

Analysis of the Behaviour of an Ultrasonic Flowmeter Installed in an Oil Offloading System

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Abstract: Application of ultrasonic flowmeters for fiscal metering has increased in the oil industry. High accuracy, a long-term reliability and no-moving parts are characteristics that define the ultrasonic meter as an attractive option to be considered in custody transfer and fiscal metering operations. The paper presents an analysis carried out on a metering system composed of two similar five beans ultrasonic meters, 24 inches size, maximum capacity of 8 000 m³/h, installed in series in an oil offloading system on board a FPSO. One of the meters operates as the fiscal meter, and the other as a master meter to run regular calibrations of the fiscal meter. The analysis was developed to evaluate the performance of the fiscal meter during the oil offloadings to tankers and to assess the meter factor drift along a series of provings against the master meter. Results showed that the ultrasonic meter presented high repeatability and good stability of the meter factor, allowing flow measurement uncertainties that fully complied with the requirements for fiscal metering based on the OIML R117 accuracy class 0.3.

Keywords: Ultrasonic flowmeter; oil fiscal metering; calibration interval; FPSO.

1. Introduction

Accuracy and long term reliability of flowmeters is of crucial importance in the oil industry, especially in fiscal metering and custody transfer operations.

In some applications, though national regulations on oil industry requires regular calibrations of the fiscal meters, technically and economically it is not an easy task to remove a quite heavy meter from a platform located 200 km offshore and send it through a long trip to a calibration laboratory every two months.

Under such a scenery, the present work was developed to evaluate the metering conditions of an oil offloading system operating on board a FPSO (Floating, Production, Storage and Offloading) platform. The study was based on statistical analysis of data obtained from provings associated with technical analysis of some intrinsic characteristics of the meters

2. The Offloading System

The oil fiscal metering system on board the FPSO is composed of two five beans ultrasonic meters installed

in series in an oil offloading system as shown in Figure 1.

In this system one of the meters operates as a fiscal meter, and the other, as a master meter to control and to run regular calibrations of the fiscal meter. The fiscal and master meters are both 24-inch size, same multipath model and 150#RF pressure class.

The maximum operating flow rate of these meters is around 8 000 m³/h, and the project operating conditions are a flow rate of 6 600 m³/h, 690 kPa-g pressure and 37°C temperature.



Figure 1. FPSO oil offloading system.

Configuration of the pipes and valves of the oil metering system of the FPSO allows the fiscal meter to be aligned in series with the master meter, so that periodic verifications and calibrations of the fiscal meter can be carried out at its normal operating conditions during an offloading operation to a tanker.

Both the fiscal and the master meters were calibrated on August 2 002, in a calibration laboratory in France before they were installed on board the FPSO. Oil production at the plant started one year later.

3. Calibration

Similarly to many other types of flowmeters, the calibration of an ultrasonic meter consists of the determination of its meter factor (MF), and which value is normally close to the unity. This dimensionless parameter can be determined by a calibration of the meter against a proper standard.

Deviations of the meter factor from the unity reflect performance deviations of the meter from an ideal behaviour. For instance, in other types of flowmeters, deviations and drifts can be caused due to wear of moving parts such as shafts and bearings, accumulation of residues in the walls inside the instrument, corrosion and ageing of electrical parts.

The operation principle of ultrasonic oil flowmeters is based on the measurement of the mean velocity of the flow, using the principle of the difference between the transit times of ultrasonic pulses emitted by a set of transducers and which crosses the flow in opposite directions.

As for getting a more reliable sample of the flow inside the meter, the model of the meters installed on board the FPSO under analysis uses a set of five ultrasonic paths, which are precisely distributed in the metering section.

Ultrasonic meters do not possess wear-likely movable parts, however, care should be taken on an eventual deposition of residues and paraffin on the inner walls of the meter and in the openings of the transducers.

The re-calibration interval of ultrasonic meters is not defined in the AGA Report No 9 [1], and this matter is still being investigated by users, calibration laboratories and manufacturers.

In September 1 999, the NEL-National Engineering Laboratory, in UK, declared in a report [2] that up to that time there was not enough information available to indicate convenient re-calibration intervals applicable for ultrasonic meters. According to the NEL report, an ultrasonic meter is not intrinsically likely to drifts in the performance, since it basically adopts digital technology instead of mechanical technology.

A search in the literature showed the non-existence of documented references from independent bodies stating re-calibration intervals for this kind of meter. Instead, lots of publications by manufacturers have been identified, most of them claiming that these meters do not need a laboratory re-calibration, as defined by Lansing [3].

4. Database

One of the main sources of information used in the analysis of the performance of the ultrasonic meter was the values of the meter factors generated in the provings between the fiscal and the master meters during the offloadings, from October 2 003 to January 2 004.

Table 1. Dates of the offloadings.

Date	Data source
Oct.31.03	Proving
Nov.26.03	Proving & historical series in dbf file
Dec.04.03	Proving & historical series in dbf file
Dec.07.03	Proving & historical series in dbf file
Jan.16.04	Proving

Another source of information used was the history of the records of parameters like speed of sound in each of

the five paths and the oil flow in each of the five paths referred to the master and fiscal meters.

The flow computer of the offloading system of the FPSO systematically stores a series of information of each offloading in its hard disc as a *.dbf file. From the information available in these files, the following data were selected to establish the behaviour standards of the metering system:

- historical data of the oil flow (m³/h) calculated from the “average” of the velocities recorded for each of the five metering paths;
- historical data of the speed of sound (m/s) recorded for each of the five paths;
- historical data of the flow (%) recorded for each of the five paths.

The database in the *.dbf file contained the values of the earlier parameters in each moment of occurrence of the associated event in intervals of hundredths of milliseconds.

In this work, average values of the selected quantities were calculated and used, in intervals of one minute, emphasising that there are, as a mean value per minute, 45 average events for the totalisation of the final oil flow and 10 events per path for totalling the speed of sound in the specific path. The interval of one minute was chosen in order to make the treatment of this information handier.

5. Operating Flowrates

The data collected during the operation of the five oil offloadings from the FPSO to the oil tankers indicated that the most common operating flow rate was around 5 500 m³/h, as shown in Figure 2.

The 5 500 m³/h range comprises the interval of 5 500 ± 250 m³/h. The other ranges have been defined in a similar way, with amplitudes of ±250 m³/h.

Figure 2 shows that during the offloadings about 74% of the total volume was transferred from the FPSO to the oil tanker in the flow range of 5 500 m³/h, while 7% and 7.5% were transferred in the range of 5 000 m³/h and 4 500 m³/h, respectively. The history of these flowrates recorded by the master meter is presented in Figure 3.

The flowrates of 2 000 m³/h to 3 000 m³/h were generated only for performing provings and collecting data under these operating conditions.

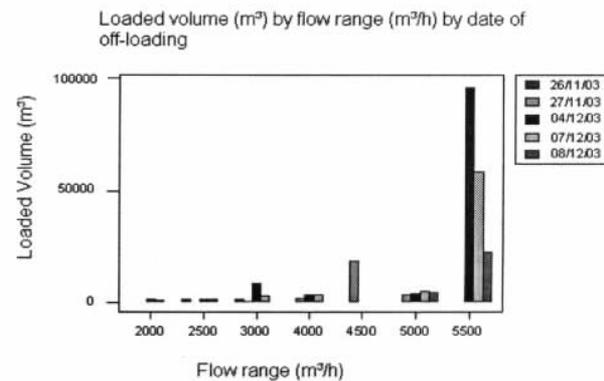


Figure 2. Totalised volume of oil as a function of the operating flow rate in the metering system during the offloadings.

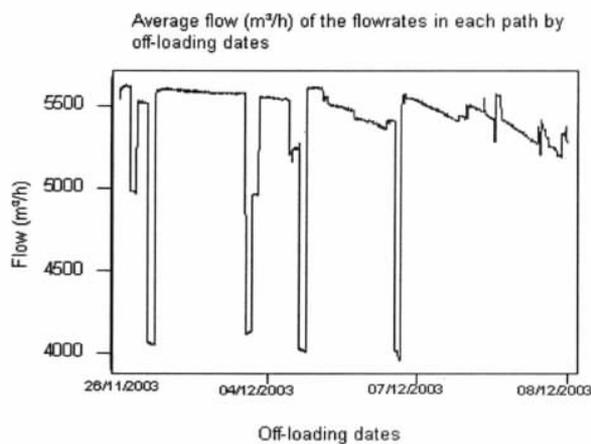


Figure 3. History of the flowrates during the offloadings recorded by the master meter.

Thus, the option was to work in the analysis only with

the data related to the usual operating flowrates, from 4 000 m³/h to 5 500 m³/h.

6. Repeatability and Reproducibility of the Meter

Figure 4 shows the history of the meter factor values of the fiscal meter, calculated from the records of the provings performed during the offloadings.

The variation range of $\pm 0.18\%$ corresponds to the maximum expected variation around the original meter factor, and the $\pm 0.24\%$ range is the maximum acceptable variation around the meter factor value so that the global uncertainty of the oil volume measured by the fiscal meter does not extrapolates the expected limit of $\pm 0.30\%$.

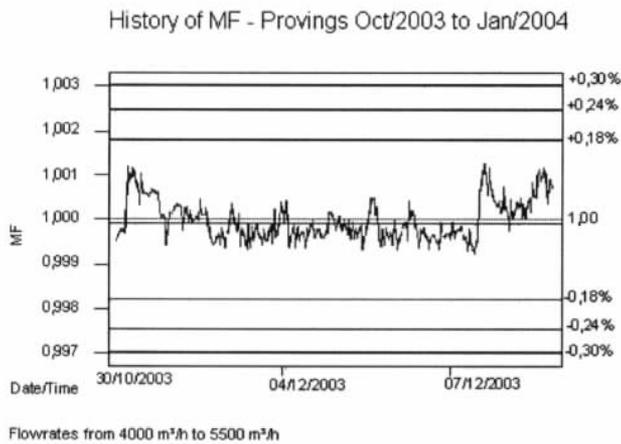


Figure 4. History of the MF values of the fiscal meter.

Table 2 presents the mean meter factor values of the fiscal meter as function of the flow rate and the respective standard deviations obtained from the provings against the master meter.

Table 2. Fiscal meter MF from the provings.

Dates of provings	Flow rate (m ³ /h)	Factor of the fiscal meter		
		Mean	Std. dev.	n
31.10.2003	4000	0.99971	0.00012	7
31.10.2003	4500	*	*	0
31.10.2003	5000	1.00105	0.00013	5
31.10.2003	5500	1.00064	0.00014	10
26.11.2003	4000	1.00036	0.00031	8
26.11.2003	4500	1.00015	0.00015	21
26.11.2003	5000	0.99985	0.00028	12
26.11.2003	5500	0.99965	0.00019	22
04.12.2003	4000	1.00012	0.00019	10
04.12.2003	4500	*	*	0
04.12.2003	5000	0.99984	0.00021	10

04.12.2003	5500	0.99970	0.00014	40
07.12.2003	4000	1.00022	0.00022	10
07.12.2003	4500	*	*	0
07.12.2003	5000	0.99961	0.00024	11
07.12.2003	5500	0.99966	0.00014	48
16.01.2004	4000	1.00100	0.00019	10
16.01.2004	4500	*	*	0
16.01.2004	5000	1.00065	0.00024	15
16.01.2004	5500	1.00027	0.00017	20

Std. Dev. = Standard deviation

n = number of repetitions

From Figure 4 and Table 2, it is possible to clearly verify that the maximum variation of the meter factor is under 0.09%, with a standard deviation under 0.045%. This indicates that the fiscal meter showed a high repeatability, reproducibility and stability during the monitoring period.

In Table 3, the meter factor were calculated from the average flowrates in one minute intervals; which shows that the maximum variation of the meter factor is under 0.17%, with a standard deviation under 0.088% in the considered period, which again indicates that the meter is highly reproducible.

That is, even if the meter is under different operating conditions (other date, other process conditions, other BS&W of the oil, etc.), characteristics of a reproducibility evaluation of the meter, it will yet give stable results.

Table 3. Meter Factor calculated from the one minute registrations.

Dates of provings	Flow rate (m ³ /h)	Factor of the fiscal meter		
		Mean	Std. dev.	n
04.12.2003	4000	1.00020	0.00088	47
04.12.2003	5000	0.99990	0.00084	45
04.12.2003	5500	0.99971	0.00071	474
07.12.2003	4000	1.00045	0.00101	41
07.12.2003	5000	0.99988	0.00078	37
07.12.2003	5500	0.99958	0.00082	629
08.12.2003	4000	*	*	0
08.12.2003	5000	0.99933	0.00071	37
08.12.2003	5500	0.99963	0.00070	191
General		0.99968	0.00080	1501

Std. Dev. = Standard deviation

n = number of repetitions

Results showed that the meter factor varied very little around the unity in the period of October 31st, 2 003 to January 16th, 2 004, as shown in Table 2 and Figure 4. Thus, it was possible to define two basic possibilities

for that:

- both the fiscal and master meters did not drift, which is the most likely event,
- both the fiscal and master meters drifted in a parallel way and in the same direction, which is an unlikely event due to the short time of operation of the metering system and to the maximum variation of the meter factors of 0.09%.

7. Stability of the Fiscal Meter

Investigation was carried out also to analyse the stability of the measuring characteristics of the fiscal meter in comparison to the master meter.

Each of the five ultrasonic paths of the fiscal and the master meters were compared in terms of their measured values for the speed of sound and the flow rate.

Table 4 shows that the maximum variability of the speed of sound ratio was 0.006% in all five paths.

Table 4. Ratio of the speed of sound in the master meter to the speed of sound in the fiscal meter.

Ratio of the speed of sound in the master meter to the speed of sound in the fiscal meter				
Path	Ratio	Flow rate (m ³ /h)		
		4000	5000	5500
Path 1	Mean	1.00892	1.00874	1.00868
	Std. dev.	0.0000309	0.0000304	0.0000344
Path 2	Mean	1.00460	1.00443	1.00436
	Std. dev.	0.0000380	0.0000383	0.0000352
Path 3	Mean	1.00078	1.00061	1.00055
	Std. dev.	0.00003190	0.00003680	0.00003700
Path 4	Mean	1.00054	1.00037	1.00030
	Std. dev.	0.0000326	0.0000275	0.0000341
Path 5	Mean	0.997463	0.997301	0.997232
	Std. dev.	0.0000308	0.0000305	0.0000367
n		88	119	1294

Table 5. Ratio of the flow rate in the master meter to the flow rate in the fiscal meter.

Ratio of the flow rate in master meter to the flow rate in the fiscal meter		
		Flow rate (m ³ /h)

Path	Ratio	4000	5000	5500
Path 1	Mean	0.996478	0.997486	0.997516
	Std. dev.	0.0016376	0.0011697	0.0011634
Path 2	Mean	0.99960	1.00003	0.99994
	Std. dev.	0.0012028	0.0010232	0.0010832
Path 3	Mean	1.00788	1.00707	1.00695
	Std. dev.	0.0008042	0.0007692	0.0006505
Path 4	Mean	1.00829	1.00862	1.00905
	Std. dev.	0.0013290	0.0009671	0.0011320
Path 5	Mean	1.01650	1.01784	1.01828
	Std. dev.	0.0011013	0.0011131	0.0010443
Master / fiscal paths	Mean	1.00032	0.99972	0.99963
	Std. dev.	0.000946	0.000817	0.000766
n		88	119	1294

Table 5 shows that the maximum variability of the ratios of the mean flowrates was 0.19% at the 4 000 m³/h range, while at the usual working flow rate, 5 500 m³/h, the maximum variation was 0.14%.

Thus, these data point again at both of the proposed possibilities.

8. Stability of the Master Meter

Figure 5 shows the history of the values of speed of sound in each path of the master meter, during the offloadings monitored, and shows that the provings were carried out at different operating conditions and with different oil characteristics.

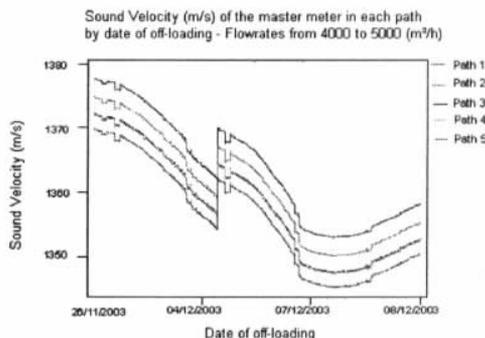


Figure 5. History of the recorded sound velocities in each path.

Although the provings have been performed with oils with different characteristics, the results presented on Tables 6 and 7 show, respectively, the stability of the relations between the speed of sound and the flowrates between the paths of the master meter.

Table 6. Ratio of the speed of sound between paths of the master meter.

Dates of offloadings	Flow (m ³ /h)	Ratio of speed of sound between paths of the master meter							
		Path 1/path 3		Path 2/path 3		Path 4/path 3		Path 5/path 3	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
04.12.2003	4000	1.004070	0.000026	1.001930	0.000031	0.999983	0.000027	0.998301	0.000034
04.12.2003	5000	1.004080	0.000031	1.001950	0.000027	0.999888	0.000027	0.998310	0.000029
04.12.2003	5500	1.004080	0.000028	1.001940	0.000029	0.999890	0.000031	0.998314	0.000030
07.12.2003	4000	1.004070	0.000024	1.001940	0.000031	0.999892	0.000020	0.998306	0.000023
07.12.2003	5000	1.004070	0.000026	1.001940	0.000022	0.999898	0.000022	0.998313	0.000027
07.12.2003	5500	1.004070	0.000023	1.001940	0.000022	0.999890	0.000023	0.998313	0.000022
08.12.2003	4000	*	*	*	*	*	*	*	*
08.12.2003	5000	1.004070	0.000023	1.001940	0.000026	0.999890	0.000027	0.998325	0.000025
08.12.2003	5500	1.004070	0.000021	1.001940	0.000023	0.999886	0.000023	0.998321	0.000021

The relationships between the speed of sound path in the paths of the master meter have maintained themselves systematically constant during the monitoring period, with maximum variability of 0.006%, which is respective to the standard deviation of 0.000 031 (see Table 6).

Table 7. Ratio of the flowrates between paths of the master meter.

Dates of offloadings	Flow (m ³ /h)	Ratio of flowrates between paths of the master meter							
		Path 1/path 3		Path 2/path 3		Path 4/path 3		Path 5/path 3	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
04.12.2003	4000	1.27415	0.00224	1.10669	0.00167	1.11670	0.00128	1.29188	0.00159
04.12.2003	5000	1.27678	0.00133	1.10823	0.00109	1.11823	0.00104	1.29431	0.00131
04.12.2003	5500	1.27719	0.00158	1.10854	0.00131	1.11853	0.00114	1.29505	0.00135
07.12.2003	4000	1.27397	0.00207	1.10684	0.00137	1.11739	0.00106	1.29265	0.00119
07.12.2003	5000	1.27881	0.00158	1.10843	0.00136	1.11827	0.00127	1.29467	0.00158
07.12.2003	5500	1.27763	0.00156	1.10884	0.00129	1.11930	0.00114	1.29596	0.00130
08.12.2003	4000	*	*	*	*	*	*	*	*
08.12.2003	5000	1.27835	0.00160	1.10891	0.00123	1.11905	0.00098	1.29564	0.00123
08.12.2003	5500	1.27792	0.00167	1.10875	0.00131	1.11946	0.00106	1.29607	0.00118

The relationship between the flowrates in the paths of the master meter have maintained themselves systematically constant during the period monitored, with maximum variability of 0.4%, which is respective to the standard deviation of 0.0024 (see Table 7).

That means these relationships have maintained themselves constant in the monitoring period and have not been affected by the operation of valves, pumps, and variations in the oil density and other external factors.

9. Conclusion

Considering that there was no derivation in the meter factor, which has maintained its value close to the unity, with maximum oscillations of 0.09% along the monitoring period, it is possible to conclude that:

- both meters, master and fiscal, have shown to be highly stable;
- the repeatability and reproducibility of both the meters, master and fiscal, did not alter during the monitoring period, from October 31st, 2 003 to January 16th, 2 004.

Additionally, according to item 5, based on the history of the meter factors around 1, with very low variability (0.09%), allows one to conclude that it is very unlikely for the master and the fiscal meters to drift.

In order to eliminate the hypothesis that both the system meters drifted in a parallel way in the same direction, it has been verified, in item 7, that the master meter is intrinsically very stable: the relationships between the records of the paths inside the master meter have maintained themselves systematically constant during the monitoring period, independently of the action of external factors.

Considering the occurrence of stability of the paths inside the master meter, one can conclude that the master meter did not drift and, consequently, none of the meters has drifted during the monitoring period, which is confirmed by the stability of the meter factor of the fiscal meter.

The present study was not carried out with the intention to justify a substitution of the traditional calibration of meters in a laboratory test bench, what is probably the best procedure to assure a reliable performance of a flow meter.

The objective was to present an alternative way to analyse the behaviour of two similar ultrasonic meters when laboratory calibration is not easily available.

Obviously, the period of analysis was very short and systematic provings shall be carried out along the time to maintain the meters under controlled metering conditions.

References

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