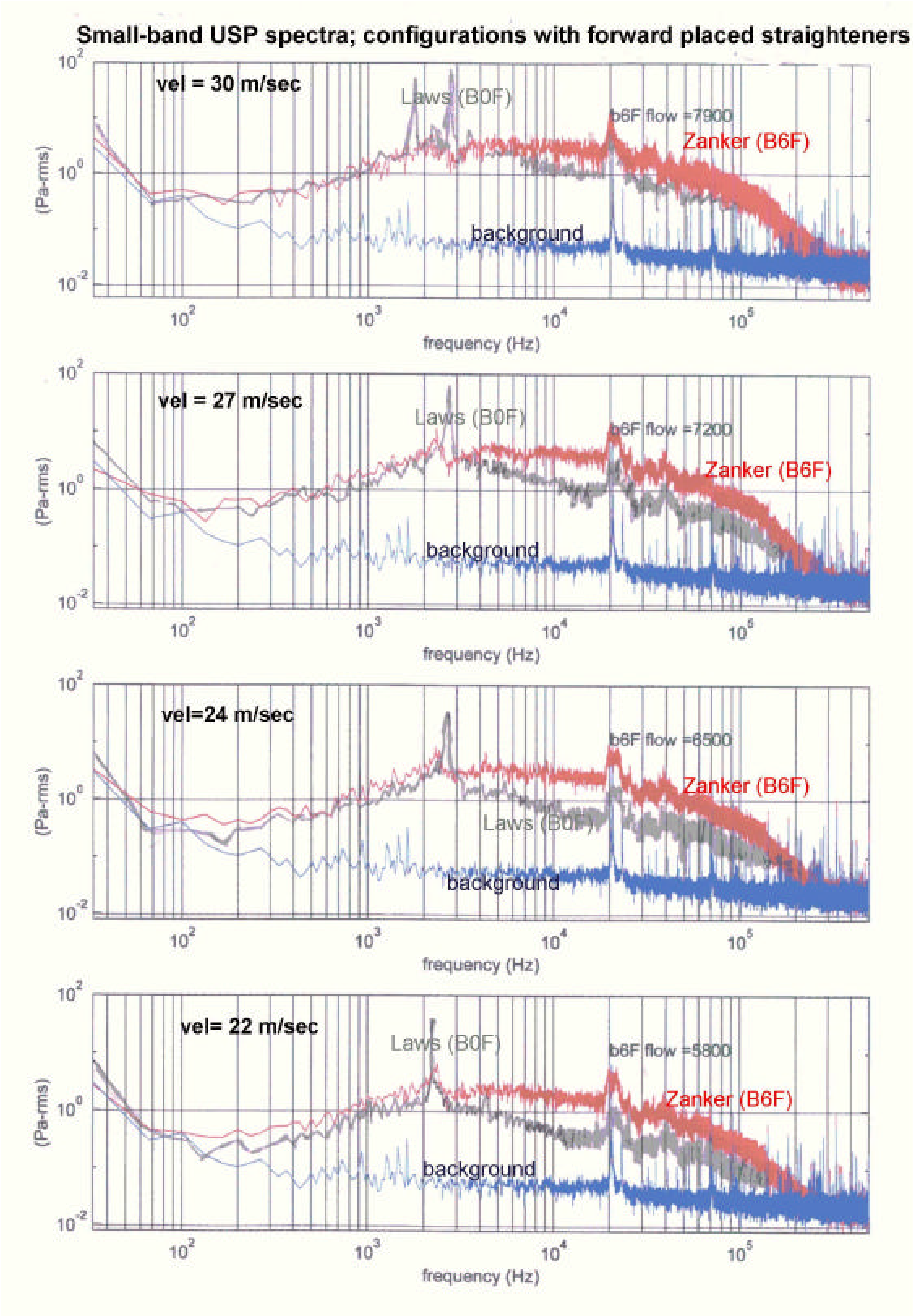

Figure A.2 - Small-band USP spectra; spectra of single Laws (B0F) and single Zanker (B6F) configuration for flow velocity of 30, 27 , 25 and 22 m/sec