PROVING A FISCAL 5-PATH ULTRASONIC LIQUID METER WITH A SMALL VOLUME BALL PROVER. CAN IT BE DONE?

Trond Folkestad, Norsk Hydro ASA

1 INTRODUCTION

Norsk Hydro is installing it's first fiscal liquid metering station based on Ultrasonic meters on the Oseberg Sør (South) platform comprising two multi-path Ultrasonic liquid flow meters in series with an Unidirectional small volume ball prover. The Ultrasonic liquid flow meters are 8" Krohne 5-path Altsonic V meters while the 12" Unidirectional ball prover is a Kongsberg Offshore design.

During flow testing of the metering system the required repeatability during proving could not be achieved. The repeatability during proving varied between more than ten times the requirement in the regulation from the Norwegian Petroleum Directorate (NPD) to just within the requirement. Most of the time varying between three to six times the requirement.

This paper will share the experience gained during flow testing the metering system for four months in Brevik, Norway. The paper will conclude with a recommendation for better test set-up and system design when using this type of Ultrasonic liquid flow meters with a small volume ball prover.

2 BACKGROUND

The Oseberg Sør platform in the North Sea, in production in the year 2000, will be a first stage separation platform. Second and third stage separation will be done at the Oseberg Field Centre 13 km away. The stabilised oil will be sent to shore in the pipeline to the Sture oil terminal in Norway, see Fig 1 and 2.

With maximum water content in the crude oil of 5 % by volume, Norsk Hydro decided to use liquid ultrasonic flow meters to measure this unstabilised crude oil, after gaining acceptance by the NPD.
Since there is little prior experience with proving ultrasonic liquid meters the metering system is a new design adapted to the limited space on the platform.

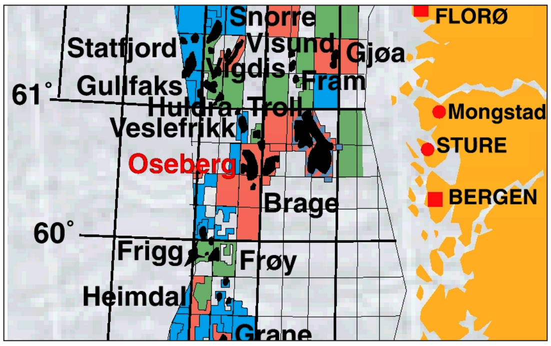

Fig 1, Location of the Oseberg Area

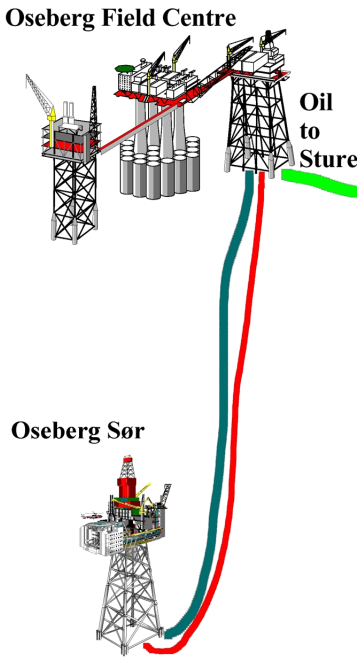

Fig 2, The Oseberg og Sør platform.

3 MEASUREMENT SYSTEM

3.1 Calibrating the Ultrasonic liquid flow meter
The 5-path Ultrasonic liquid flow meters were calibrated using a water tower at Krohne Altometer in Sliedrecht, Holland. The meters achieved results well within the NPD linearity requirements (Flow range 10:1 ±0.25%, flow range 5:1 ±0.15%) and satisfied the repeatability requirement as well (±0.020%), see Fig 3.

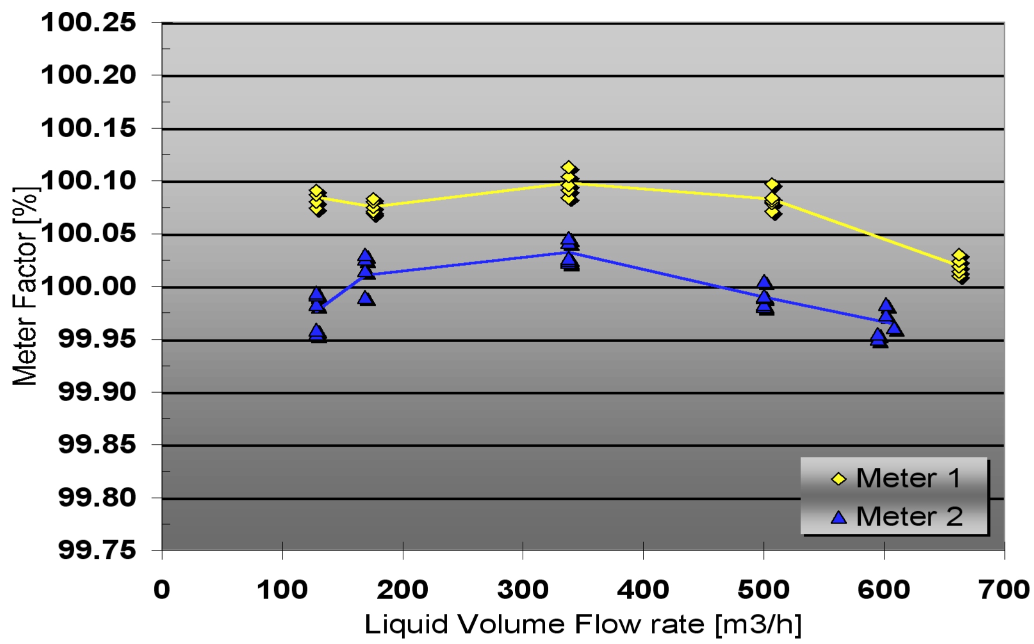

Fig 3 Calibration results, 5-path Ultrasonic liquid flow meters, with water. Meter 1 adjusted by - 0.058% after calibration.

3.2 System design
The metering system consists of two 5-path Ultrasonic liquid flow meters in series with a Unidirectional small volume ball prover, see Fig 4. 10D in front of the first ultrasonic meter is a flow conditioner and there is 5D between the two ultrasonic meters.

There are four volumes in the prover varying from 592 litres to 630 litres. The number of pulses from the ultrasonic meters during one proving trial is from 3150 to 3355 pulses, requiring pulse interpolation during proving.

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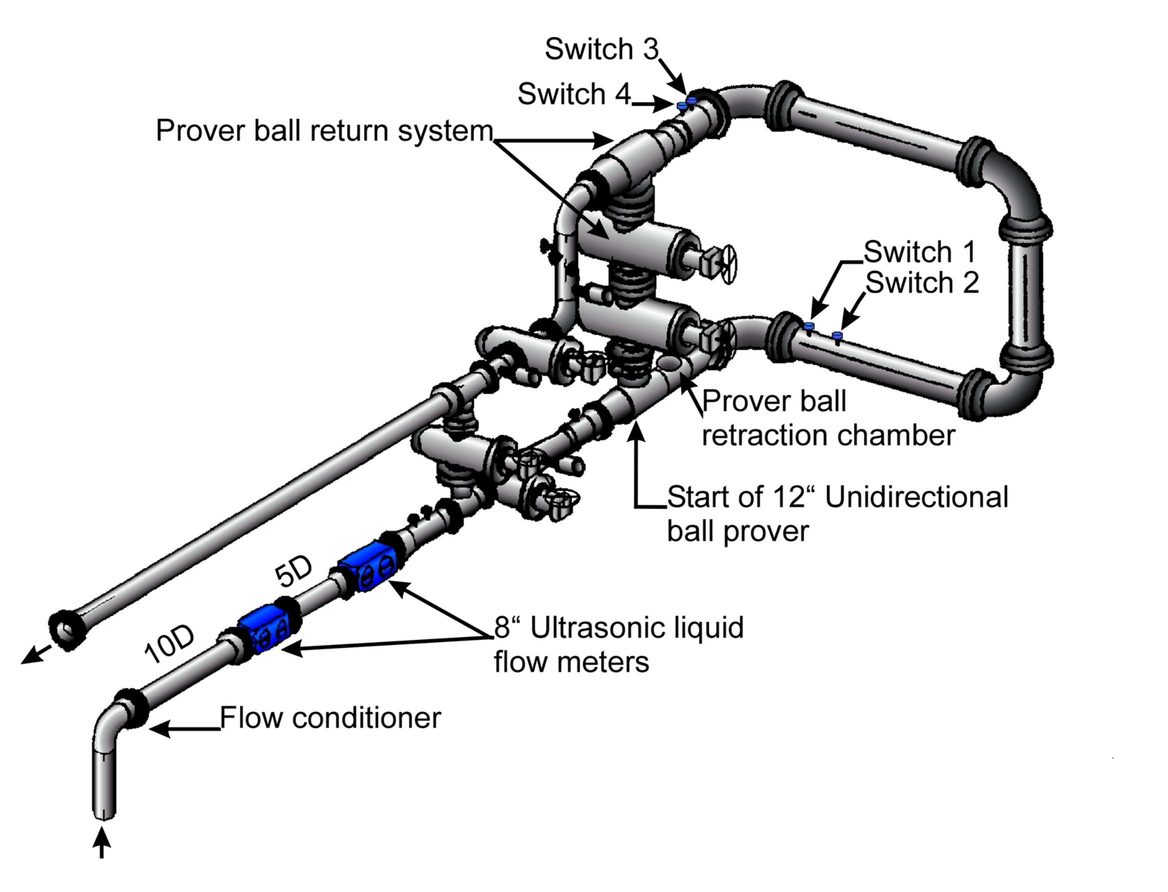

Fig 4 Layout metering system.

4 FLOW TESTS WITH POOR REPEATABILITY

Kongsberg Offshore started flow testing of the metering system in Brevik, Norway, in late November 1998. The repeatability results achieved during the initial test were surprisingly poor and no valid meter factor could be established within the NPD requirement.

Some errors were corrected without improving the repeatability results in any significant way. Krohne Altometer was also involved without finding any apparent reason for the poor repeatability results. Tests continued until February 1999, trying different ways to improve repeatability, without success.

According to the NPD regulation a valid meter factor is the average meter factor from a sequence of five consecutive proving trials when these five meter factors lie within a band of 0.050% of the average meter factor. If this is not true after five proving trials up to a total of ten proving trial can be made, always using the last five meter factors to calculate a valid meter factor. If no valid meter factor can be established after ten proving trials, a new proving sequence must be started.

Typical meter factors from single proving trials showing the large spread and consequently poor repeatability compared to the NPD requirement, are given in Fig 5 and 6 for both low and high flow rates.

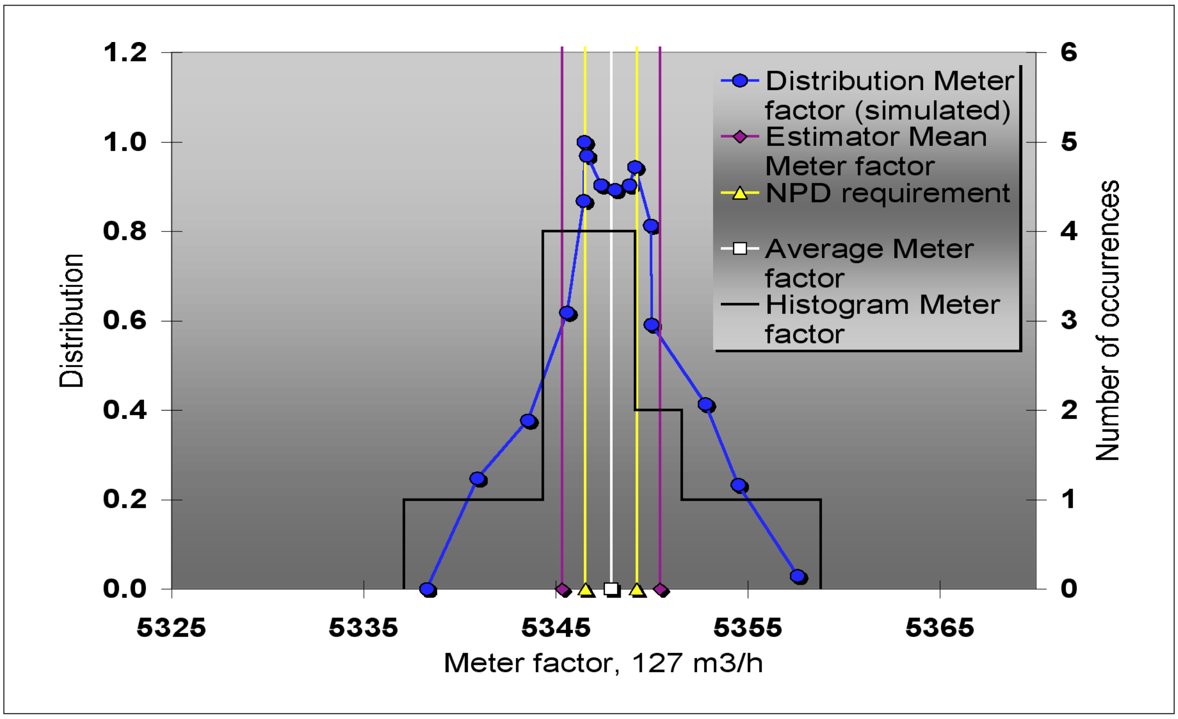

Fig 5 Typical proving trial results at low flow rate. The repeatability of the Estimator for the Mean meter factor is calculated at 95% confidence level.

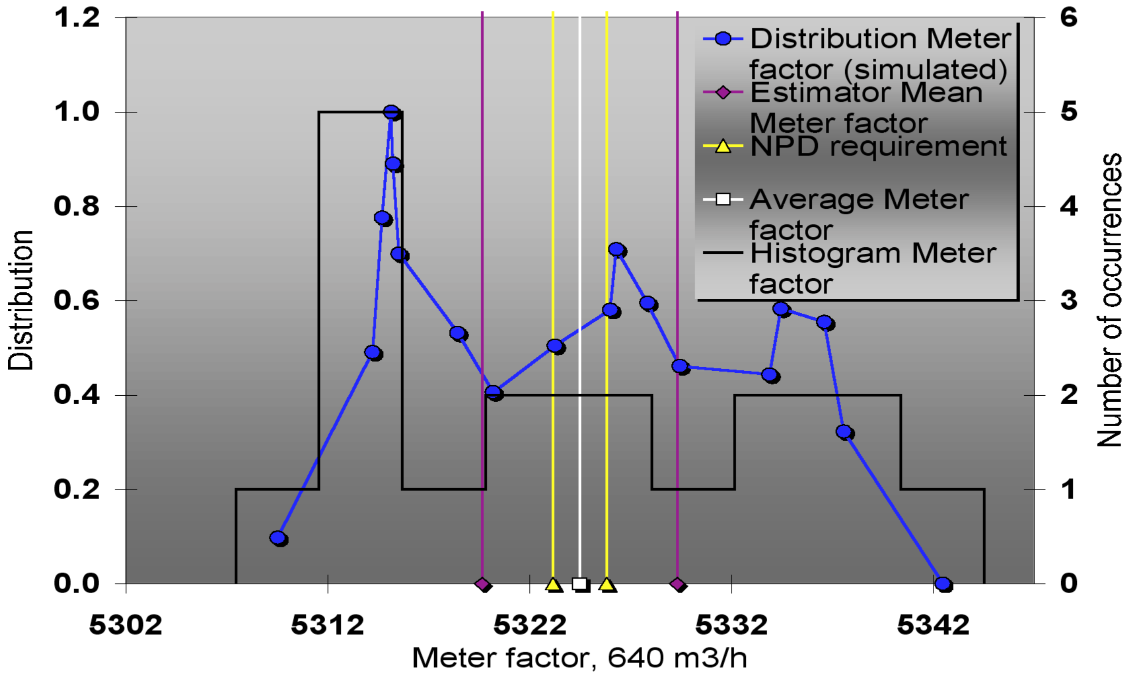

Fig 6 Typical proving trial result at high flow rate. The repeatability of the Estimator for the Mean meter factor is calculated at 95% confidence level.

The relative repeatability varies from 1.6 to 10.3 times the NPD requirement. Typical variation in Meter factor during several proving sequences is given in Fig 7 and 8.

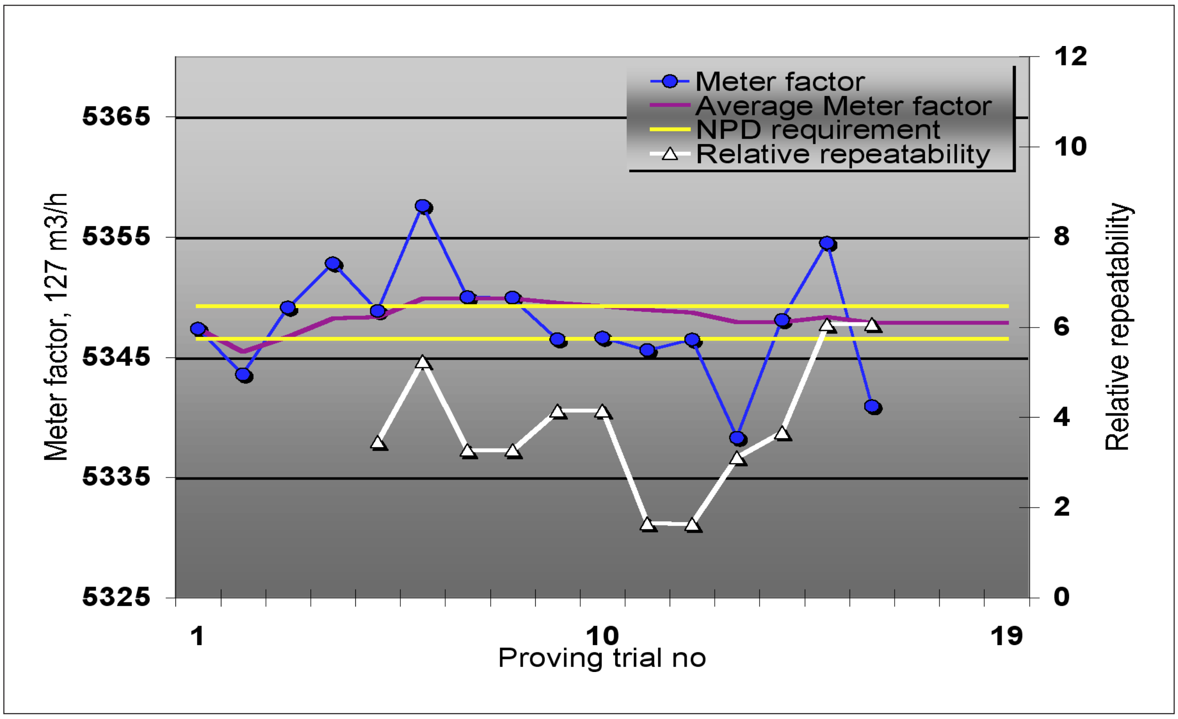

Fig 7 Typical variation in proving trial results at low flow rate.

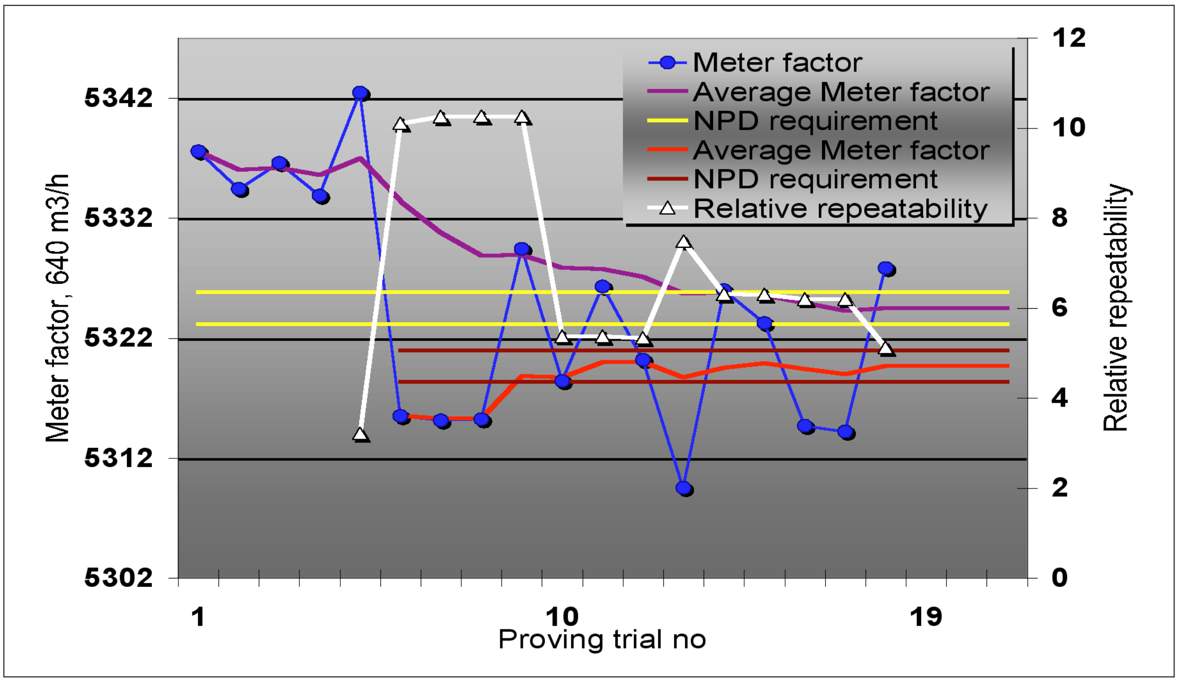

Fig 8 Typical variation in proving trial results at high flow rate.

In Fig 8, the average meter factor is also calculated when discarding the five first proving trials, giving a significant shift in average meter factor.

The conclusion so fare was that the small volume prover was not able to prove the ultrasonic meters within NPD requirements and that the system should be accepted as is. No fault could be found in either the prover system or the ultrasonic meters.

Norsk Hydro could not accept this conclusion, stating that a reason had to be found for the poor repeatability during proving. Norsk Hydro decided to use more resources to analyse the problem and to continue with the flow testing in Brevik.

5 PROBLEM ANALYSIS

There are mainly three sources of error when proving with poor repeatability. The pulse interpolation system can be faulty, the pulses coming from the ultrasonic meters can be unstable or the flow rate can be unstable. The two first sources of error were checked out and the metering system found to work properly. That left unstable flow rate.

The time series from the ultrasonic meter was analysed and it was discovered as expected that the time series revealed pulsation in the signal, see Fig 9 and 10. The pulsation looks to be periodic and with a peak amplitude of 2 - 3% of the average flow rate. This is a large pulsation amplitude compared to the NPD repeatability requirement.

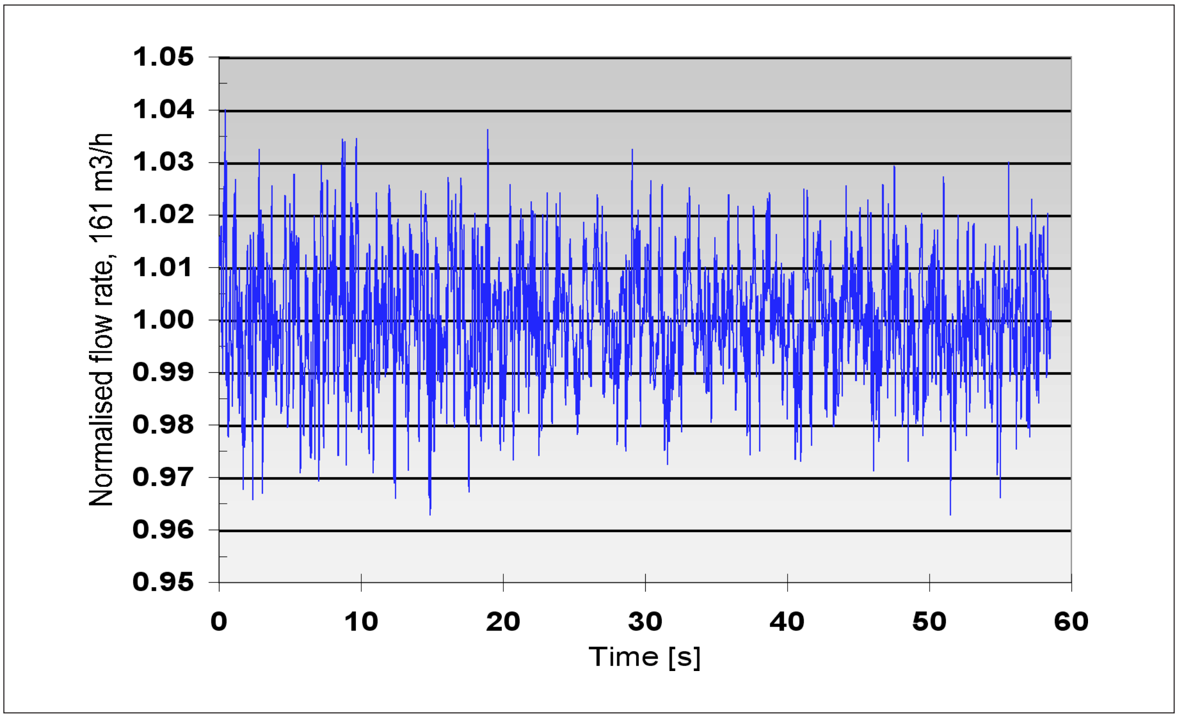

Fig 9 Typical time series at low flow rate show fluctuating flow rate.

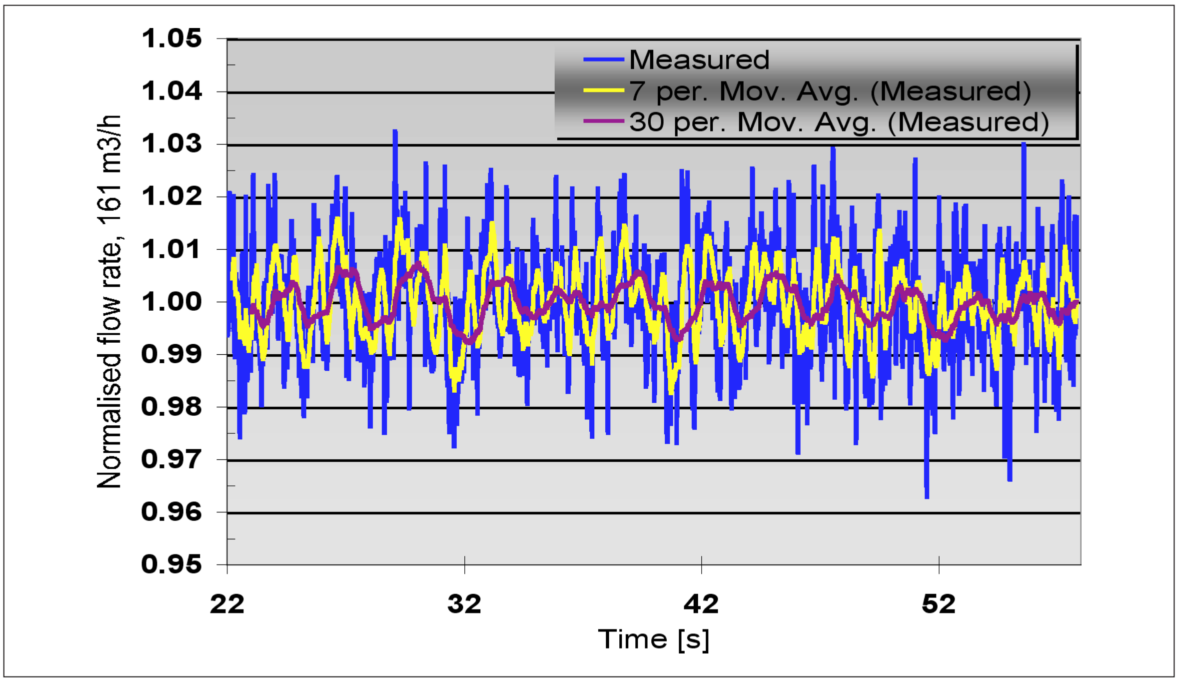

Fig 10 Typical time series at low flow rate indicates periodic pulsation with large amplitude.

The frequencies in the identified periodic pulsation look like 0.36 Hz and 1.3 Hz.

5.1 FFT reveals Pulsating flow

By performing a Fast Fourier Transform on the time series in Fig 9, the frequency components in the pulsation at low flow rate could be determined from the power spectrum, see Fig 11.

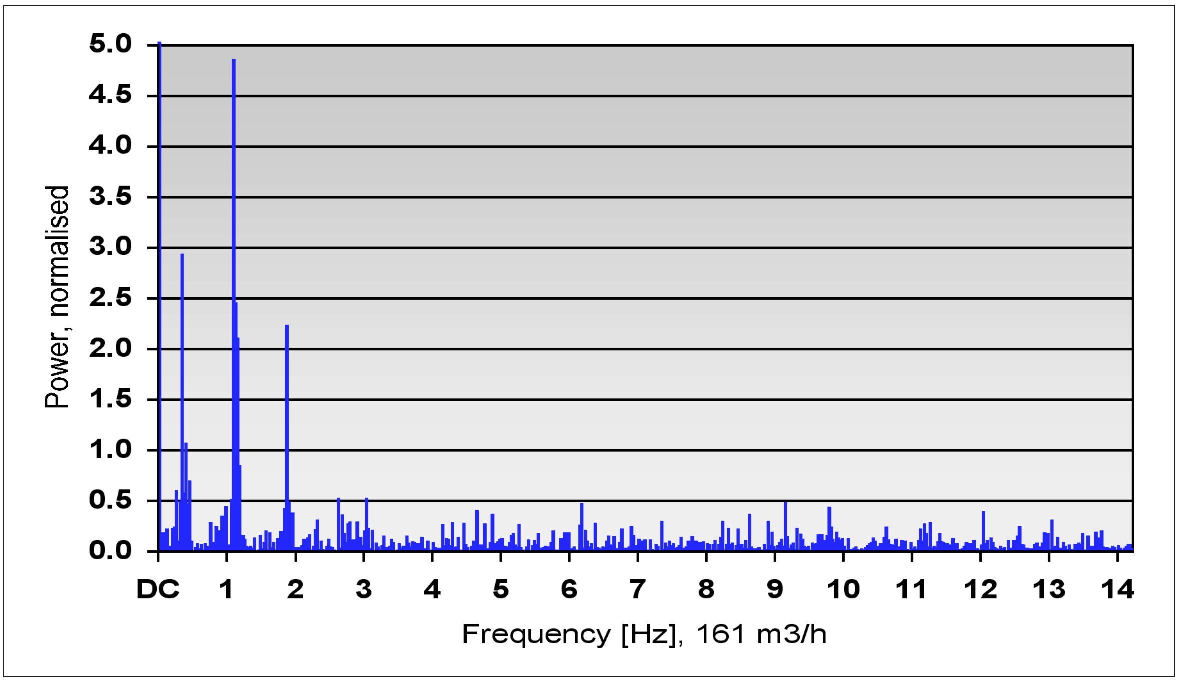

Fig 11 FFT on time series identifies pulsation frequencies at low flow rate.

For the low flow rate case, the centre frequencies of the three dominating frequency peaks and the cumulative peak amplitudes of these pulsations were calculated to be:

Table 1 Pulsation frequencies at low flow rate, 161 m3/h.

Pulsation frequency no.	1	2	3
Frequency, f_i	0.33Hz	1.09Hz	1.87Hz
Peak amplitude, x_i	0.53%	0.70%	0.44%

For the high flow rate case, see Fig 12, the centre frequencies of the four dominating frequency peaks and the cumulative peak amplitudes of these pulsations were calculated to be:

Table 2 Pulsation frequencies at high flow rate, 627 m3/h.

Pulsation frequency no.	1	2	3	4
Frequency, f_i	0.14Hz	0.64Hz	1.42Hz	2.37Hz
Peak amplitude, x_i	0.22%	0.32%	0.22%	0.26%

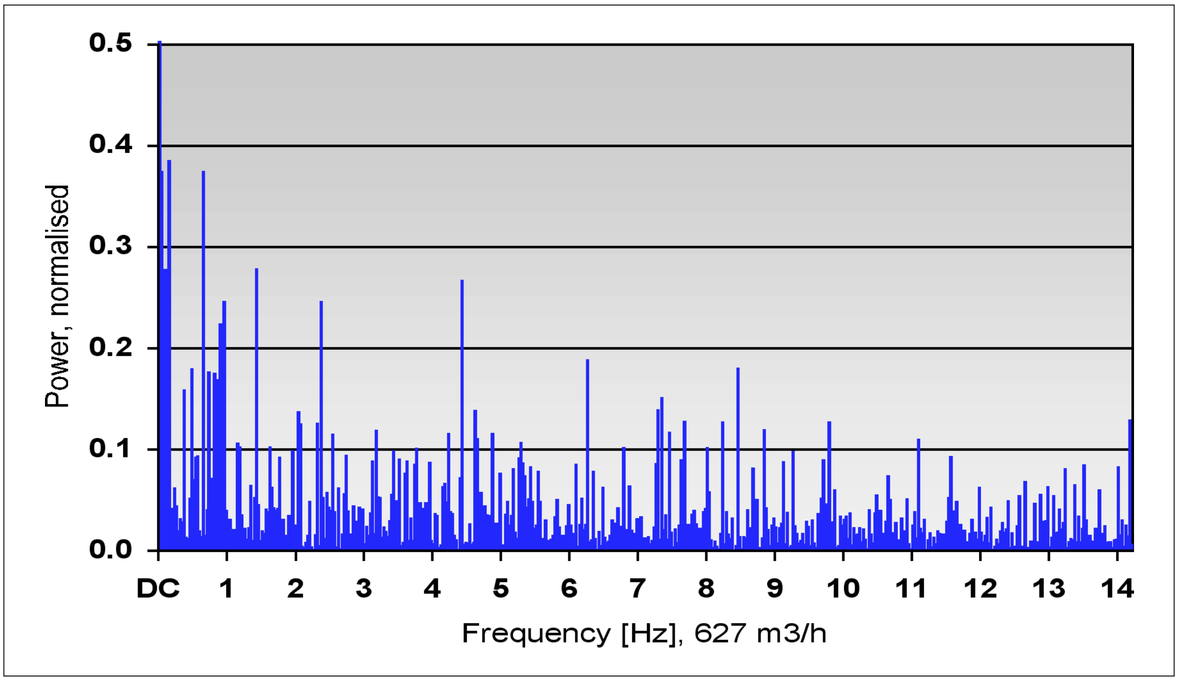

Fig 12 FFT on time series identifies pulsation frequencies at high flow rate.

Now, the questions remained, were these pulsation frequencies due to the flow or due to some inherent problem in the ultrasonic meters and could these pulsation frequencies explain the poor repeatability?

5.2 Simulations of proving results

To answer these questions, I simulated a proving trial with pulsating flow using the predominant frequencies with amplitudes as found from the time series. Finding the maximum and minimum meter factors, from Equation 1, the worst case repeatability for the meter factors could be calculated for each flow rate.

$$\text{Meter factor}_n = \frac{Q \cdot P_{max}}{Fr_{max} \cdot PrVol} \cdot \int_0^L \left[1 + \sum_{i=1}^{k} x_i \cdot \sin\left(2\pi f_i \left(t + \phi_i(n)\right)\right)\right] dt \quad \left[\text{pulses/m}^3\right] \qquad (1)$$

where

Q	=	Flow rate in m3/hr.
P_{max}	=	Maximum pulses pr second from the ultrasonic meter.
Fr_{max}	=	Maximum flow rate in m3/hr corresponding to Pmax.
PrVol	=	Prover volume in m3\ at standard conditions.
L	=	Duration of one proving trial in seconds.
k	=	Number of pulsating frequencies used in the simulation.
$\phi_i(n)$	=	Phase shift as a function of n.

The simulations assumed that the ultrasonic meter was truly measuring the flow variations and that the prover was almost unaffected by the same flow variations. These simulations revealed that the poor repeatability results could be explained to a large extent by the pulsating flow found in the time series. See Fig 13, where the meter factor in Equation 1 is plotted as a function of n.

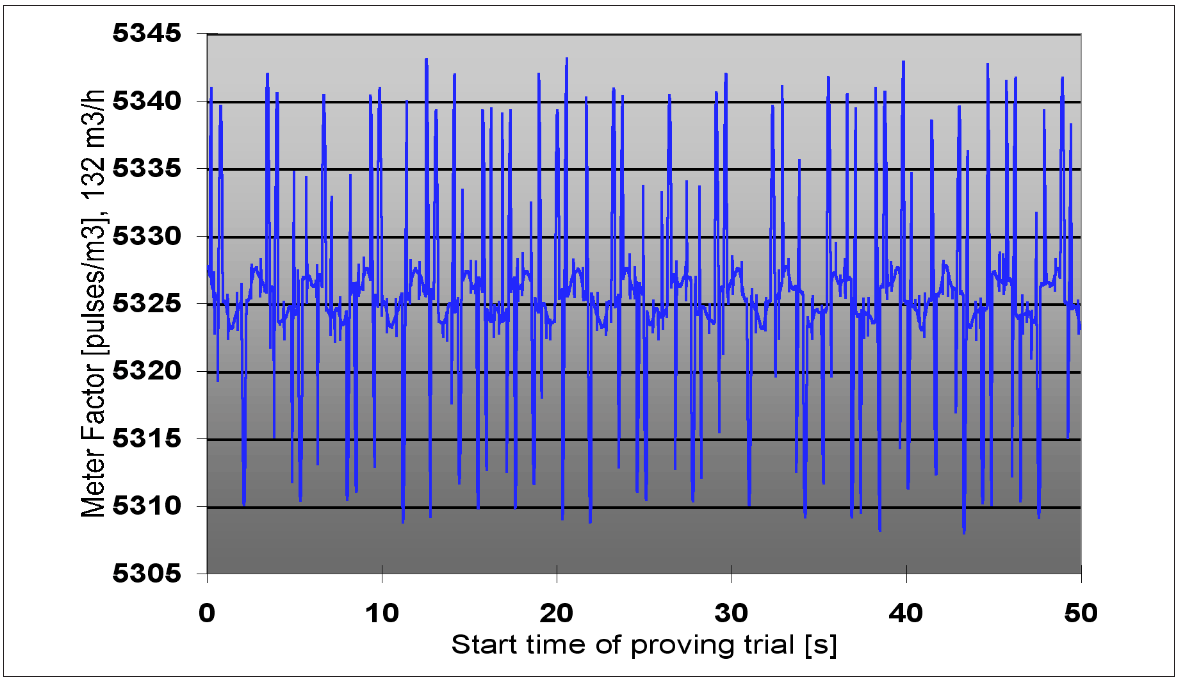

Fig 13 Simulated meter factors during proving with pulsating flow, low flow rate.

The worst-case repeatability found from the simulations varied from 0.3% to 0.8% for low flow rates and from 0.25% to 0.4% for high flow rates. This is from 5 to 16 times the NPD requirement.

The reason for this effect is that the periods of the pulsation frequencies are very small non-integer multiples of the time between the switches for one proving trial. At low flow rates the periods of the dominating pulsation frequencies are from 0.54 to 3.0 seconds while the time between the switches vary from 11 to 17.6 seconds. At high flow rates the periods of the dominating pulsation frequencies are from 0.42 to 7.1 seconds while the time between switches vary from 3.3 to 4.4 seconds.

For simplicity's sake, let us consider what happens in a flow pulsating with a single frequency, 0.38Hz. For such a flow, the worst-case shift from "true" average flow rate occurs when the period of the pulsation frequency is 0.5 times the time between the switches. The second worst-case shift is when the period of the pulsation frequency is 1.5 times the time between the switches. In Fig 14 is indicated that when the fluctuation in flow is asymmetric over time round the "true" average flow, during one proving trial, this causes a shift in the average flow rate and thus in the meter factor. Assuming the prover ball reacts to the "true" average flow rate. The size of the shift depends on the phase of the fluctuation at the start of proving and can be zero. This is why repeatability is sporadically within the NPD requirement.

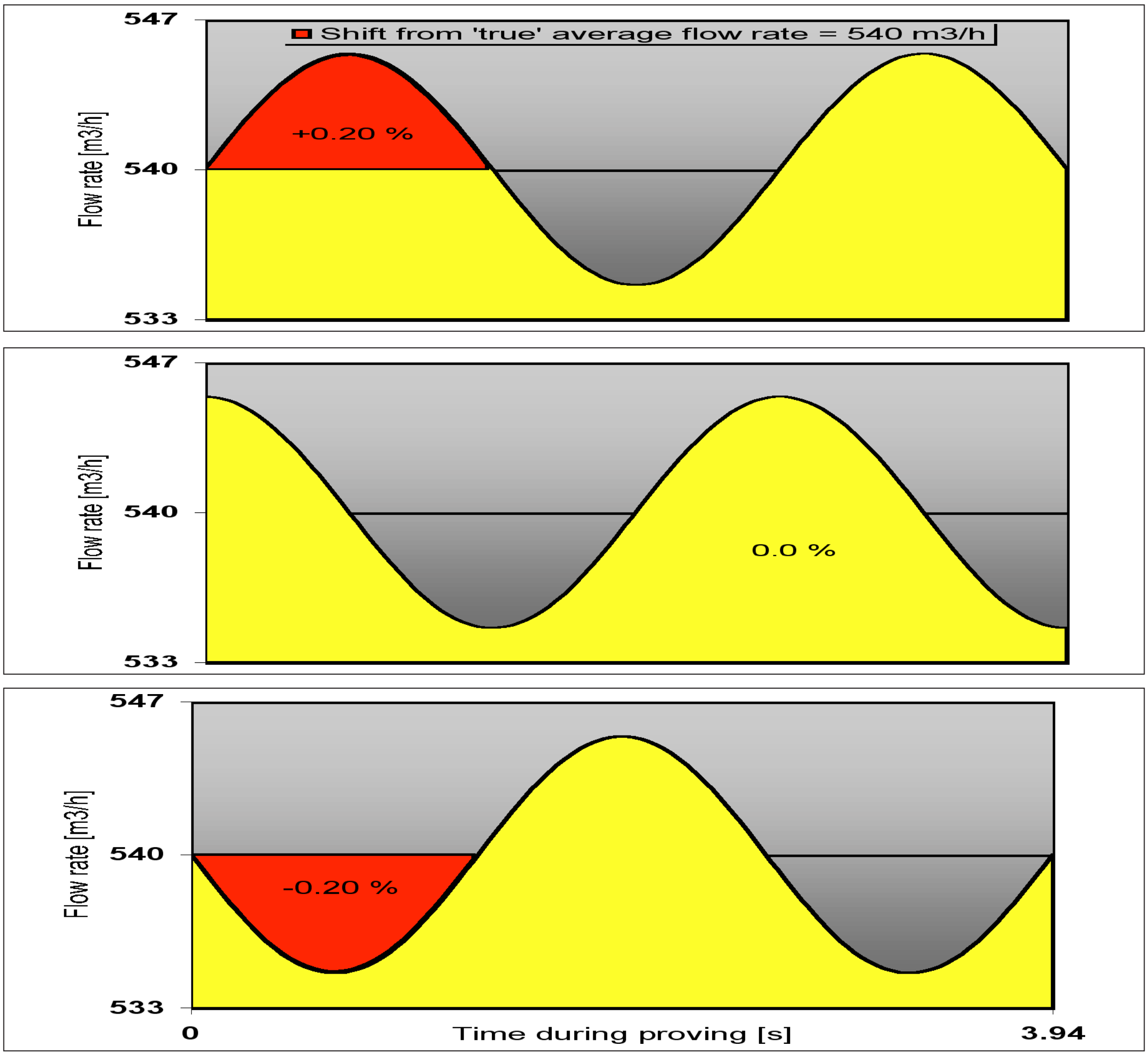

Fig 14 Simulated second worst-case shifts from "true" average flow rate due to pulsating flow at 0.38Hz, during one proving trial of 3.94 seconds.

In addition to the pulsating flow rate, the reduction and fluctuation in flow rate caused by the prover ball dropping down and travelling through bends, may also affect the proving result, but probably in a minor way compared to the pulsating flow.

What causes the flow fluctuations and what can we do to reduce or eliminate them?

5.3 Improvements to test loop

Looking at the test loop, flexible hoses were replaced by pipe or reinforced flexible hoses. This gave some improvement to the repeatability and some proving sequences at low flow were performed within the NPD requirement, see Fig 22, red dot. However, proving results were still not consistently within the NPD requirement, compare Fig 5, 6, 7 and 8 with Fig 20, 21, 22 and 23. FFT analysis revealed that there had been a slight reduction in the peak amplitudes of the dominating pulsation frequencies, thus corroborating the theory so fare.

5.4 Test with turbine meter

To eliminate any doubt that the prover was actually functioning properly it was decided to install a turbine meter in place of the second ultrasonic meter. Several proving sequences were performed for various flow rates within the NPD requirements, see Fig 15 and 16.

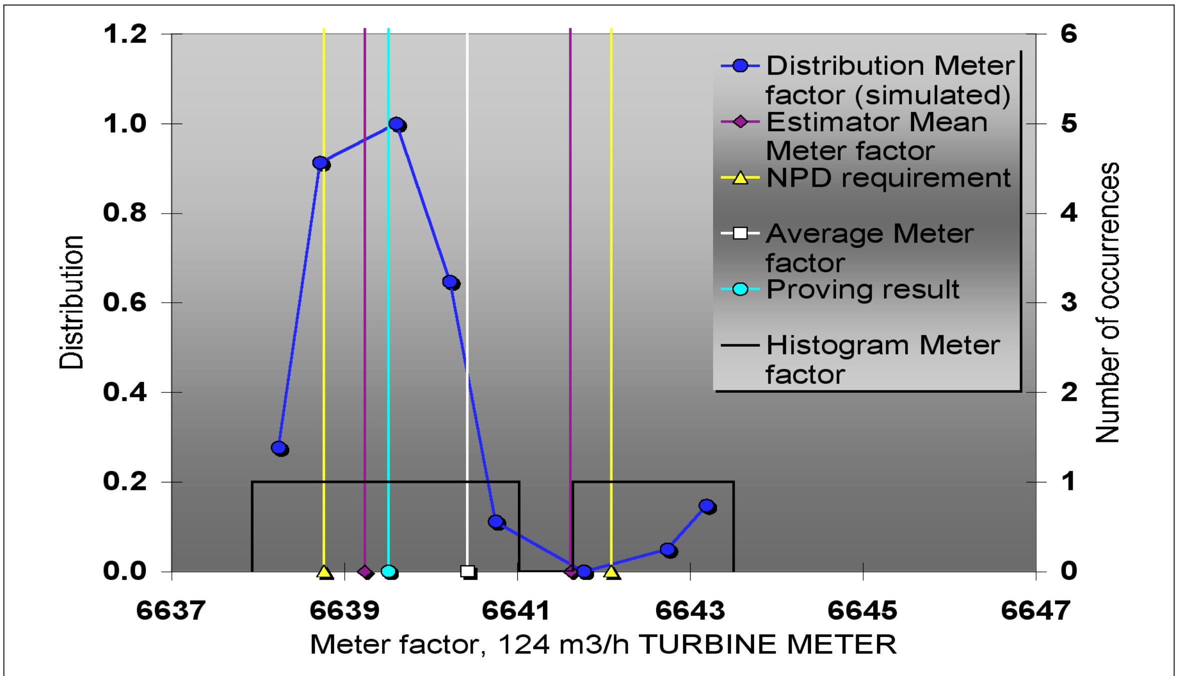

Fig 15 Typical proving trial results at low flow rate for turbine meter. The repeatability of the Estimator for the Mean meter factor is calculated at 95% confidence level.

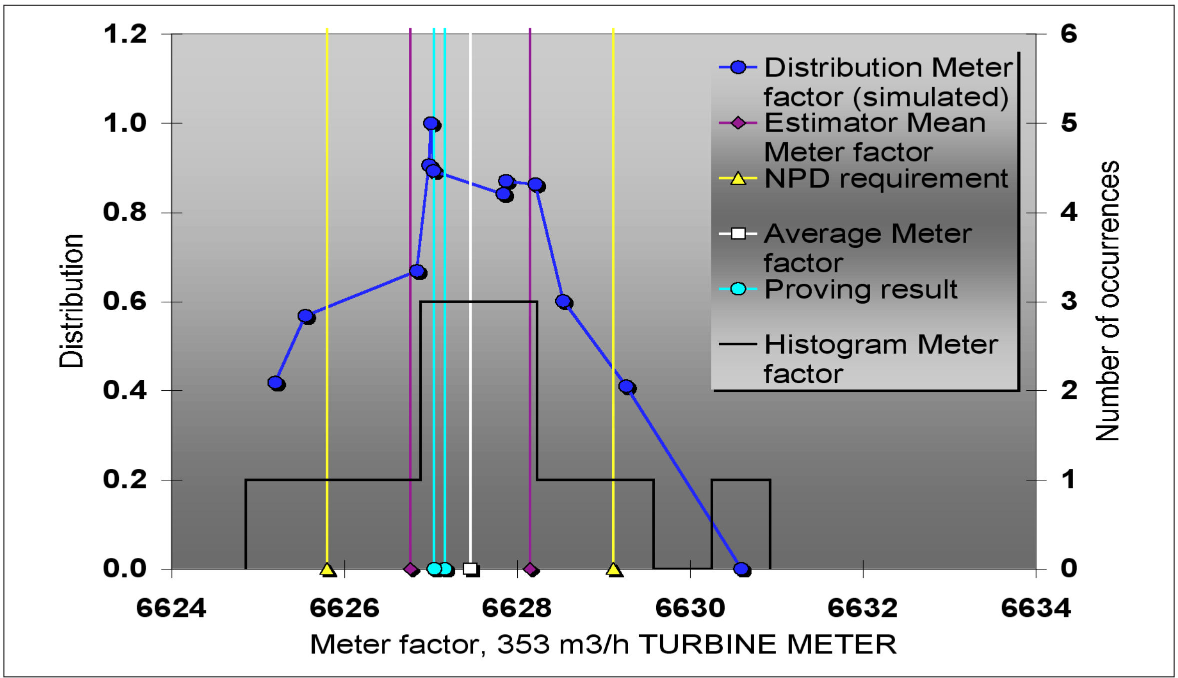

Fig 16 Typical proving trial results at medium flow rate for turbine meter. The repeatability of the Estimator for the Mean meter factor is calculated at 95% confidence level.

However, overall variation in meter factor of 0.081% indicated that the turbine meter also reacted to the pulsation in the flow, see Fig 17 and 18. As can be seen from comparison of the ultrasonic and turbine meter, displayed by the database computer in the metering system, see Fig 19. We can also see that during proving there is a significant drop in prover outlet pressure.

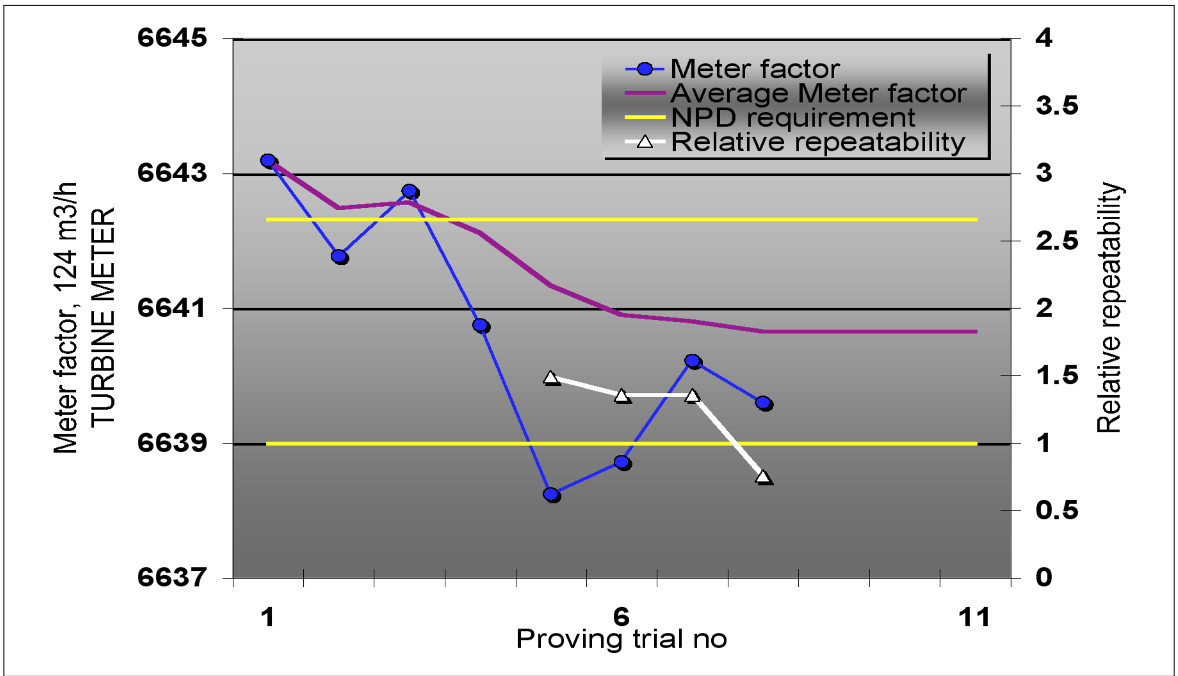

Fig 17 Typical variation in proving trial results at low flow rate for turbine meter.

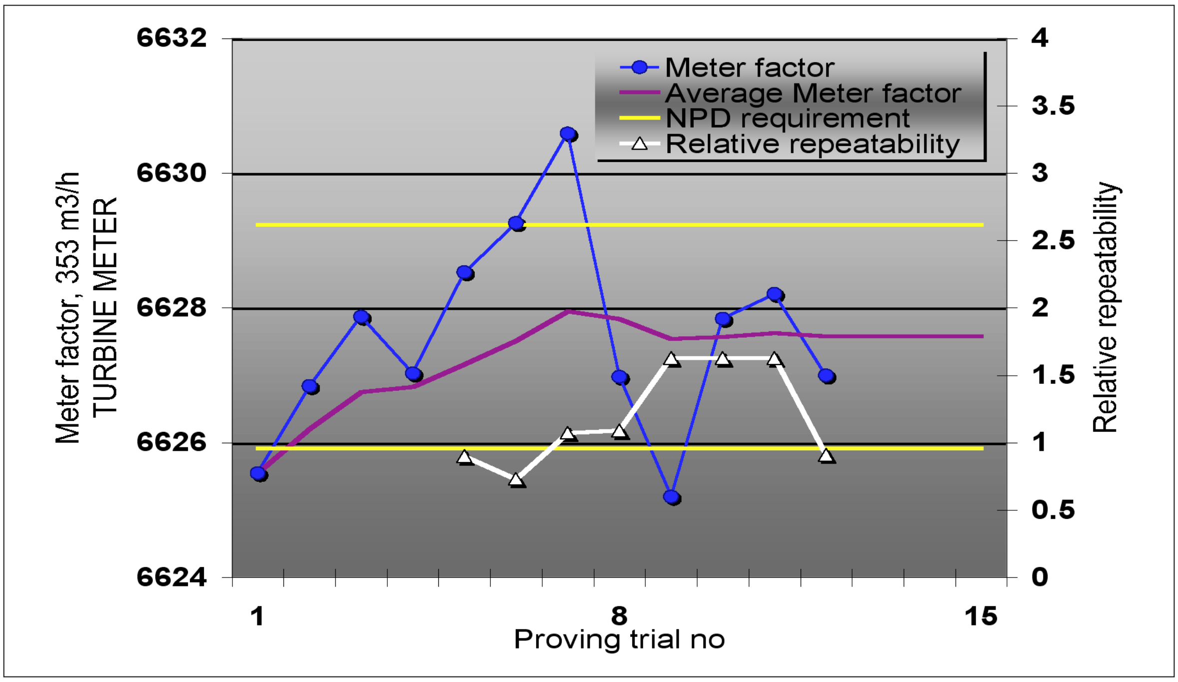

Fig 18 Typical variation in proving trial results at medium flow rate for turbine meter.

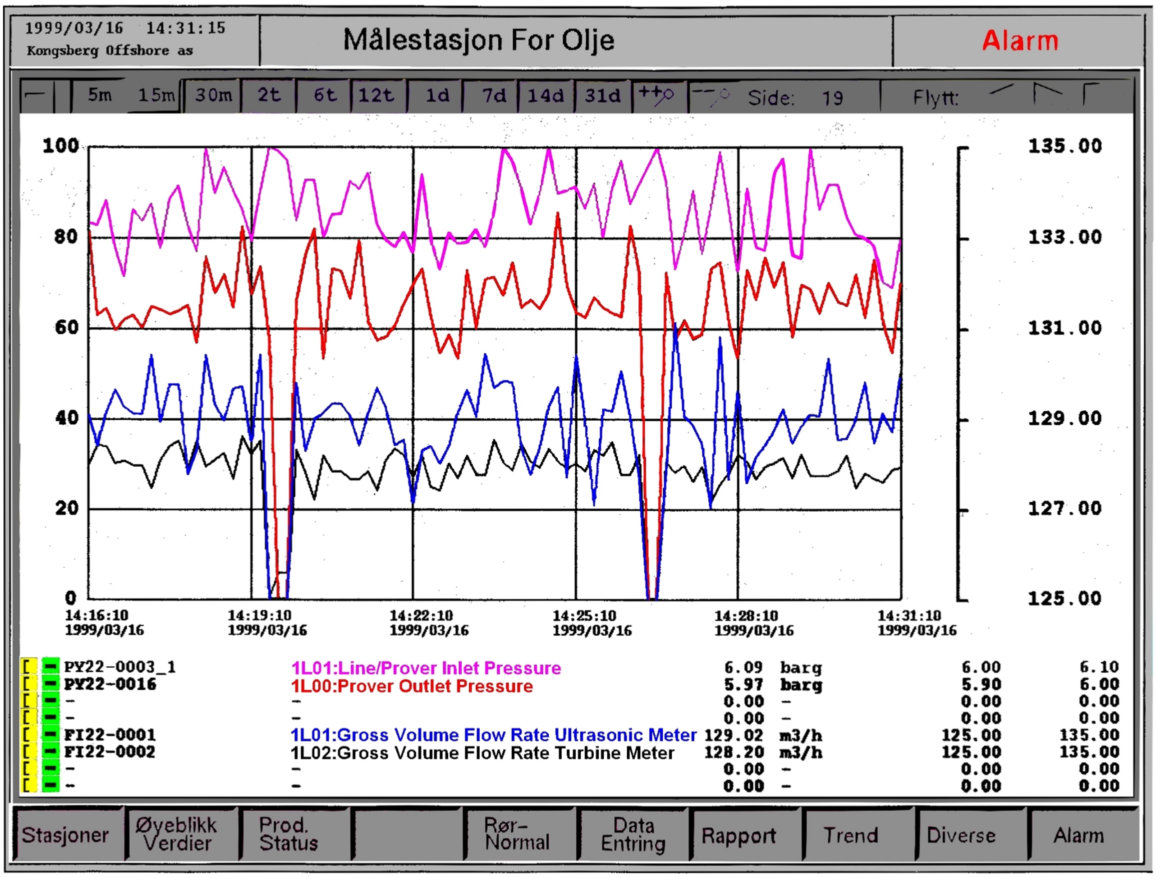

Fig 19 Trend display showing that the turbine meter and the ultrasonic meter reacts differently to the pulsating flow.

5.5 Probable cause of poor repeatability

The pulsation was finally determined to come from cavitation in the pumps in the flow loop. By using flow control valves to try to reduce cavitation, some improvement was achieved. However, we still could not achieve proving results for all flow rates consistently within the NPD requirement. There seemed to be no way that the test facility in Brevik could be sufficiently improved, in a short time, to give stable enough flow. It was therefore decided, in agreement with the NPD, to end the flow tests at Brevik and to prepare new flow tests on the Oseberg Sør platform during commissioning, in the year 2000. As preparation for the flow test a study to determine methods to achieve improved repeatability was started.

6 HOW TO ACHIEVE IMPROVED REPEATABILITY

There seem to be three ways to reduce the problem of pulsating flow and poor repeatability. One way is to improve design so that pulsating flow is reduced or eliminated. The second way is to use statistical methods and base the proving sequence on more than five consecutive proving trials and the third way is to make the ultrasonic meter behave more like a turbine meter.

6.1 Mechanical design

The installation of the metering system on the Oseberg Sør platform will have improved flow conditions due to more rigid and stable upstream flow from large pumps followed by a static mixer. This will possibly sufficiently reduce or eliminate the pulsating flow. Problem solved. However, this is not certain, so the other two ways of reducing the problem must also be considered.

6.2 Statistical evaluation of meter factors

Using enough proving trials to calculate the average meter factor, will give a representative average meter factor, when the flow is not shifting too much (normal production). How many proving trials is needed and how long will it take to prove the two ultrasonic meters? Using 15 to 20 proving trials will give a stable average meter factor for all flow rates, see Fig 20, 21, 22 and 23.

An estimator for the Mean meter factor, , is given by Equation 2. Assuming that the n meter factors, X, follow a normal distribution with standard deviation, s, and average, $\overline{X}$, the estimator for the Mean meter factor will follow a Student-t distribution with (n-1) degrees of freedom.

$$\overline{X} - t_{\frac{\alpha}{2}} \frac{s}{\sqrt{n}} < \text{ì} < \overline{X} + t_{\frac{\alpha}{2}} \frac{s}{\sqrt{n}} \tag{2}$$

The repeatability of the estimator for the Mean meter factor, , in percent is then found to be

$$\sigma = 2\,?\,t_{\frac{\alpha}{2}} \frac{s}{\overline{X}\,?\sqrt{n}} \quad [\%] \tag{3}$$

The repeatability of the estimator for the Mean meter factor is calculated at 95% confidence level, , and is not within the NPD repeatability requirement at any flow rate, with n less than 25. The repeatability of the estimator for the Mean meter factor will fall within the NPD repeatability requirement, when n is large or when the flow is more stable. If n then is for example 30, the time needed to prove two ultrasonic meters will be more than 7 hours which is fare to long.

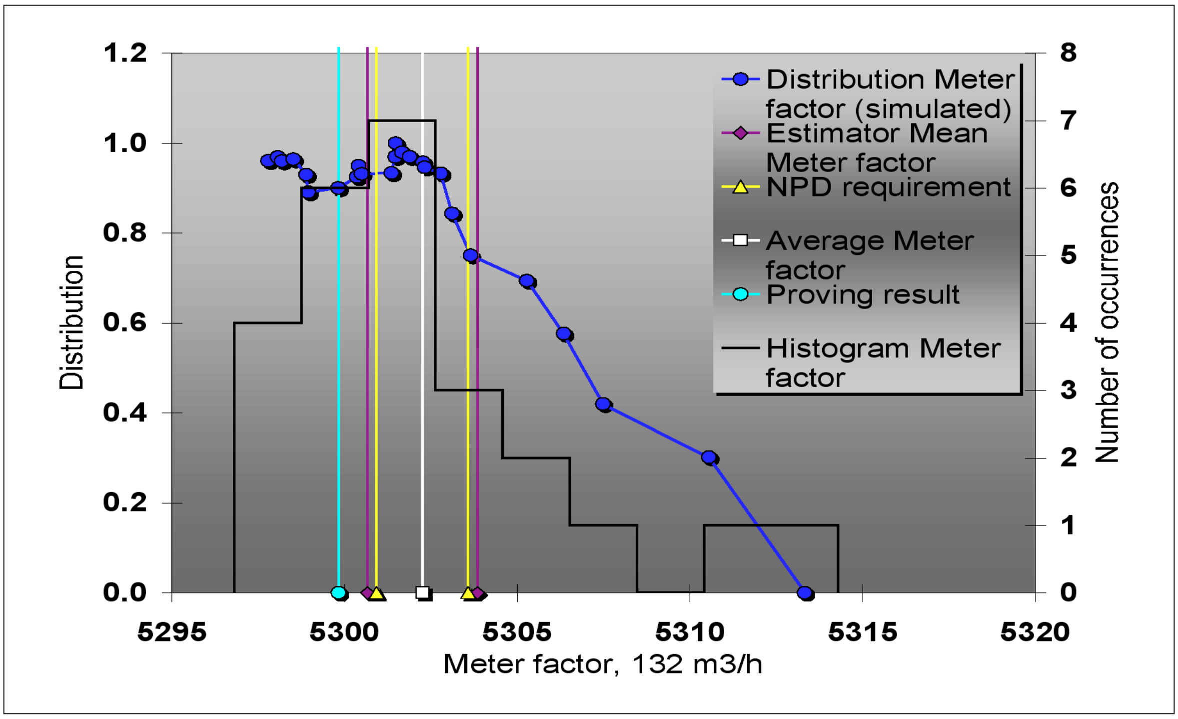

Fig 20 Typical proving trial result at high flow rate. The repeatability of the Estimator for the Mean meter factor is calculated at 95% confidence level.

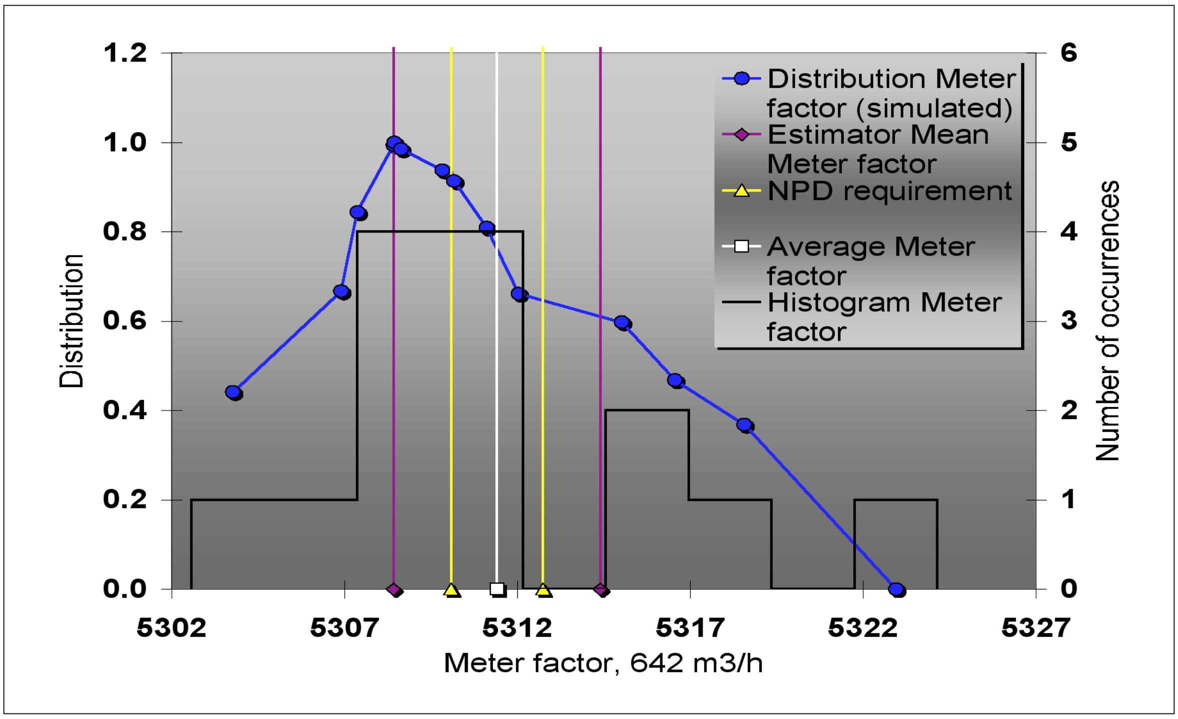

Fig 21 Typical proving trial result at high flow rate. The repeatability of the Estimator for the Mean meter factor is calculated at 95% confidence level.

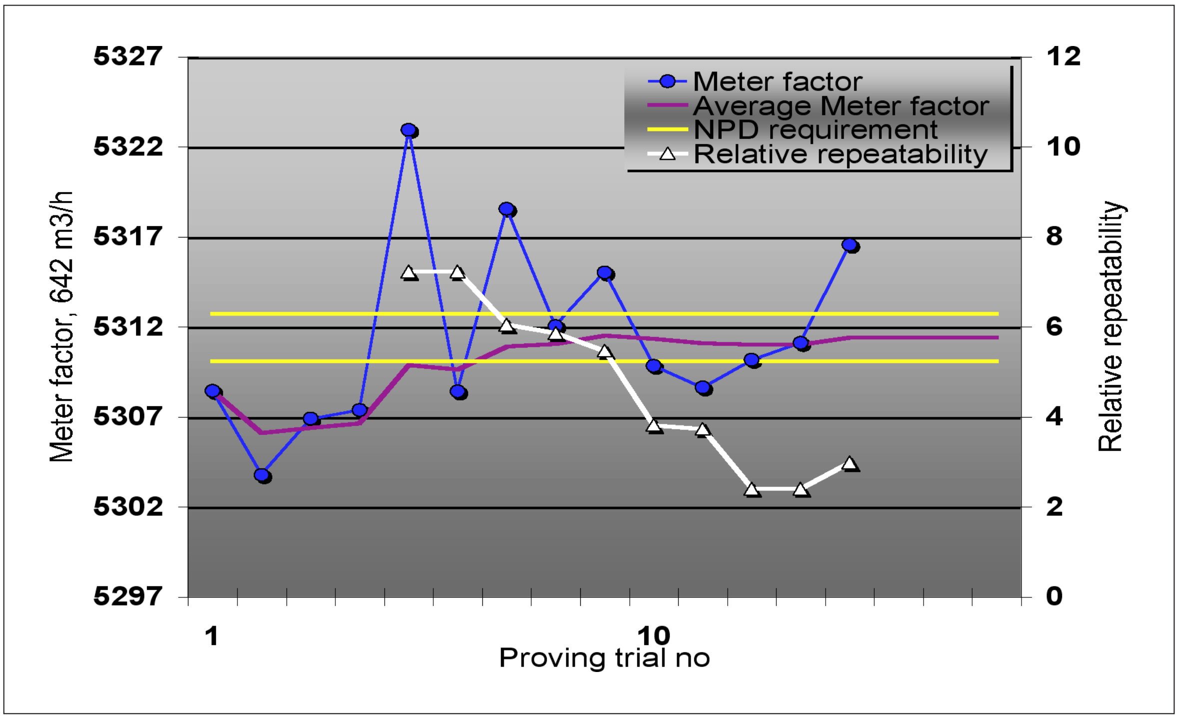

Fig 22 Typical variation in proving trial results at low flow rate.

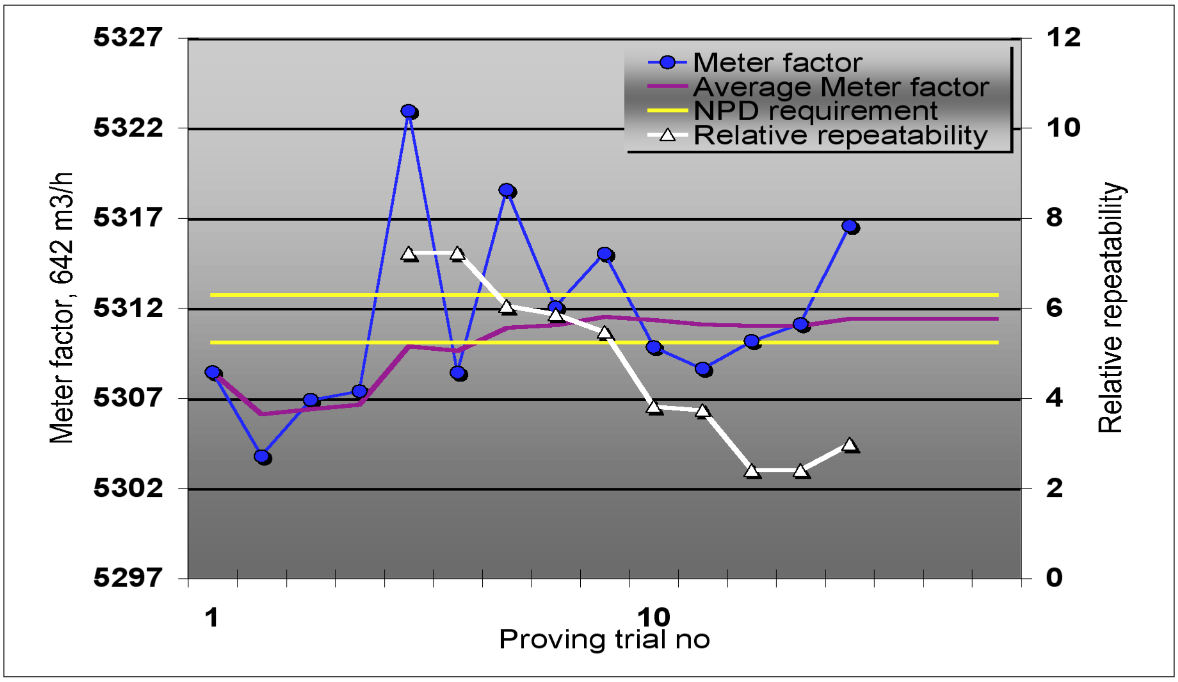

Fig 23 Typical variation in proving trial results at high flow rate.

The red dot in Fig 22 indicates that five consecutive proving trials lie within the NPD requirement. However, using these five meter factors to calculate the average meter factor will give a low meter factor, see Fig 20, not representative for all the data in Fig 20 and 22. Since it is just thanks to a random event that the NPD requirement was satisfied, this indicates a weakness in the current method for accepting new meter factors.

My proposed statistical method for accepting and calculating average meter factors is based on all meter factors being equally correct. The average meter factor is calculated using all consecutive meter factors from the start of the proving sequence as in Fig 22 and 23. The criterion for convergence of the average meter factor should be at least one-tenth the NPD repeatability requirement (±0.0025% change from the previous average value). At least five and maybe maximum twenty proving trials should be performed.

The proving data from Brevik indicates that stable enough average meter factors can be reached after 5 to 16 proving trials with this method, for all test series and flow rates.

To reduce random spurious convergence of the average meter factor and avoid accepting a new meter factor before the average meter factor has reached a sufficiently stable value, a two step convergence criterion is proposed. The two step criterion for convergence of the average meter factor should be at least one-fifth and one-tenth the NPD repeatability requirement (first ±0.0050% change from the previous average value, then the next average value must change less than ±0.0025% from the previous average value). This is a more robust method.

Using this method, convergence of the average meter factor could not be reached for some of the flow rates in Brevik, even after more than twenty proving trials. Convergence of the average meter factor was normally reached after 8 to 15 proving trials with this method and will be reached after five proving trials for more stable flow conditions, just like the current method accepted by the NPD.

Under more stable conditions the repeatability of the estimator for the Mean meter factor in Equation 3, could be used as a criterion, but it will require more proving trials than the proposed statistical methods described above.

The current method of using five consecutive proving trials within a sequence of ten, discarding as much as 50% of the values before calculating the average meter factor, is not a good method in a statistical sense. Completely valid meter factors are not used in calculating the average, not only outliers are discarded. When you have large fluctuations in flow rate, you need more values to calculate a good average than with stable conditions. This is not possible with the current method which requires very stable proving conditions to work properly.

6.3 Filtering meter response

By making the ultrasonic meter respond to flow more like a turbine meter, some of the inherent advantages of using ultrasonic meters are lost. This is therefore the least preferred way of reducing the problem with pulsating flow and poor repeatability.

Many time series were logged by Krohne Altometer in Brevik, see Fig 24 for a typical time series during proving.

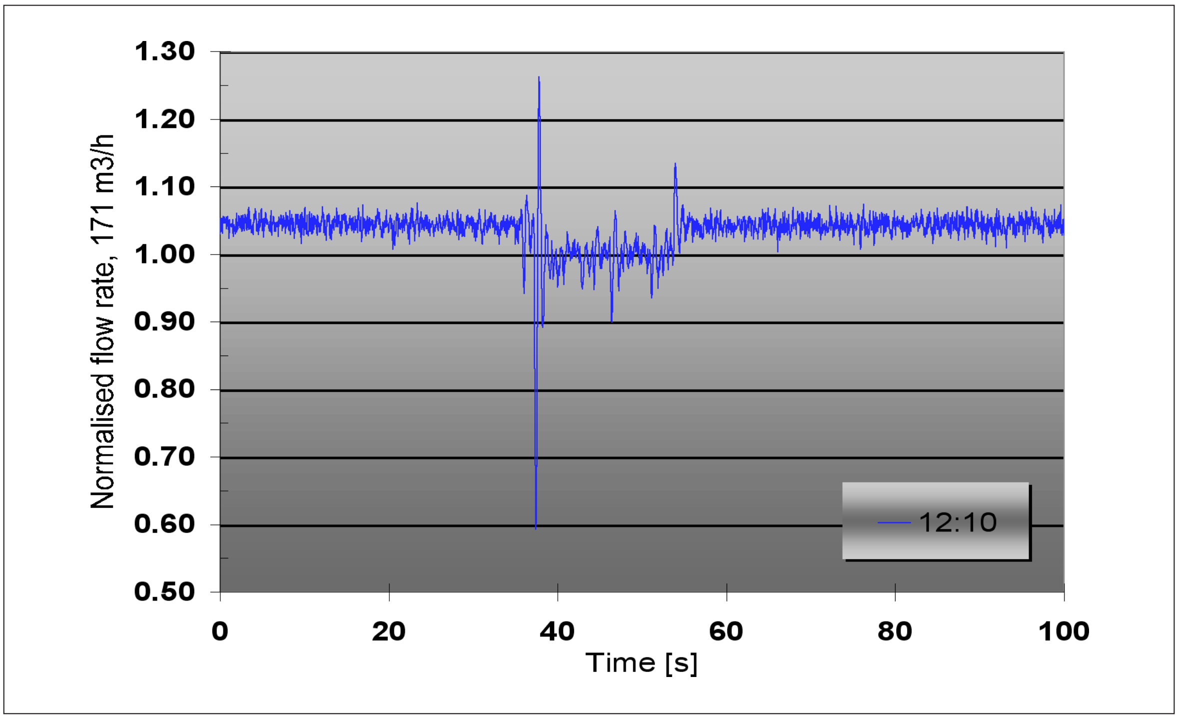

Fig 24 Typical time series during proving.

By calculating the volume of various portions of the prover and by using the relationship in Equation 4, the position of various events are identified in the time series, see Fig 25. Two reference positions are used—the ball drops down and the second bend.

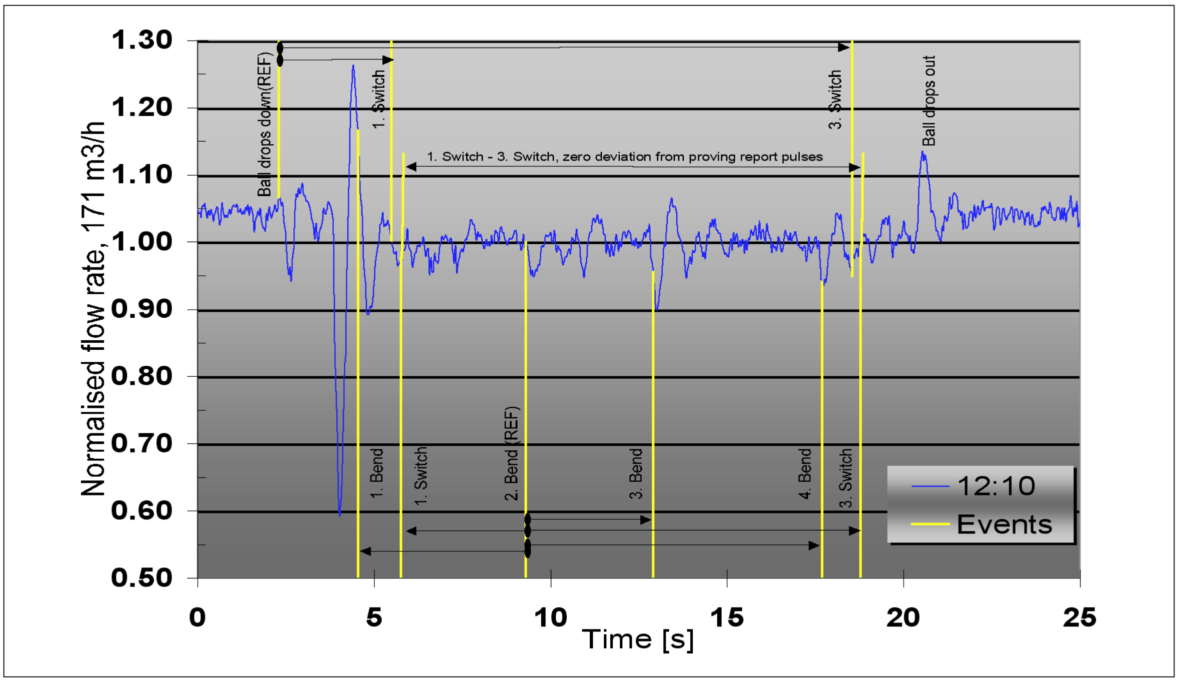

Fig 25 Typical time series during proving identifying the various events during proving.

The effect of various methods of changing the performance of the ultrasonic meter, like filtering time series, should therefore be readily verifiable. —Not so. It turned out after much deliberation that the timestamp on the time series and the timestamp on the proving reports from Brevik were not synchronised, so this had to be sorted out first.

The position in the proving trial of the first switch, D, can be determined in each time series from the integral in Equation 4. When this integral of the number of pulses from the ultrasonic meter during the proving trial, equals the number of pulses read from the proving report, the starting value d=D. So when d=D the Deviation(d) is zero and we know which part of the time series is the proving trial, corresponding to a known meter factor. By filtering the time series and integrating over the proving trial again, new meter factors can be calculated for the same time series. By using five consecutive proving trials the repeatability for the new average meter factor can be calculated and compared to the NPD requirement.

$$\text{Deviation}(d) = \int_{d}^{d+L} \text{Pulses from USM}(t)\,dt - \text{Proving report pulses} \quad [\text{pulses}] \qquad (4)$$

where

$$L = 3600 \cdot \text{Pr Vol} \cdot C_{PSP} \cdot C_{TSP} / Q_{\text{Proving report}} \qquad [\text{seconds}]$$

In Fig 26 is given a graphical illustration of Deviation(d) when stepping through all values of d. All time series have been aligned according to the position of the second bend. So ideally, the function Deviation(d) should be zero for the same value of d for all time series. This was not the case. After much analysis and number crunching I found that only by shifting the time stamps 20 minutes could the requirement that the Deviation(d) in Equation 4 should be zero, be reasonably satisfied simultaneously for all time series, at both low and high flow rates.

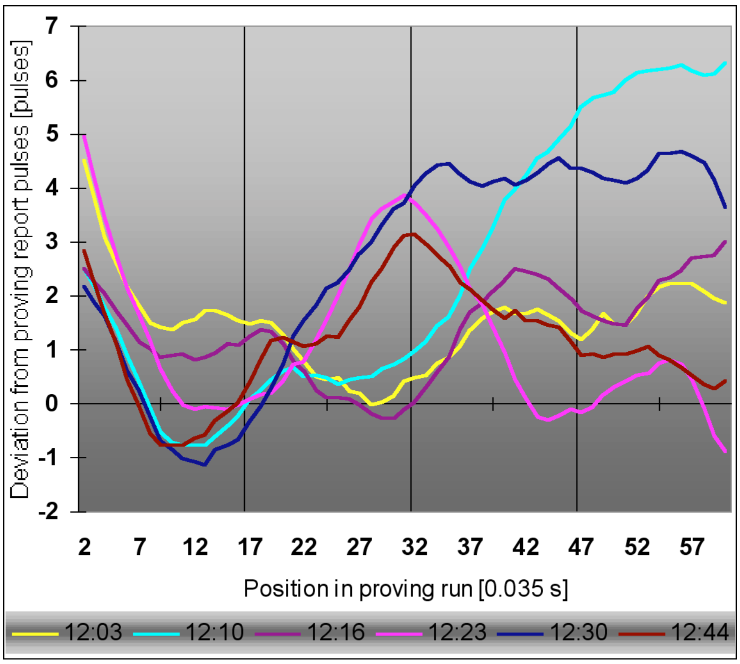

Figure 26 Deviation(d) for various time series

The duration of the proving trial, L, is calculated from the data in the proving report, see Fig 27 for the proving report used for these analysis.

1999/03/11 12:39 Oseberg Sør - Oljemålestasjon KOS FCM 212
USM KALIBRERING OG KORREKSJONSFAKTORER Side 1 av 2

Volum i bruk.......: A (1-3) Status: AVBRUTT
Rørnormal Volum Sm3: 0.617910 USM Nr: 1

Forsøk Nr.	Antall Pulser	Linje Temp grdc	Linje Trykk barg	Rørnorm Temp grdc	Rørnorm Trykk barg	Std. Tetthet kg/Sm3	Volum Strøm m3/h	Meter K-faktor P/m3	KOS Time	Krohne Time
1	3284.4	30.70	5.92	30.67	5.57	800.00	171.30	5312.37	11:43	12:03
2	3286.5	30.82	5.92	30.79	5.56	800.00	170.64	5315.68	11:50	12:10
3	3284.7	30.94	5.91	30.91	5.60	800.00	171.20	5312.75	11:57	12:16
4	3282.4	31.06	5.91	31.02	5.59	800.00	170.24	5309.00	12:04	12:23
5	3282.0	31.16	5.92	31.15	5.65	800.00	171.38	5308.41	12:11	12:30
6	3283.2	31.29	5.90	31.26	5.55	800.00	171.26	5310.33	12:18	-----
7	3283.9	31.41	5.90	31.39	5.59	800.00	171.42	5311.40	12:25	12:44
8	3286.5	31.54	5.92	31.51	5.60	800.00	171.11	5315.55	12:32	
9	###	###	###	###	###	###	###	###	12:39	
10	###	###	###	###	###	###	###	###		
Gj.snitt Siste 5 Forsøk	3283.6	31.29	5.91	31.27	5.59	800.00	171.08	5310.94		

K-faktor i bruk: ###
Repeterbarhet: 0.134 Differanse.....: ###

Forsøk Nr.	CPSP	CTSP	CPLP	CTLP
1	1.0000447	1.0005250	1.0005420	0.9848999
2	1.0000447	1.0005289	1.0005421	0.9847872
3	1.0000450	1.0005331	1.0005462	0.9846669
4	1.0000449	1.0005368	1.0005453	0.9845606
5	1.0000454	1.0005409	1.0005520	0.9844396
6	1.0000446	1.0005449	1.0005426	0.9843264
7	1.0000449	1.0005490	1.0005465	0.9842073
8	1.0000450	1.0005529	1.0005481	0.9840931
9	###	###	###	###
10	###	###	###	###

Gj.snitt siste 5 forsøk

CPSP	CTSP	CPLP	CTLP
1.0000449	1.0005449	1.0005469	0.9843254

1999/03/11 12:39 Oseberg Sør - Oljemålestasjon KOS FCM 212
USM KALIBRERING OG KORREKSJONSFAKTORER Side 2 av 2

Forsøk Nr.	CPSM	CTSM	CPLM	CTLM
1	1.0000000	1.0000000	1.0005765	0.9848772
2	1.0000000	1.0000000	1.0005771	0.9847522
3	1.0000000	1.0000000	1.0005766	0.9846365
4	1.0000000	1.0000000	1.0005773	0.9845268
5	1.0000000	1.0000000	1.0005785	0.9844272
6	1.0000000	1.0000000	1.0005769	0.9843038
7	1.0000000	1.0000000	1.0005773	0.9841817
8	1.0000000	1.0000000	1.0005796	0.9840610
9	###	###	###	###
10	###	###	###	###

Gj.snitt siste 5 forsøk

CPSM	CTSM	CPLM	CTLM
1.0000000	1.0000000	1.0005779	0.9843001

Fig 27 Proving report used during analysis of time series.

The new meter factors after filtering can be calculated from Equation 5.

$$\text{Meter factor} = \frac{\text{Pulses from USM} \cdot C_{TLM} \cdot C_{PLM}}{\text{Pr Vol} \cdot C_{TSP} \cdot C_{PSP} \cdot C_{TLP} \cdot C_{PLP}} \quad \left[\text{pulses/m}^3\right] \qquad (5)$$

By applying various filtering techniques, the repeatability during proving can be improved as in Fig 28.

There can however just as easily be introduced a systematic offset in the meter factor as a result of filtering, if one does not for example consider carefully the effect the reduction in flow rate during proving have on the outcome of the filtering (step response and transient response). One must also consider that filtering will be active during normal measurement.

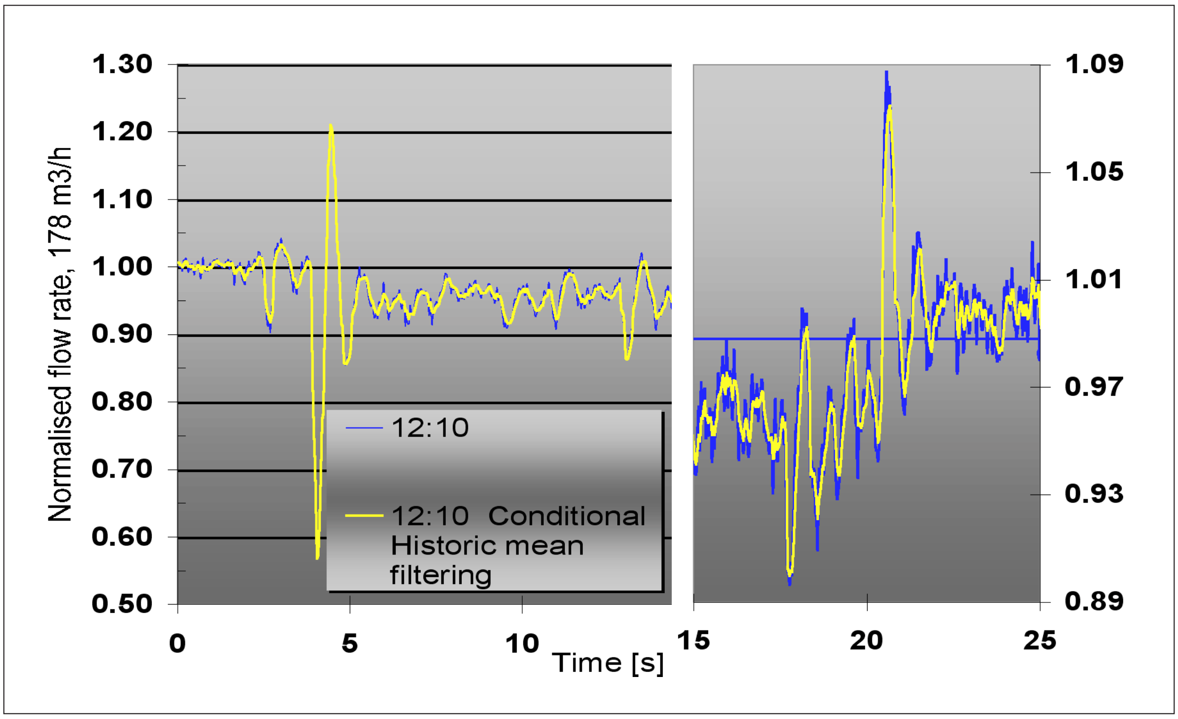

Fig 28 Unfiltered and filtered time series improving repeatability but possibly reducing accuracy. Blown up section show good transient response to large fluctuation in flow.

From Fig 24 and 25, we can see that the prover ball influences the flow rate during proving, especially when passing through bends. The fluctuation in flow this causes is still in effect when the detector switches are passed.

If we assume that a turbine meter will respond to the flow seen in Fig 24 with a low pass filter response, it is probable that although a turbine meter could be proven within the NPD requirements in Brevik, each meter factor achieved were consistently larger than it should be. The described effects will result in a slightly higher average flow rate during proving (slow step response) when a simple low pass filter is applied to the flow seen in Fig 24. The realisation that you can have good repeatability without good accuracy seems to be true in this case.

A conditional historic mean filter is used in Fig 28. The condition is that if the current measured flow rate varies from the previously determined flow rate by more than ±4%, then the measured flow rate is used, else the historic mean filtered flow rate is used, with 39% weight to the last measured flow rate. This conditional filter gives both good step and transient response.

Using this simple filter the repeatability is improved from 0.140% to 0.101% for the proving trial in time series 12:03 to 12:30. Other filtering methods can improve this further. Using a simple historic mean filter, however, the repeatability gets worse!

So filtering the time series can just as easily worsen the repeatability as improve it, therefore one has to be careful which filtering method is used.

Why then did a turbine meter have better and not worse repeatability in Brevik? This is probably due to the different ways in which the ultrasonic meter, the turbine meter and the prover ball reacts to pulsating flow. The output from the ultrasonic meter is directly proportional to the changes in flow rate, having no mechanical part affected by the flow and thus having a very good step and transient response. The turbine meter on the other hand, being a mechanical device, probably reacts more to the changes in kinetic energy in the flow than the changes in flow rate and thus having a slower step and transient response. The prover ball probably reacts solely to the changes in kinetic energy in the flow, since the flow has to perform work on the prover ball overcoming friction and changes in inertia when passing bends.

For very stable flow conditions, the outcome will be the same for all three, but with severely pulsating flow, this is not the case. Making the ultrasonic meter behave more like a turbine meter (if someone should wish that), can therefore probably not be achieved by filtering the time series alone. One must also take into account the changes in kinetic energy in the flow which is the way in which the reference i.e. the prover ball sees the pulsating flow, see Fig 29.

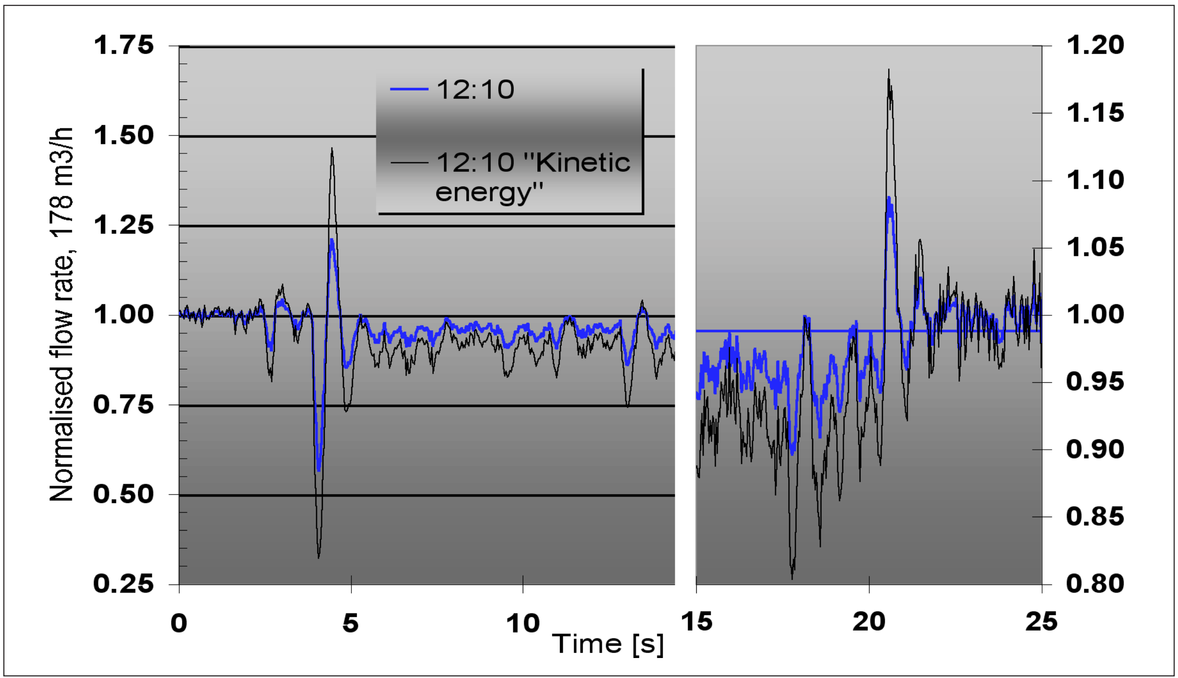

Fig 29 Unfiltered "kinetic energy" time series, possibly the way the prover ball sees the pulsating flow. Blown up section show that "kinetic energy" is more symmetrical in amplitude than the flow rate.

The best solution to poor repeatability of course is to have stable flow conditions and to make the metering system as insensitive to pulsating flow as possible.

7 CONCLUSION

The small volume ball prover is designed according to relevant standards and it performs as expected.

The 5-path ultrasonic liquid flow meters operate with good accuracy and stability and measure any fluctuation in flow below 14 Hz.

Pulsating flow with dominating low frequency components is the main cause of the poor repeatability during proving in Brevik. The reason for this is that one period of the pulsating frequencies are a small non-integer multiple of the proving time and the pulsation amplitudes are high. Higher frequency pulsations have no significant effect on repeatability.

To avoid cavitation in pumps during testing the liquid reservoir should be large and split between inlet and return volumes to avoid amplifying pulsations. One should also give the pumps as much head as possible. Low frequency pulsation should of course be avoided.

Upstream bends in the prover should be kept as far away from the detector switches as possible. The run-up length before the first detector switch should be as long as possible.

This type of Ultrasonic liquid flow meter is now recommended for use in fiscal liquid metering systems operated by Norsk Hydro.

We are convinced that proving a fiscal 5-path ultrasonic liquid meter with a small volume ball prover can be done, but final proof can only be given in the year 2000 during the final flow test.

ACKNOWLEDGEMENT

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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.