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North Sea FLOW Measurement Workshop

Index

Paper 6.3

CFD Analyses of the Influence of Flow Conditioners on Liquid Ultrasonic Flow Metering. Oseberg Sor – A Case Study

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ABSTRACT

Norsk Hydro experienced problems with an oil metering station consisting of two ultrasonic meters (USM 1 & 2) in series on the Oseberg Sør platform. Depending on the flow rates, the K-factor of USM 1 was outside the NPD requirements. USM 2, however, was inside the specifications. The problems could be caused by flow instability in USM 1. To investigate this a CFD study was carried out.

Upstream of the meters was a flow conditioner (FC) in form of a seven-pipe tube bundle, and an asymmetric pipe contraction. The study revealed that the problems could be related to the tube bundle. The FC generated local jets after the pipes, and the distance from the FC to USM 1 was insufficient for proper mixing to take place. Different axial flow patterns were produced when the flow rate varied, giving unstable velocity profiles in USM 1. The CFD study was extended to look at the consequences of modifications to the flow line. Better results were obtained when the tube bundle was replaced with an Etoile (star) straightener, giving a more stable flow. Norsk Hydro has since then replaced the tube bundle with an Etoile FC, and recent results shows that both USM 1 and USM 2 will now satisfy the NPD requirements.

1 INTRODUCTION

Oseberg Sør is a satellite oil field to the Oseberg field, 130 km northwest of Bergen. The production started on 30.08.2000. The 1st separation step take place on the platform, while 2nd and 3rd separation steps take place on the Oseberg Field Centre, 13 km from Oseberg Sør. From the Field Centre the oil is transported in a pipeline to the Sture Terminal.

On the Oseberg Sør platform Norsk Hydro has installed a fiscal oil measurement station, consisting of two 8” Krohne 5-beams Altosonic V ultrasonic meters in series and a 12” uni-directional prover with a small prover volume. The measurement station is showed in Figure 1. On the deck below the measurements station the upstream pipe goes through two 90 Deg bends out of plane. The internal pipe diameter (D) in this section is 300 mm. At the measurement level a 90 Deg bend is immediately followed by an asymmetric reducer, after which D=194 mm. The flow then enters a FC, which initially was a 7-pipe tube bundle. The reducer and FC are shown in Figure 2. The distance from the reducer down to USM 1 is 10D; the distance between the USM is 5D. The internal piping through the meter has a shape like a Venturi tube, with a throat diameter of 146.3 mm.

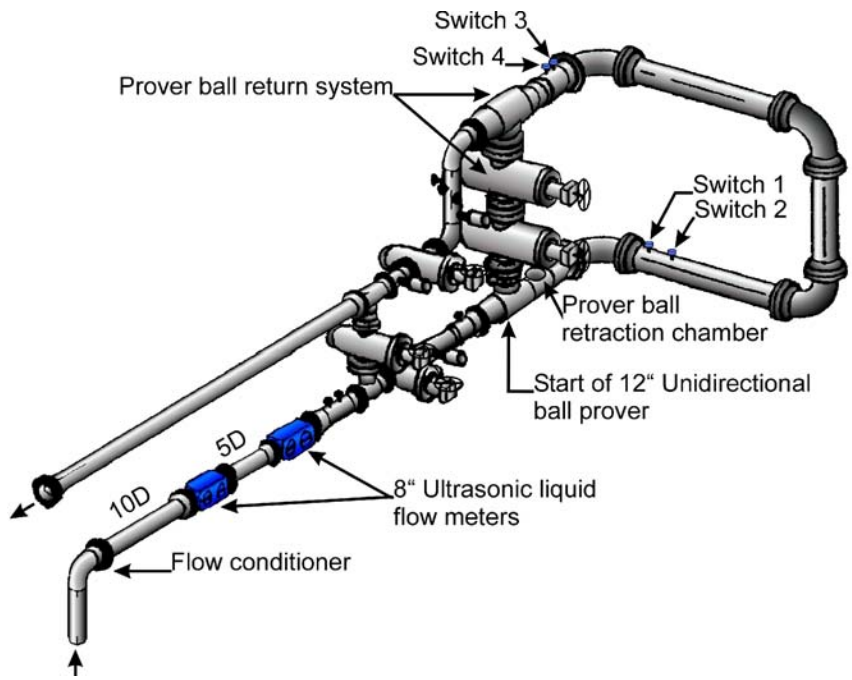

Figure 1 Measurement station on Oseberg Sør

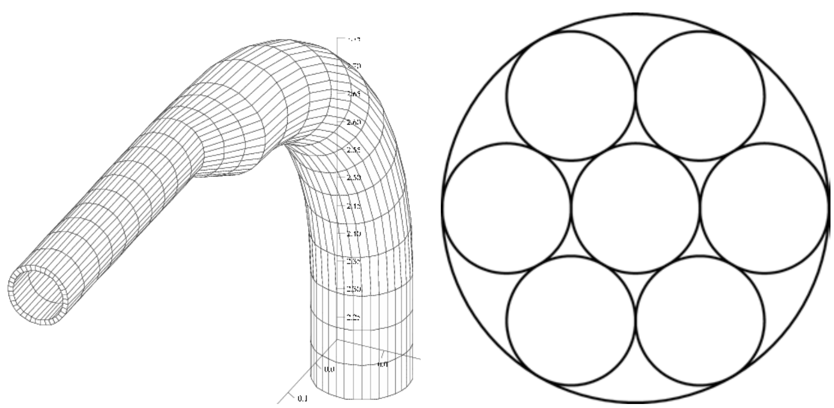

Figure 2 Details of the initial geometry, showing the asymmetric reducer to the left and cross-sectional view of the pipe bundle flow conditioner to the right.

During the calibration of the meters Norsk Hydro noticed a large spread in the K-factor for USM 1, while the K-factor for USM 2 was satisfactory. Plots of the K-factors are shown in Figure 3 and Figure 4. The reason for this may be found in the possible unstable flow profile in USM 1. One will notice that the upstream pipe is not favourable for flow measurement; bends out of plane are known to generate swirl flow, the swirl will be intensified by the pipe reduction.

To improve the flow profile a rebuild of the upstream pipe was considered. It was decided to simulate the actual flow profiles with CFD, and if flow unsteadiness was confirmed, the effect of pipeline modifications on flow profiles should be evaluated by CFD.

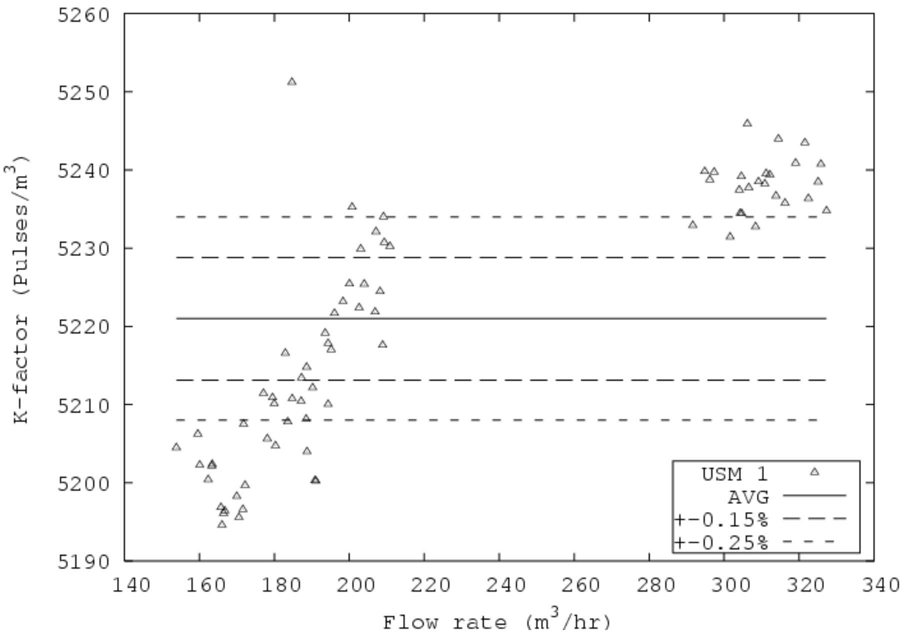

Figure 3 Stability of K-factor for USM 1 with pipe bundle FC, data from prover

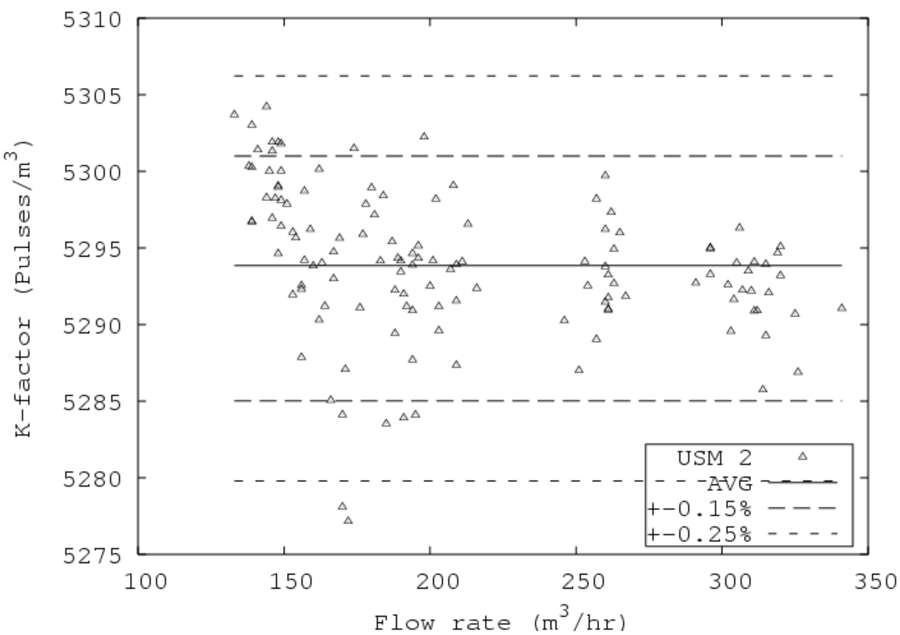

Figure 4 Stability of K-factor for USM 2 with pipe bundle FC, data from prover

2 CFD ANALYSES

The simulations were carried out with the finite volume CFD code MUSIC-2.0. This code is developed at CMR, and has been validated for turbulent pipe flow [1]. The program has been used in project work at CMR together with the GARUSO [2] uncertainty code for USM,. The projects have addressed the influence of different upstream conditions on the accuracy of ultrasonic meters, as well as the effect of flow profiles on meter installations outside the specifications given by the vendor.

The accuracy of the CFD-simulations will in general depend on three factors

- the grid quality i.e. the density of the gridlines and the angle between the crossing grid lines
- the quality of the turbulence model for the actual flow
- the order of the differencing scheme on the given grid

Here the code was used with 2'nd order central differencing, blended with 1'st order upstream differencing of the convective terms in the momentum equations. In the turbulence equations upstream differencing was applied. The turbulence model was the k-omega model with wall functions to model the wall boundary layers.

Multi-block boundary-fitted grids were used with 5 grid blocks in contact with the pipe wall and one grid block in the centre. In the pipe cross-section 25 control volumes (CV) was used over a diameter with finer spacing towards the wall. In the axial direction 4 CV was used pr diameter with a higher resolution in bends, FC and meters. This grid layout and grid density typically gives an error of less than 2–3% for velocity profiles in straight pipes and Reynolds number above 10^5 together with the k-omega turbulence model. The errors in and after bends are higher; the magnitude of the errors will depend on grid density and the quality of the turbulence model for flow phenomena like swirl etc.

All geometry except the pipe bundle was represented exactly on the grid. The pipe bundle is geometrically complex, and was represented by a simplified geometry shown, together with the flow, in the top right part of Figure 5. In the approximate geometry the channels between the pipes were neglected. The modification will give smaller mixing of the fluid after the bundle, since the number of individual fluid jets was reduced. The inner diameter of the central tube was set to a fraction f=0.38 of the diameter of the pipe. This was a compromise between f=0.447, which would give seven channels with equal cross-sectional area, and f=0.34, which would give approximately equal hydraulic diameter in the seven channels and hence equal flow resistance. Test simulations were performed with f=0.447 respectively f=0.34. The differences in the flow when compared with the simulation for f=0.38, were small. The actual value chosen for f should therefore not have critical influence on the results.

The errors in the CFD simulations of the flow profiles are higher than the error in the USM measurement of mean velocity. To reduce the CFD errors higher-level turbulence models like large eddy simulation can be used. Such models are computational intensive, however, and unfeasible in most engineering projects. The simulation model is still sufficient accurate to represent the main flow features. "What-if" simulations to see the effect of modifications to the pipeline will give a good indication of the optimal design..

3 SIMULATION RESULTS

Simulations were first run with the existing geometry to identify possible causes for the measurement problems in USM 1. Some possible modifications to the pipeline, including change of FC from tube bundle to Etoile were then tested, and a recommendation made from the simulations results.

3.1 Existing Geometry

The simulation domain starts upstream the two 90^o bends on the lower deck and ends 5D downstream of USM 2. As inlet values for the velocities and turbulence was used developed profiles taken form simulations in long straight pipes. A series of simulations was carried out with the inlet flow rate varying from 100 m^3/h to 800 m^3/h in steps of 100 m^3/h. The fluid density was set to 805 kg/m^3, the dynamic viscosity to 0.00108 kg/ms.

The main cause to the unsteadiness of the axial flow through USM 1 could be related to the tube bundle. Downstream of the FC local jets emerged from the seven pipes in the bundle. The jets will, at some downstream location, be mixed and form a developed flow profile. Here the distance from the FC to USM 1 was not long enough for sufficient mixing to take place. The rotating flow upstream of the FC will give different distributions of the axial velocity through the individual tubes, depending on the flow rate. The axial profile in front of USM 1 will then be unstable as a function of the flow rate. The axial profile in front of USM 2 was stable, this was an effect partly of the longer distance from the pipe bundle, partly by the additional flow conditioning caused by the reduced internal diameter in USM 1.

The centre tube in the tube bundle also transmits the central core of the swirl upstream of the FC. This central swirl tube was still present in USM 1. In USM 2 the swirl has dissipated, and is replaced with cross flow.

Cross-sectional plots are shown in Figure 5 and Figure 6 for a flow rate of 200 m^3/h at different axial locations. Noticeably the rotation upstream of the FC was more damped in the outer channels, than in the central pipe.

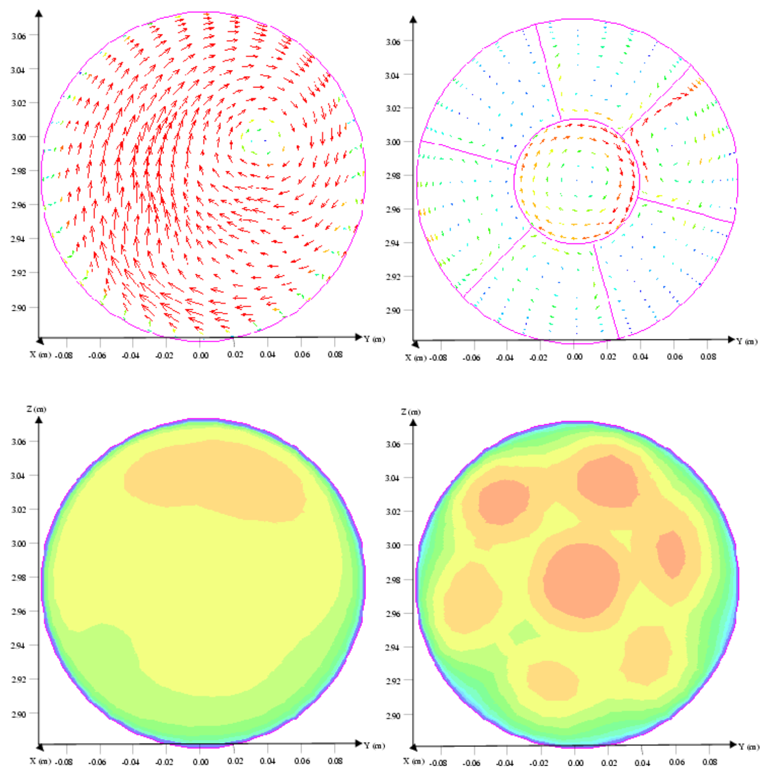

Figure 5 Flow with pipe bundle FC. To the top left the transversal velocity vectors are shown in the asymmetric reducer. To the bottom left the axial flow is shown at the same position in the pipe. At the top right is shown the transversal velocity vectors in the model of the pipe bundles. At the bottom right is shown the axial velocity 2D after the pipe bundle. The flow rate is 200 m^3/h.

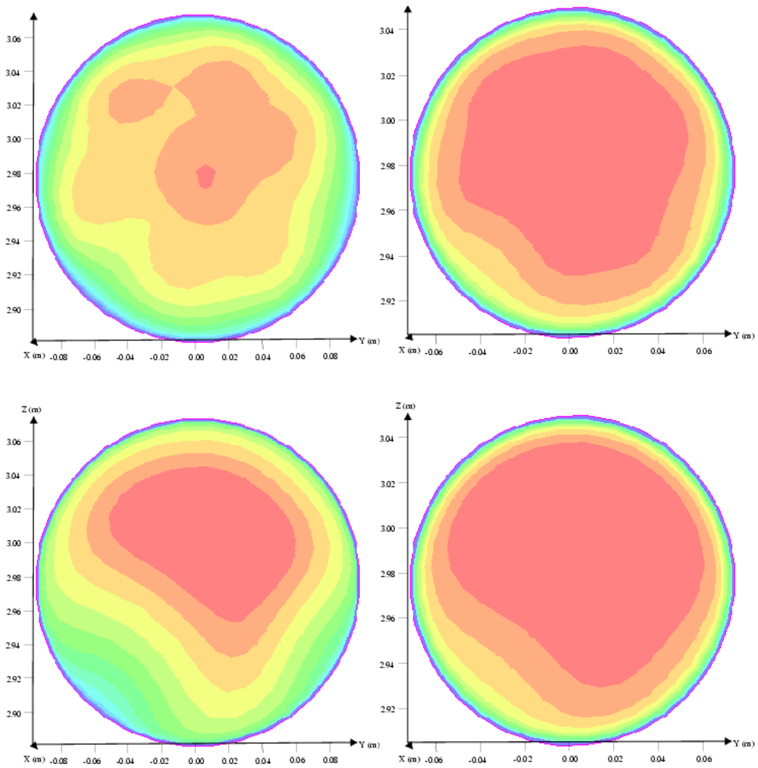

Figure 6 Flow with pipe bundle FC. To the top left the axial velocity is shown 2D before USM 1. To the bottom left the axial flow is shown 2D before USM 2. At the top right is shown the axial velocity vectors in the middle of USM 1. At the bottom right is shown the axial velocity in the middle of USM 2. The flow rate is 200 m^3/h

3.2 Modification of Geometry

Two modifications to the initial pipe configuration were investigated

- change the FC from pipe bundle to Etoile (vane)
- move the asymmetric pipe contraction upstream

The Etoile FC was modelled by reducing the dimension of central grid block, and by setting in solid walls representing the FC plates in the outer grid blocks. In this the 8 channels in the FC were created. The geometry is shown in the upper right part of
Figure **7**,

The simulations were repeated with the modified geometries for flow rates 200 m^3/h and 300 m^3/h. In general the flow profiles were now improved. The Etoile FC was effective in reducing the swirl, and the axial flow between the FC and USM 1 was much more homogeneous.

To move the pipe contraction upstream to the lower deck seemed not to improve the results. The skewness in the axial profile entering the FC increased, and the differences between the axial profile in USM 1 and USM 2 were larger than when only the FC was changed.

The recommendation based the simulations was to change the tube bundle with an Etoile FC, and let the asymmetric pipe contraction remain at its current position. This would stabilise the flow in USM 1 and take away the swirl. There would still, however, be differences in the axial flow profiles between USM 1 and USM 2.

Plots of the flow at different axial positions are shown in Figure 7 and Figure 8 for the case when only the FC was changed. The swirl was now reduced in each channel in the FC, and the axial profile was more symmetric after the FC. Some swirl and cross flow was still left, and this would change the axial flow profiles downstream the FC and between USM 1 and USM 2.

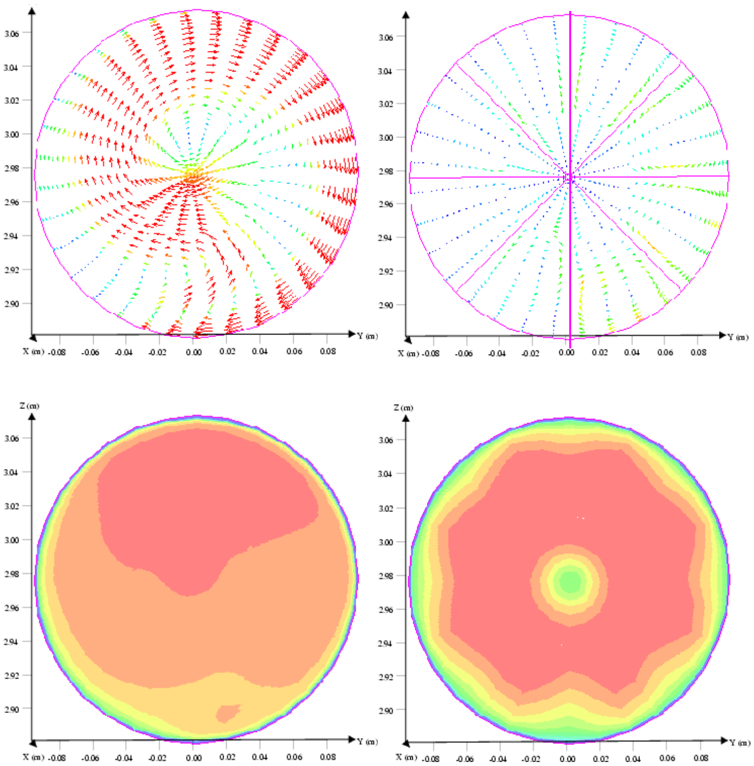

Figure 7 Flow with Etoile FC. To the top left the transversal velocity vectors are shown in the asymmetric reducer. To the bottom left the axial velocity is shown at the same position in the pipe. At the top right is shown the transversal velocity vectors in the exact representation of the Etoile FC. At the bottom right is shown the axial velocity 2D after the FC. The flow rate is 200 m^3/h

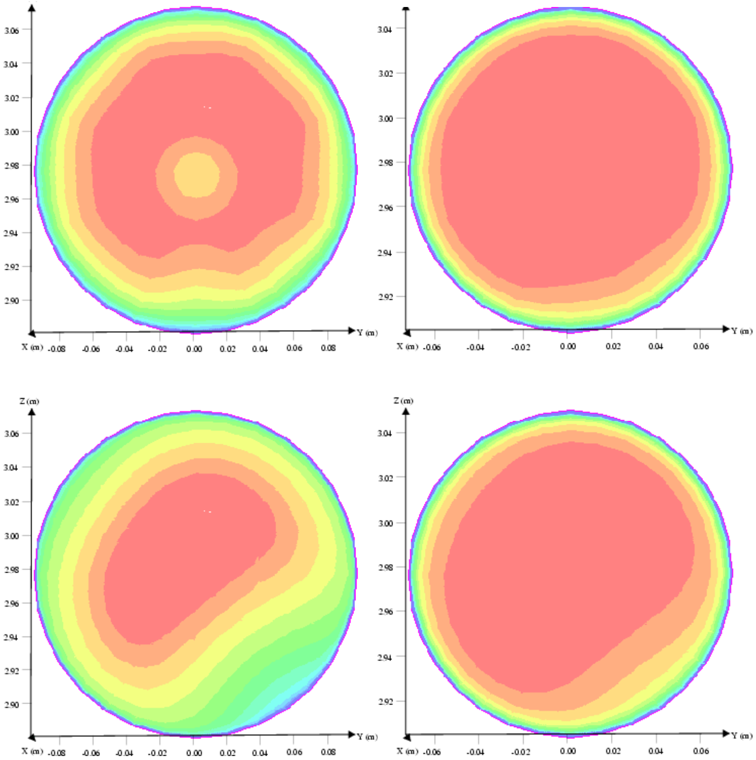

Figure 8 Flow with Etoile FC. To the top left the axial velocity is shown 2D before USM 1. To the bottom left the axial flow is shown 2D before USM 2. At the top right is shown the axial velocity vectors in the middle of USM 1. At the bottom right is shown the axial velocity in the middle of USM 2. The flow rate is 200 m^3/h

4 MODIFICATION OF PIPE

The recommendation based the simulations was to replace the tube bundle with an Etoile FC, and let the asymmetric pipe contraction stay at the same position. How this would affect the measurements was not clear, the axial flow profiles in USM 1 and USM 2 give no indication of measurement accuracy. However, better stability with respect to variation in flow rate was expected.

Norsk Hydro decided to replace the pipe bundle with an Etoile FC. The modification was successful. Proving showed that the stability of the K-factor for USM 1 was much better, while the stability of the K-factor of USM 2 remained satisfactorily. The results from the proving are shown in Figure 9 and Figure 10.

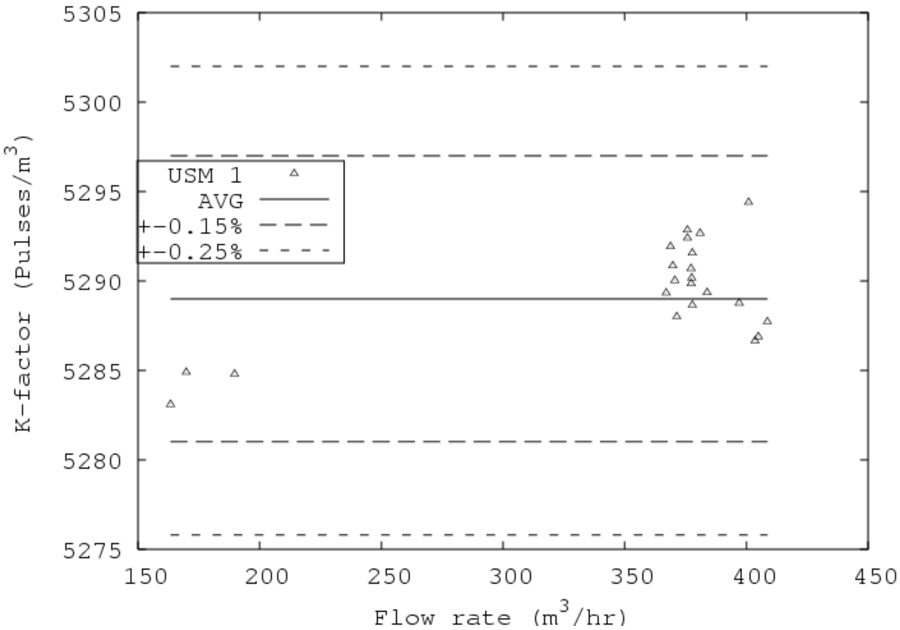

Figure 9 Stability of K-factor for USM 1 with Etoile FC, data from prover

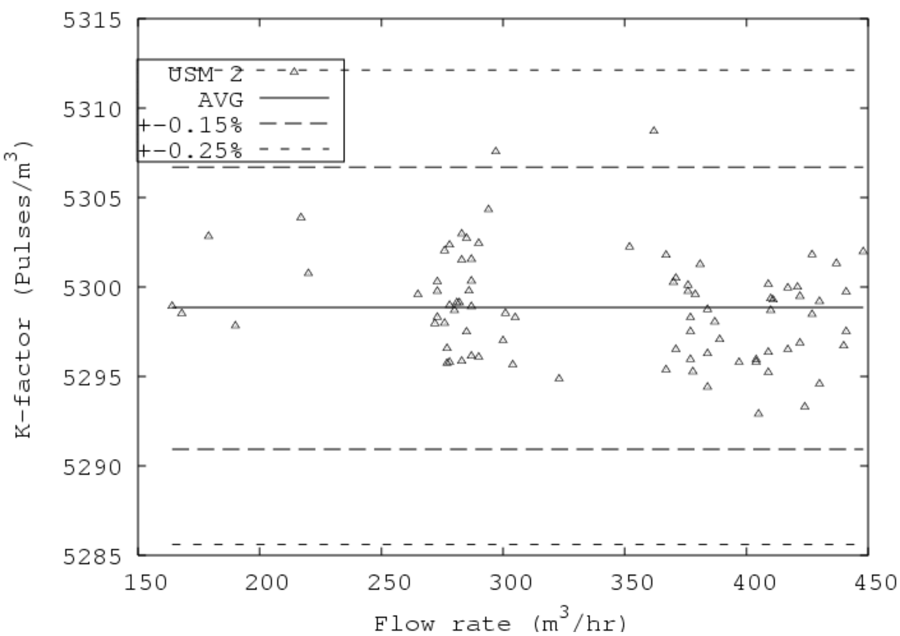

Figure 10 Stability of K-factor for USM 2 with Etoile FC, data from prover

5 CONCLUSIONS

Upstream flow conditions gave problems with the stability of the first of two USM meters in series on the Oseberg Sør platform. The flow profiles were investigated with CFD, and the insufficient upstream mixing length from bends down to the meter was found to be the main problem. The installed pipe bundle FC gave an axial flow profile that varied with the flow rate.

CFD simulations showed that by substituting the pipe bundle with an Etoile FC, the axial profile became more uniform and stable. When Norsk Hydro implemented the recommendation and replaced the pipe bundle with an Etoile FC, the stability of USM 1 was much improved.

This project has demonstrated the power of CFD to identify installation problems, and its strengths in investigating the consequences of alterations to the pipeline. In this case it helped the operator to choose a cost-effective working modification without delay.

The results obtained demonstrate the importance of the flow conditioner on metering; in this case the Etoile FC was better than the pipe bundle. How general this result is for flow conditioning of ultrasonic flow meters is difficult to say, but it deserves further investigation.

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[2] P. Lunde, K.-E. Frøysa, and M. Vestrheim. GARUSO-Version 1.0. Uncertainty model for multipath ultrasonic transit time gas flow meters. CMR Report No. CMR-97-A10014, Christian Michelsen Research AS, Bergen, August 1997.

ACKNOWLEDGEMENT

The author will thank Hallvard Tunheim and Trond Folkestad from Norsk Hydro for valuable discussions during the project, and for supplying the proving measurements and graphics of the metering station.

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