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Improvements to the Primary LNG Mass Flow Standard

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Abstract

In 2013 LNG mass flow meters were traceably calibrated by the gravimetric primary LNG mass flow standard with an estimated Calibration and Measurement Capability (CMC) of 0.12% to 0.15%. Dominant uncertainty sources included the uncertainty associated with the correction for so-called parasitic forces. Modifications to the primary standard were made with the objective to reduce the measurement uncertainty associated with the parasitic forces. A Level Compensation System (LCS) was installed to control the level of the weighing vessel during the weighing process. Several experiments were performed, and the results analysed. It was demonstrated that the LCS has the potential to reduce the measurement uncertainty associated with the parasitic forces. An alternative method to reduce parasitic forces was made possible by the installation of a dry-break coupling. Future activities will aim to provide a proof of principle of the improvements due to the LCS and the dry-break coupling when using liquid medium (e.g., LNG) in the weighing process.

1. Introduction

Liquified Natural Gas (LNG) is traded between the exporter and the importer during custody transfer. Typical applications of LNG are (at the large scale) to regassify it and inject it into the gas grid, and (at the small to midscale) as a transport fuel. LNG is an alternative to pipeline gas, with strategic and, for long distances, economic benefits [1]. Further LNG has considerable environmental benefits. Engines running on LNG will meet the (new) limits set on NO_x and CO_2 emissions and produce less noise than diesel operated engines. LNG fuelled trucks are an alternative to diesel fuelled trucks for long-distance road freight transport. LNG shipments may overtake inter-regional pipeline shipments in the 2020s [2]. Clearly, the global trade in LNG is growing and there is a need for metrological support to facilitate it. The quantity of LNG traded is based on the amount of energy transferred [3]. To determine this amount, current practice is to measure the volume of LNG which, in combination with the mass density and the measurement of LNG composition, allows to compute the amount of energy transferred (see for example [3]).

One method to measure the volume is based on level gauges and calibration tables in the LNG carrier. Another method is to measure the flow when custody transfer takes place, such as when fuelling an LNG truck or in LNG ship bunkering. Typical instruments used in the second method are ultrasonic flow meters (USM) and Coriolis Mass Flow (CMF) meters. Currently, CMF meters are calibrated with water and interpolation methods are applied to compensate for temperature effects at cryogenic conditions when measuring LNG flow (see for example [4,5]). Clearly traceable calibrations with LNG will help to establish confidence in LNG flow metering and therefore in LNG custody transfer.

Within the European Metrology Research Programme (EMRP), the European Metrology Programme for Innovation and Research (EMPIR), and the “Regeling Nationale EZ subsidies” (Dutch Ministry of Economic Affairs and Climate Policy) research and innovation projects were undertaken to establish metrological support for LNG applications. Originating from these projects is the roadmap for the development of SI-traceable LNG flow meter calibrations shown in Figure 1. A gravimetric primary LNG mass flow standard was realised with an estimated Calibration and Measurement Capability (CMC) of 0.12% to 0.15% [6]. Subsequently a facility was built in the port of

Rotterdam, The Netherlands, to enable cryogenic liquid SI-traceable calibrations with a targeted maximum flow rate of about 200 m³/h and associated targeted uncertainty of 0.15% in mass flow rate. In the future, larger flow rates can be targeted that serve the small scale LNG market for transportation (≤ 1000 m³/h) and the large scale custody transfer market (up to 10,000 m³/h).

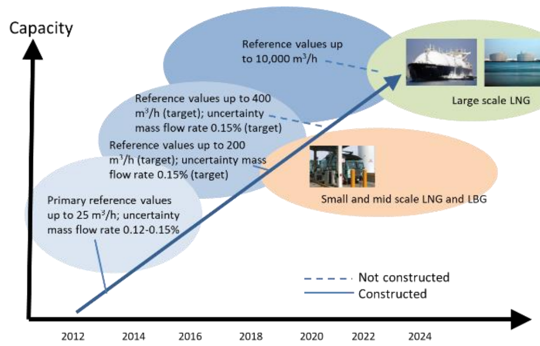

Figure 1: Roadmap for traceable LNG flow meter calibrations. LBG denotes liquified biogas.

In 2013 LNG mass flow meters were calibrated by the gravimetric primary LNG mass flow standard. Typical deviations of the flow meters with respect to the primary standard are within 0.5% in terms of mass flow rate [7]. The primary standard CMC of 0.12-0.15% in mass flow rate, equates to about 0.2% in volume flow rate. The primary standard flow rate is limited implying that the CMC of larger flow rate facilities will increase (i.e., will have a larger measurement uncertainty) when relying on the primary standard for their traceability. Conventional fuels have a typical flow rate measurement uncertainty of about 0.5%. To enable the usage of LNG as a transport fuel, a similar measurement uncertainty is required for the so-called small-scale to mid-scale applications which coincide with LNG truck fuelling and ship bunkering and flow rates <1000 m³/h [8].

Dominant uncertainty sources of the primary mass flow standard are associated with the correction for so-called parasitic forces, calibration time uncertainty and temperature uncertainty. The parasitic forces arise as the appendages attached to the weighing vessel on the balance exhibit minor displacements during the weighing process. This paper describes modifications to the primary standard which were made with the objective to reduce the measurement uncertainty associated with the parasitic forces. A Level Compensation System (LCS) was installed to maintain the level of the weighing vessel close to its reference (starting) state during the weighing process. An alternative method to reduce parasitic forces was made possible by the installation of a dry-break coupling.

2. Level Compensation System

2.1 Description of the LCS

The LCS was installed in the primary LNG mass flow standard in 2017. Figure 2 illustrates how an upward (parasitic) force is created when filling the tank of the gravimetric standard. The filling pipe is lowered relative to its initial state as the load cells below the balance top plate on which the tank rests are loaded. Due to the stiffness of the filling pipe (and other appendages), a resulting force is exerted on the tank which acts in opposite direction as the weight. Therefore, a smaller mass reading than the actual mass is expected.

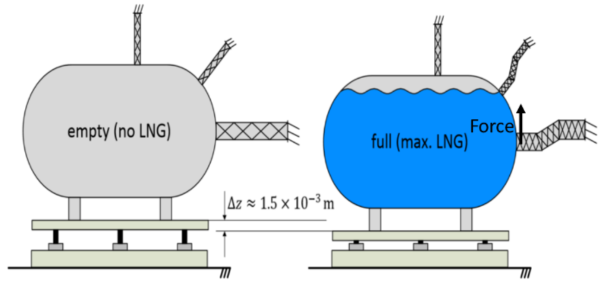

Figure 2: When the tank is loaded during the filling process of the weighing tank, a resulting force is created due to the lowering of the tank and the stiffness of the filling pipe (and other appendages).

Figure 3 shows the components of the LCS system. The balance (1) and weighing vessel (2) are supported by a floor board (3) which reduces the fluctuations during the weighing process. Actuators (4) attached to the frame (5) on which the weighing vessel rests compensate the displacement during filling/loading of the tank. Typical vertical displacement is in the order of several hunderds of μm's. The control system (6) translates measured displacement of the system to vertical compensation enforced by three actuators along the tank frame in a closed loop servo control scheme. Calibration weights (7) are used to calibrate the balance and to provide traceability to the mass measurement.

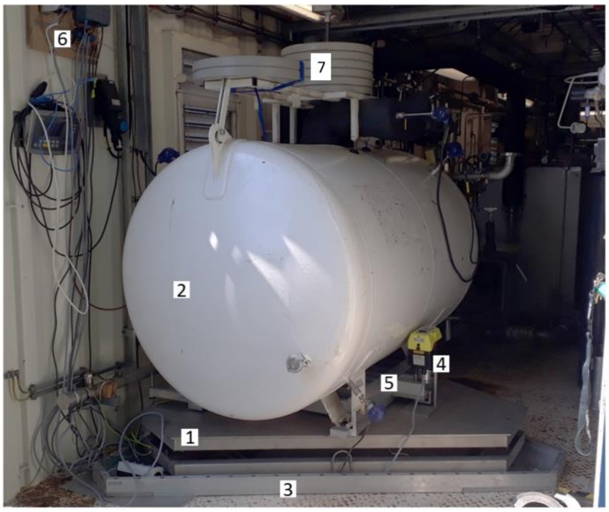

Figure 3: The LCS, balance, and weighing vessel of the primary LNG mass flow standard. Components are: balance (1), weighing vessel (2), floor board (3), actuators (4), tank frame (5) LCS control system (6), and calibration weights (7).

An elaborate description of the LCS functional requirements, assembly, and construction is described in a MSc thesis [9].

2.2 LCS preliminary experiments and results

In a first experiment calibration mass pieces were sequentially placed on the weighing vessel in 100 kg steps to simulate the filling of the vessel during the weighing process. Figure 4 shows the results with the LCS on (solid) and with the LCS off (blue) as a function of time.

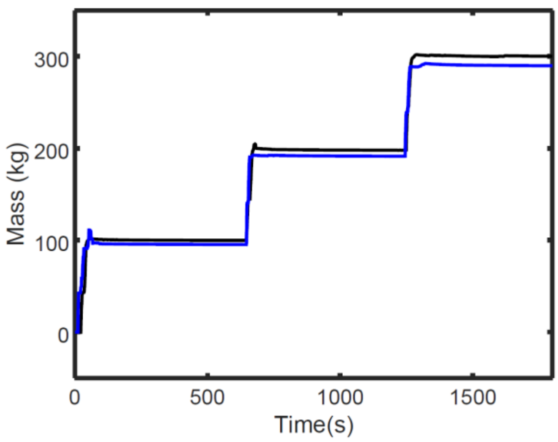

Figure 4: Mass readings as a function of time with LCS on (black) and LCS off (blue).

The mass readings with LCS on are higher than with the LCS off. The mass readings with the LCS on turn out to be closer to the corresponding calibration masses. This is expected as the LCS is compensating the vertical displacement and the tilting of the tank relative to the pipes and is thus compensating the parasitic forces. Independent measurements with level gauges showed that the LCS kept the vessel in place during the weighing process with some retardation (less than 30 s) while the balance plate was lowered due to the calibration weights. A drift on the order of g/s occurs after loading with the calibration weights. During the experiments a rigid (filling) pipe of 2-3 m length was attached to the weighing vessel. It is speculated that this resulted in large relaxation effects. The experiment indicates that the LCS is reducing the parasitic forces. Thus, it is also expected that the corresponding uncertainty due to correcting for the parasitic forces will have a smaller contribution to the measurement uncertainty of the primary LNG mass flow standard.

In a second experiment, using the LCS on open loop mode to intentionally lift the tank up and down, the stiffness corresponding to the parasitic forces was determined by enforcing negative and positive displacements and measuring the corresponding apparent mass deviation. Figure 5 (top) shows the discrete displacements set by the LCS and Figure 5 (bottom) shows the corresponding mass deviations. The stiffness k is estimated from $F = k\Delta z$ or $\Delta mg = k\Delta z$, where Δm is the apparent mass deviation corresponding to displacement Δz, and $g = 9.81$ m/s^2. From the regression in Figure 4 (bottom) a stiffness of 3 x 10^3 N/m ± 3 x 10^3 N/m (k = 2) is obtained. An independent measurement on the (detached) filling pipe directly yielded a value of 7.84 x 10^3 N/m ± 2.14 x 10^3 N/m (k = 2). While these values are somewhat in correspondence it could also be expected that the estimated stiffness value from the experiment with the tank and filling pipe would be larger than the independent value measured directly on the (detached) filling pipe since the filling tank has more pipes/appendages attached to it than the filling pipe alone. Further experimentation is needed to explain the difference.

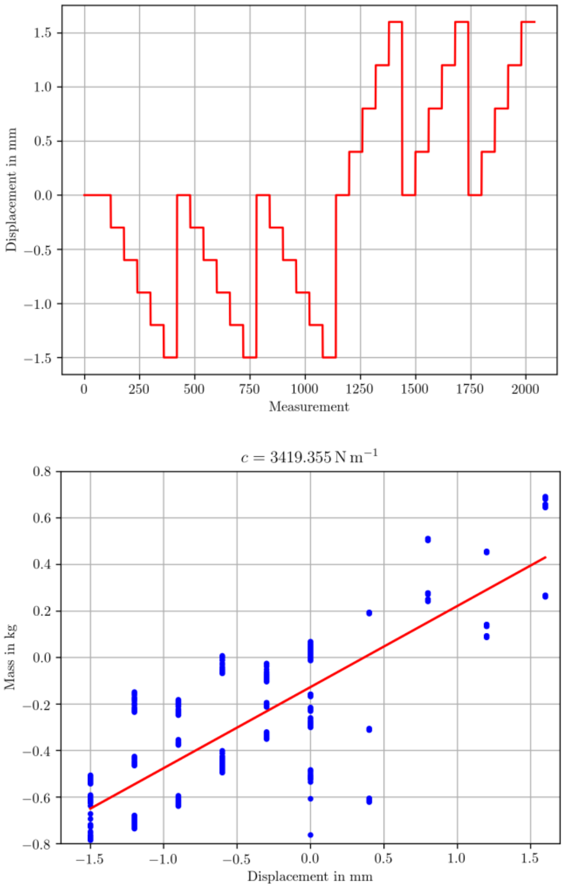

Figure 5: Actual displacements enforced by the LCS (top; negative is lowering) and corresponding measured mass deviations (bottom). From the linear regression a stiffness value of the filling pipe and other tank appendages is estimated.

3. Dry-break coupling

The filling pipe attached to the weighing vessel is a significant contributor to the parasitic forces and thereby a significant uncertainty source. For this reason, a dry-break coupling was installed into the primary standard. Figure 6 shows the filling pipe (1), the dry-break coupling (2), and the swivel pipe (3). The dry-break coupling allows to detach the filling pipe appendage prior to and after the weighing process. The swivel pipe is flexible in the vertical and flow direction, which is expected to further reduce parasitic forces. The swivel pipe and dry-break coupling are supported by flexible supports (chains).

The dry-break coupling has the expected potential to reduce the uncertainty contribution of the parasitic forces by detaching the weighing tank prior and after the calibration, to achieve an approximate equivalent geometry of the tank, filling pipe and other appendages when determining the increase in mass during the calibration.

Figure 6**:** Dry-break coupling in the primary LNG mass flow standard. Components indicated are: filling pipe (1), dry-break coupling (2), and the swivel pipe (3).

4. Discussion

Two approaches were chosen with the aim to reduce the contribution of parasitic forces to the measurement uncertainty of the primary LNG mass flow standard.

The LCS system shows higher readings closer to the corresponding calibration masses, and independent measurements showed that the LCS kept the vessel in place during the weighing process. This provides a strong indication that the LCS is compensating the parasitic forces due to the filling pipe and appendages attached to the weighing tank during the weighing process. Thus, it is also expected that the corresponding uncertainty due to correcting for the parasitic forces will have a smaller contribution to the measurement uncertainty of the primary LNG mass flow standard. Further investigation is needed to fully characterize the reduction of parasitic forces in an actual calibration process. The difference in the inferred and measured stiffness values indicates that the parasitic forces are not caused by the stiffness of the filling pipe alone.

The dry-break coupling is the second approach with the expected potential to reduce the uncertainty contribution due to parasitic forces.

Future activities will aim to provide a proof of principle of the improvements due to the LCS and the dry-break coupling when using cryogenic liquid in the weighing process.

5. Conclusion

Two systems were installed in the existing LNG primary mass flow standard that have the potential to reduce the uncertainty caused by parasitic forces.

These forces are a dominant uncertainty source of the primary standard Calibration and Measurement Capability (CMC). For the LCS initial results indicate that the parasitic forces are reduced indeed, and therefore the corresponding uncertainty contribution of the correction for the parasitic forces to the CMC is expected to be reduced as well. The dry-break coupling has not yet been tested for its potential to reduce the uncertainty contribution of the parasitic forces. Future activities will aim to provide a proof of principle of the improvements due to the LCS and the dry-break coupling when using cryogenic liquid in the weighing process

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