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Metrological controls and tests

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TITLE OF INTERNATIONAL RECOMMENDATION

Road and rail tankers with level gauging

Part 2 – Metrological controls and tests

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Foreword

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Terminology

The terms and definitions given in R 80-1 [1] apply in this Recommendation.

In addition, the following terms and definitions are used in this R 80-2:

Residual volume

Liquid content of the compartment including pipework at the cut-off point level.

Cut-off point

Level where the level gauge sensor is able to measure the minimum filling height at the maximum inclination of the tank. Below this point a measurement of the filling height cannot be guaranteed. This volume is a fixed metrological value and has to be stored in the measuring system.

1 Scope

This Recommendation is applicable to testing of road and rail tankers with level gauging, as defined in OIML R 80-1 [1], and may be used within the context of the OIML Certificate System.

This Recommendation sets out details of the test program, principles, equipment and procedures to be used for type evaluation and initial verification testing of a tanker model.

The provisions of this Recommendation also apply to ancillary devices if required by national regulations.

The provisions include requirements for testing complete road and rail tankers with level gauging and for testing the level gauge and the indicating device of road and rail tankers with level gauging as separate units.

2 Metrological control

2.1 General

2.1.1 In general (depending on national or regional legislation), legal metrological control can consist of type approval, initial and subsequent verification, and metrological supervision.

2.1.2 The essential elements of a measuring system, mainly those listed below, may be subject to separate type approvals:

- measuring tank,
- level gauging device.

2.1.3 The results of metrological control may be used for purposes of safety control.

2.2 Type approval

2.2.1 Documentation

The application for type approval of a road or rail tanker shall include the following documents:

- the documentation prescribed in 6.2 of R 80-1;
- a description giving the technical characteristics and the principle of operation;
- a description of the electronic devices with drawings, diagrams and general software information explaining their characteristics and operation;
- operating instructions;
- test outputs, their use, and their relationships to the parameters being measured; and
- documentation or other evidence that supports the assumption that the design and characteristics of the measuring instrument comply with the requirements of this Recommendation.
- drawings representing
 - a general assembly of the road or rail tanker;
 - a general assembly of the measuring tank, including its compartments;
 - a general assembly and function of the level gauging system;
 - auxiliary and ancillary installations, as appropriate;
 - details of the dome, reinforcing elements and discharge device(s);
 - identification plate;
 - the location of seals and verification marks.

2.2.2 The body responsible for type evaluation decides about the number of specimens necessary for the type approval tests.

In case the applicant wants to have approved several versions or measuring ranges, the body responsible for type evaluation decides which version(s) and range(s) shall be supplied.

Several tests can be carried out in parallel on different specimen. In this case, the body responsible for type evaluation decides which version or measuring range will be subjected to a specific test.

If a specimen does not pass a specific test and as a result, it has to be modified or repaired, the applicant shall carry out this modification to all the instruments supplied for test. If the testing laboratory has sound reasons to fear that the modification has negative influence on tests that already had a positive result, these tests shall be repeated.

2.2.3 The type examination of a road or rail tanker includes the following operations :

- external inspection,

- leak test,
- pressure test, if required,
- check on temperature dilatation of the tank,
- check on shape invariability,
- check on invariability of capacity in service,
- check on correct filling,
- check on complete discharge,
- calibration,
- check on sensitivity and expansion volume,
- check of ancillary devices and of the inclination correction (if any),
- check on rest volumes,

Note: The results of any test performed only for safety issues may be used.

2.2.4 If a pressure test is required, it shall be performed before the volumetric calibration.

2.2.5 The type examination of the gauge measuring device includes the following examinations, if applicable:

- units;
- accuracy classes and their symbols;
- measuring ranges;
- scale intervals or resolution;
- performance tests of the electronic parts.
- presentation of the measured value;
- adjustment facilities;
- protection against fraud;
- checking facilities;
- durability protection;
- software;
- durable recording of measuring results;
- printing device;
- storage of measured value;
- inscriptions;
- instruction manual;
- sealing and stamping.

2.2.6 As a rule, tests will be carried out on the complete measuring system. Simulation of any part of the system tested should be avoided. If this is not possible, for instance for components which cannot be tested either partially or with the whole system, all parts of the measuring system that can be affected by the influence factor or disturbance shall play an active role in the measurements

If the size or configuration of the measuring system does not lend itself to testing as a whole unit, or if only a separate device of the measuring instrument is concerned, the tests, or certain tests, shall be carried out on the devices (modules) separately, provided that, in the case of tests with the devices in operation, these devices are included in a simulated setup, sufficiently representative of its normal operation.

2.2.7 Type approval certificate

The following information shall appear on the type approval certificate:

- name and address of the issuing authority and name of responsible person,
- name and address of the applicant of the type approval certificate,
- name and address of the manufacturer, if it is not the applicant,
- principal metrological and technical characteristics,
- type approval mark,
- date of issue and period of validity,
- information on the location of marks for type approval, initial verification and sealing (e.g. a picture or drawing),
- list of documents accompanying the type approval certificate,
- specific remarks,
- the version and signature of the metrological part of the evaluated software, if applicable, and
- sufficient information to perform the tests during initial and subsequent verification.

2.2.8 Modification of an approved type

2.2.8.1 The applicant of the type approval shall inform the body responsible for the approval of any modification or addition, which concerns the metrological part of an approved type.

2.2.8.2 Modifications and additions shall be subject to a supplementary type approval when they influence, or are likely to influence, the measurement results or the measuring system's regulatory conditions of use.

The body having approved the initial type shall decide to which extent the examinations and tests described below shall be carried out on the modified type in relation to the nature of the modification.

Note: The manufacturer shall present a written evidence (of this fact) issued by approval body, when introducing the product on market.

2.2.8.3 If the body having approved the initial type judges that the modifications or additions are not likely to influence the measurement results, this body shall allow in writing the modified measuring systems to be presented for initial verification without granting a supplementary type approval.

2.2.8.4 A new or supplementary type approval must be carried out whenever the modified type no longer fulfils the provisions of the initial type approval. A modification of the metrological part of the software requires a new software version with signature which has to be stated in the addendum of the approval.

2.3 Equipment under test

For components of the measuring system which can not or only partially be tested within the whole system, e.g. temperature sensors, it is recommended to test them

separately and to document the test results in a suitable way and in accordance with the applicable national regulations.

Unless stated otherwise, all instruments or parts having undergone one of these separate tests for initial verification shall be marked and, if necessary, sealed.

2.3.1 Test of temperature measuring device

2.3.1.1 A temperature measuring device shall be tested in at least three points from the temperature range of the rated operating conditions fixed in accordance with 5.1.5 of R80-1. Recommended test points are minimum (or value near 0 °C), reference and maximum temperatures.

2.3.1.2 Analogue temperature sensor and conversion device may be tested independently of each other. The conversion device can be tested by simulation of the sensor. In this case the permissible errors of the temperature sensor shall not exceed 3/5 and of the conversion device 2/5 of the requirements of 5.1.5 of R80-1, respectively.

2.3.2 Separate test of inclination sensors

The inclination sensors shall be examined for a matrix-like type of inclinations the range of which is stated in the type approval, in both (longitudinal and transverse) directions, as well as in the all possible (i. e. four) simultaneous inclination in both directions. The accuracy of these examination shall be so that the requirements of OIML R80-1 5.5.4 are met.

Note: Experience has shown that for common tank shapes these requirements will be met if the deviation of inclination indication is not greater than $0,1^\circ$ in any of the directions to be tested.

Recommended number of test points is 9. Maximum deviation of all of these points shall be recorded on the calibration certificate of the sensor.

The direction of mounting shall be stated on the housing of the inclination sensor.

2.3.3 Separate test of volume conversion devices

The function of the volume conversion software shall be checked at least in three temperatures for each used product or product group by using simulated values. The test volume shall be at least 10 000 litres.

Maximum permissible errors and significant faults on quantities of liquid indications applicable to calculators, positive or negative, are equal to one-tenth of the maximum permissible error defined in line A of Table 2.

2.3.4 Separate test of floats

2.3.4.1 General

2.3.4.1.1 For pattern approval, at least one float of each type has to be tested in reference conditions at least with one liquid close to the minimum density and one liquid close to the maximum density of the density range of the intended liquids and the liquid generally used for tank calibration (e.g. water) if the liquid is different from the liquid close to the maximum density. The respective immersion depth shall be in the intended altitude range of the float (cylindrical area).

2.3.4.1.2 For measuring systems with corresponding corrections the change of the immersion depth within the permissible density range of each intended liquid is determined by calculation against the dimensions and weight of the float. The immersion depth of the float should be calculated at the maximum permissible density and at the minimum permissible density of each liquid. The deviation between the immersion depth at the maximum permissible density and at the minimum permissible density of each liquid shall not exceed the value given in table 8 of R80-1.

2.3.4.1.3 For measuring systems not fitted with corresponding corrections the immersion depth, is determined at least with one liquid close to the minimum density and one liquid close to the maximum density of the density range of the intended liquids and the liquid generally used for tank calibration (e. g. water) if the liquid is different from the liquid close to the maximum density, by calculation against the dimensions and weight of the float. The deviation between the immersion depth at the maximum permissible density and at the minimum permissible density of the density range of the intended liquids should be included in the uncertainty evaluation of the level measurement. The expanded uncertainty shall not exceed values given in table 6 of R80-1

2.3.4.1.4 At pattern approval one float should be defined as reference float. For initial verification, dimensions and weight of the float shall be within the permissible tolerances specified in the type approval certificate. The immersion depth offset of the individual float shall be determined in relation to the reference float of the same or equivalent type and shall be documented for each float.

2.3.4.1.5 To avoid influences on the metrological properties, the floats need not be marked. The serial number of the float together with the individual parameters shall be documented.

2.3.4.2 Test of the float construction for pattern approval

2.3.4.2.1 Chemical resistance

In the case were the chemical resistance of the float material is not inherent it has to be tested. Tests have to be made with FAM testing fluid according DIN 51604-1 and the typical fluids for its later use. These fluids shall not have any influence on the specified physical characteristics of the float.

2.3.4.2.2 Pressure resistance

The float has to be tested with a 1.5 overpressure of the nominal pressure of the system for which it is intended. The float has to withstand this pressure without deformation.

2.3.4.2.3 Adoption of float to the rod

The float has to be tested at the maximum inclination of the later use that it is not stuck on the level gauge rod.

2.3.4.2.4 Temperature influence on inversion depth

The influence of the liquid temperature to the inversion depth of the float has to be tested when it is not sufficient to show in a numerical calculation that the influence of the temperature has no significant influence on the accuracy of the whole system.

2.3.4.3 Proposal for a float test stand

A test setup for measuring the float inversion depth is shown in figure 1. Two level gauges of the same type of later use are affixed in a liquid-tight container with a support for each level float which had been fixed at the bottom. The spacers are necessary for a good reference surface for the floats. The level gauge is used to measure the height of float under the same conditions of later use.

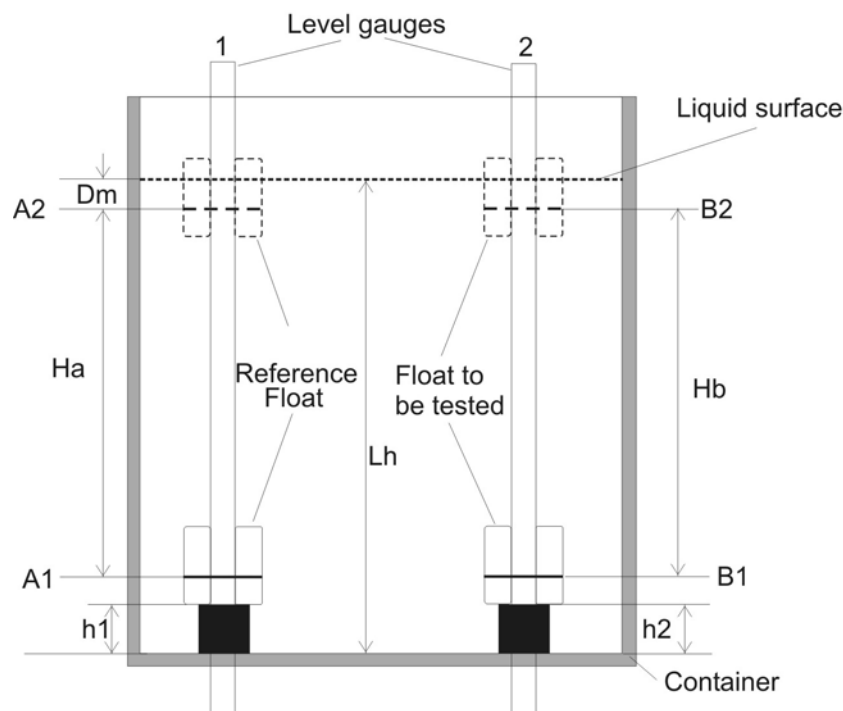


Fig. 1: Test setup for measuring the float inversion depth

2.3.4.3.1 Calibrating the test set up with a reference float

The value $A1$ has to be determined when the float is lie on the support by reading the value of the level gauge. Then the container is filled with test fluid. The value $A2$ can be taken from the level gauge after the calming of the fluid. The inversion depth can now be calculated with the following formula

$$Dm = Lh - h1 - Ha$$

Level gauge 2 has to be checked in the same way and should give the same results for the inversion depth Dm . The inversion depth of the reference float is calibrated and is used as a master float.

2.3.4.4 Necessary tests for production

2.3.4.4.1 Determine the float inversion depth

Level gauge 1 with the reference float is now the master for determining the inversion depth of the floats used in the measuring system. Level gauge 2 is for the float that has to be calibrated. The container is empty and the values $A1$ and $A2$ have to be taken. The container is filled with test fluid, the values for $A2$ and $B2$ has to be taken. Calculate the length $Ha = A2 - A1$ and $Hb = B2 - B1$. The inversion depth of the float can now be calculated with $k = h2 - h1$

$$D_{float} = Dm + Ha - Hb + k$$

The immersion depth of the float shall not change by more than the value given in Table 8 of R80-1.

2.3.4.4.2 Checking the physical dimensions of the float

Check the correct marking, measure the mass and the dimensions of the float required by the approval. The serial number together with all relevant measures of the float has to be documented and written in a calibration report.

The float has to inspect for its integrity, especially for cracks and holes.

2.3.4.4.3 Documentation of the test results

All test results has to be documented. At least the serial number, the test fluid and the method of determine the inversion depth together with other individual has to be written in the accompanying document of the float.

To avoid influences on the metrological properties, the floats need not be marked.

2.3.5 Separate test of ultrasound level sensors

The ultrasound level sensors are checked with a shortened reference pipe, containing a well-defined reference echo mark in the level measuring pipe at a distance of 350 ... 500 mm. The reference pipe shall be attached by screws to the sensor to be tested. The arrangement shall be immersed in de-ionised, gas-free water, taking care to remove any gas bubbles which may be trapped in the pipes. When connected to a reference controller, the deviation of the level reading obtained from the controller and the distance of the echo mark shall be less than the value specified in the type approval.

2.3.6 Separate test of dipsticks for float systems

The dip stick has to be tested with a filling height simulator at least at three different heights in both directions. The deviation shall be less than one third of the value of table 5 of R80-1 for full compartment delivery and of table 6 of R80-1 for partial delivery.

For initial verification, the serial number of the dipstick shall be documented together with all relevant metrological parameters, e.g. sound velocity, linearity correction data, sensor type, software version, check sum, length of the dip stick, if applicable.

2.3.7 Separate test of dipstick pipes for ultrasound systems

The mechanical dimensions of the reference marks of the dipstick pipes shall be tested, for example by clamping the pipe into a gauge and comparing the distance of the reference marks from the reference edges of the gauge with the values given on the gauge. The permissible deviations are specified in the type approval certificate.

2.3.8 Separate test of computer or controller

The evaluation of the conversion device shall be part the type approval procedure. Its accuracy, the correct functioning of the checking facilities, etc. have to be checked.

For initial verification, the software (modules) used as well as their signature shall be checked for compliance with the versions stated in the type approval certificate. If present, the protection function (e.g. electronic sealing) for the data of legal relevance shall be checked.

2.3.9 Separate test of a indicating device

For type approval, the checking facilities of the indicating devices have to be checked, for instance by connecting/disconnecting the indicating device.

2.4 Initial verification

2.4.1 General

2.4.1.1 Initial verification shall comprise the following operations, where applicable:

- Check of results of separate tests according to 2.3,

Note: If components of the measuring system have not been separately tested in accordance with 2.3, these tests shall be performed during initial verification,

- visual inspection according to 2.4.2,
- leak test,
- pressure test,
- inspection of the tank calibration tables or curves,
- accuracy test (*),

Note: Systems intended for partial deliveries shall be tested by stepwise emptying in volume steps not higher than 2*MMQ. The last test step shall comprise complete emptying of the tank.

- check of pipework volume(*),
- check of the inclination correction (*),
- check of expansion volume (*),
- check of cut-off point of the level sensor,
- check of ancillary devices.

(*) examples for these actions see also informative annex 3

2.4.1.2 All test equipment used shall have the required accuracy and must, to the extent possible, be traceable to national standards. The use of simulators or computer-aided measuring facilities is permitted.

2.4.2 Visual inspection

The following items are to be checked:

- external and internal appearance of the tank or compartment(s), damage(s),
- compliance (conformity) with the specifications of the type approval certificate, including the version of the software (modules) and signatures used, if appropriate,
- stored values of the metrological relevant parameters (e.g. float correction values, product data, mode of volume conversion, etc.),
- check of all sealing points,
- availability and completeness of the measuring system document.

2.4.3 The tank shall be leak tested according to clause 5.2.2.2 of R 80-1

2.4.4 The tank shall be calibrated according to clause 5.5 of R 80-1.

2.4.4.1 The expanded uncertainty of the determination of volume of liquid in tank for initial verification shall not exceed one-third of the maximum permissible error according to R80-1, Table 2. The expanded uncertainty shall be estimated according to the *Guide to the expression of uncertainty in measurement* [1] with $k = 2$.

2.4.4.2 Specification of the minimum measured quantities

The minimum measured quantity shall be specified for each measuring compartment in accordance with 5.1.7 of R 80-1 unless stated otherwise in the type approval certificates for the level gauging system or for the measuring tank. The minimum measured quantity according to 5.1.7.2 of R 80-1 may be specified within the scope of the tank calibration. When it is determined within the scope of the tank calibration, it may be changed during the initial verification at the latest (for example if the measurement results exceed the error limits).

2.4.5 Test of residual volume, if it is not done during accuracy test.

To test the correct set up of the residual volume a complete empty compartment and its associated pipework is filled up with the nominal volume of the proving can. The compartment will be discharged completely and the delivered volume has to be inside the stated accuracy. This volume consists of a metered part by the level gauge sensor and the fixed part of the residual volume.

2.4.6 Test of the pipework volumes for delivery by gravity

The volume of the pipework between the bottom valve of each measuring compartment and the respective transfer point are stored as metrological relevant values of the measuring system and are tested as follows:

The measuring compartment and the pipework are filled via the loading connection with fluid that the bottom valve of the compartment is completely flooded. After a waiting time

for removing all air out of pipe, the bottom valve shall be closed and the pipework will be emptied via the transfer point. The deviation of this quantity and the stored value shall be less than one third of E_{\min} of the compartment.

2.4.6 Test of delivery via collector

The compartment with the smallest MMQ of the measuring container shall be selected for this test. Each available delivery path (full and/or empty hose(s)) are to be tested separately in two steps, each time delivering a test volume of 1.000 litre or the smallest delivery quantity of the selected compartment, whichever is smaller. For an initial flushing, the compartment is filled with at least 200 litre and subsequently emptied through the collector and the selected delivery path. The quantities used and indicated during flushing are irrelevant.

2.4.6.1 Measuring systems with gas separator or level sensor for the cut-off point

After flushing, the compartment is filled with twice the test volume.

In a first step, the test volume is discharged through the originally empty collector line and the same delivery path as during initial flushing, using a volume standard or reference meter. In the second step, the remaining product is delivered through the same delivery path until the system stops. The maximum permissible error for this deviation is $\pm 0,5$ % of the minimum measuring quantity of the compartment used for the test.

2.4.6.2 Measuring systems with level sensor for the pipework system

After flushing, the test volume plus approximately half the volume of the collector pipework is filled into the compartment. The test volume (not including the added volume for the pipework) shall then be delivered into/through the volume standard or reference meter.

In the second step, the test volume minus the pipework volume which had been added before, is filled into the compartment, and subsequently delivered into/through the standard/reference meter, until the system shuts off.

The maximum permissible error for these deviations is $\pm 0,5$ % of the minimum measuring quantity of the compartment used for the tests.

2.5 Subsequent verification

2.5.1 Subsequent verification is subject to national regulations. The following actions are recommended:

2.5.1.1 Visual inspection

The visual inspection comprises the inspection of the following items:

For the measuring tank:

- external damage (if damage to a measuring compartment cannot be safely excluded, the operator may be requested to clean the compartment so that the compartment can safely be inspected from inside)

- compliance with the type approval certificate.

For the level gauging system:

- compliance of the parameters or signature(s) relevant to verification with those at the time of initial verification
- compliance of the version of the software (modules) used as well of their signature with the type approval certificate or supplements
- availability of the measuring system document
- identification of the incorporated components
- mechanical damage of the level sensors
- presence of measuring system type plate
- availability of operating instructions

2.5.1.2 Volumetric test using a volume standard

The principles of testing are described in A3.2 as an example, assuming accuracy class 0,5 and a reference container volume of 1000 litres.

It is sufficient however, to prove that three measurements of 1.000 litre each, taken at filling states of approx. 90% and 50%, and when emptying the compartment completely, are within a deviation of $\pm 0,5\%$ of the measured quantity (i.e. 5 litre).

Should this limit be exceeded in one or several of these tests, further deliveries of 1.000 litre each may be performed until 80% of the minimum delivered quantity of the compartment under test is reached or exceeded. The deviation of the sum of these successive measurements of the sum of the standard readings shall be within $\pm 0,5\%$.

Checking of the temperature sensor according to A.3 should be carried out simultaneously with these tests.

2.5.1.3 Volumetric test using a reference meter

The test is carried out in analogy to A3.4. The testing quantities shall be equal to the minimum delivery quantity.

2.5.1.4 Checking of pipework volumes for measuring systems with collector

The pipework system including the collector is subjected to a simplified test, which consists of the second test step described in A3.6.1, preceded by an initial flushing, as described in A3.6.

The maximum permissible error for this measurement deviation is $\pm 0,5\%$ of the minimum measuring quantity of the measuring compartment selected for this test.

2.5.1.5 Checking of inclination correction

The test shall be carried out as described in A3.7 but only at one level in the range of 30 to 70 % of the nominal volume of each compartment.

2.5.1.6 Locations of seals

Missing or damaged seals shall be renewed by the verification officer.

2.5.2 Recommended actions after replacement of components for measuring systems for full compartment delivery/receipt

In case of a replacement components of the measuring system under legal control, the actions below are recommended:

2.5.2.1 Actions on replacement of the controller or computer

- Separate test of new device according to 2.3.8,
- entry of the new data into the measuring system document,

2.5.2.2 Actions on replacement of a simple indicating device

- Separate test of the indicating device according to 2.3.9

2.5.2.3 Actions on replacement of dipsticks for float systems

- Comparison with a mechanical dipstick at a level close to nominal capacity,
- entry of the new data into the measuring system document,

2.5.2.4 Actions on replacement of a sensor/float

- Comparison with a mechanical dipstick at a level close to nominal capacity,
- entry of the new data into the measuring system document,

2.5.3 Recommended actions after replacement of components for measuring systems for partial compartment delivery/receipt

In case of a replacement of a component of the measuring system under legal control, the actions below are recommended:

2.5.3.1 Actions on replacement of the controller or computer

- Separate test of new device according to 2.3.8,
- entry of the new data into the measuring system document,
- single volume measurement by verification authority with quantity of about MMQ delivered from the random compartment, check of the indicated and corrected volume,
- comparison and evaluation of parameters.

2.5.3.2 Actions on replacement of a simple indicating device

- Separate test of the indicating device according to 2.3.9

2.5.3.3 Actions on replacement of dipsticks for float systems

- Separate test of new dipstick for float system according to ,

- entry of the new dipstick correction values into the level gauging system,
- entry of the new data into the measuring system document,
- single volume measurement by verification authority, quantity of about (1 to 2) MMQ delivered from the compartment fitted with new dipstick, check of the volume at working conditions, unless otherwise specified in the type approval
- comparison and evaluation of parameters.

2.5.3.4 Actions on replacement of a sensor/float

- Separate test of a new float according to ,
- entry of the new float correction values into the level gauging system,
- entry of the new data into the measuring system document,
- single volume measurement by verification authority, quantity of about (1 to 2) MMQ delivered from the compartment fitted with new float, check of the volume at working conditions, unless otherwise specified in the type approval
- comparison and evaluation of parameters.

2.5.3.5 Actions on replacement of dipsticks for ultrasound systems

- Separate test of new dipstick for ultrasound systems according to 2.3.5 and 2.3.7,
- entry of the new correction values into the level gauging system,
- entry of the new data into the measuring system document, if applicable
- single volume measurement by verification authority, quantity of about (1 to 2) MMQ delivered from the compartment fitted with the new dipstick, check of the volume at working conditions, unless otherwise specified in the type approval
- comparison and evaluation of parameters.

2.5.3.6 Actions on replacement of a temperature sensor

- Separate test of a new temperature sensor according to 2.3.1,
- entry of the new sensor parameters into parameter list,
- entry of the new data into the measuring system document,
- temperature measurement by verification authority during delivery of a random quantity from the relevant compartment,
- recording and comparison of the delivery temperature with certified thermometer), comparison and evaluation of parameters.

2.5.4 Recommended actions after repair or corrections of the measuring system

2.5.4.1 Actions after compilation of a new calibration table for a measuring compartment (recalibration of a tank or compartment, e.g. after repair of the tank)
After a new calibration table has been compiled for one or several tank compartments, the verification of the measuring system is no longer valid.

2.5.4.2 For the following verification, all re-calibrated measuring compartments shall be tested as for initial verification. The re-examination of the pipe-work volumes may be dispensed with if these have not changed. Prior to the due date the compartments for which no new calibration tables have been compiled need not be subsequently verified due to the repair. After the repaired compartments have been checked, the measuring

system shall be provided with a seal stating the original period of validity of the verification (if applicable, depending on national legislation).

2.5.4.3 If the repair was carried out within the scope of a subsequent verification, the repaired compartments will be treated as in initial verification and the other compartments as in subsequent verification.

3 Performance tests for type approval of electronic measuring systems

3.1 General

All components, including the tank compartment, of the system have to fulfill the requirements of this chapter 3 and the MPE has not been exceeded.

This sub-clause defines the program of performance tests intended to verify that electronic measuring systems may perform and function as intended in a specified environment and under specified conditions. Each test indicates, where appropriate, the reference conditions for determining the intrinsic error.

These tests supplement any other prescribed test.

When the effect of one influence quantity is being evaluated, all other influence quantities are to be held relatively constant, at values close to reference conditions.

3.2 Reference conditions

Except for the parameter being tested, the following reference conditions shall be kept by the testing laboratory during the tests:

| Parameter | Value |
|--|---|
| a) Environmental temperature | 20 °C ± 5 °C |
| b) Humidity | ≤ 85 % RH |
| c) Vibration | negligible |
| d) AC mains voltage (*) | $U_{nom} \pm 2 \%$ |
| e) AC mains frequency | $f_{nom} \pm 2 \%$ |
| f) Voltage of internal battery | Voltage of new battery specified by the manufacturer |
| g) Voltage of a road vehicle battery (*) | Nominal voltage of the battery; stable (no other equipment is connected, except voltmeter and EUT). |
| h) Radiated radio-frequency electromagnetic fields | < 0,2 V/m |
| i) Conducted radio-frequency fields (*) | < 0,2 V emf |
| j) Power frequency magnetic field | < 1 A/m |
| k) Bursts (transients) on power, signal, data and control lines (*) | negligible |
| l) Surges | negligible |
| m) AC mains voltage dips, short interruptions and voltage variations (*) | negligible |

| | |
|---|--|
| | |
| (*) Whatever power source is applicable | |

Conditions h), i), j), k), l), m) can be expected to be fulfilled without specific measures. it is usually not deemed necessary to measure/monitor these values.

3.3 Environmental classification (see OIML D 11 [2])

For each performance test, typical test conditions are indicated which correspond to the climatic, mechanical and electromagnetic environmental conditions to which the tankers are usually exposed.

According to OIML D 11 the following classes are recommended

- Climatic environment: Class H3

This class applies to instruments or parts of instruments used in open locations with average climatic conditions, thus excluding polar and desert environments.

- Mechanical environment: Class M2

This class applies to locations with significant or high levels of vibration and shock. Without particular reasons applicable to all measuring systems on trucks.

- Electromagnetic environment: Class E3

This class applies to instruments supplied by the battery of a vehicle. (WELMEC Guide 8.15)

According to these classes, severity levels given by the following Table 1 shall be applied.

Table 1: Severity levels for the performance tests

| Kind of performance tests | Test description | Evaluation ¹⁾ | OIML D 11 | Severity level ²⁾ |
|---------------------------|--|--------------------------|-----------|------------------------------|
| Climatic | 3.4.1 Dry heat | I | 10.1.1 | 3 |
| | 3.4.2 Cold | I | 10.1.2 | 3 |
| | 3.4.3 Damp heat, cyclic (condensing) | D | 10.2.2 | 2 |
| Mechanical | 3.4.4 Vibration (random) | I | 11.1.1 | 2 |
| Electrical, general | 3.4.5 Radiated electromagnetic fields | D | 12.1.1 | 3 |
| | 3.4.6 Conducted radio-frequency fields | D | 12.1.2 | 3 |
| | 3.4.7 Electrostatic discharge | D | 12.2 | 3 |
| | 3.4.8 Power frequency magnetic field | D | 12.3 | 4 |

| | | | | |
|--|--|---|--------|-----|
| | 3.4.9 Bursts (transients) on signal, data and control lines | D | 12.4 | 3 |
| Electrical, AC mains voltage ⁴⁾ | 3.4.10 AC mains voltage variation | I | 13.2 | 1 |
| | 3.4.11 Surges on AC lines | D | 13.8 | 3 |
| | 3.4.12 AC mains voltage dips, short interruptions and voltage variations | D | 13.4 | 3 |
| | 3.4.13 Bursts (transients) on AC mains | D | 13.5 | 3 |
| Electrical, internal battery ³⁾ | 3.4.14 Low voltage of internal battery | I | 14.1 | 1 |
| Electrical, power from external 12 V and 24 V road vehicle batteries ⁵⁾ | 3.4.15.1 Voltage variations | I | 14.2.1 | C/F |
| | 3.4.15.2 Electrical transient conduction along supply lines | D | 14.2.2 | IV |
| | 3.4.15.3 Electrical transient conduction via lines other than supply lines | D | 14.2.3 | IV |

- 1) I - Influence factor
D - Disturbance

- 2) Severity levels are in accordance with OIML D11 and IEC standards mentioned in the following clause 3.4

- 3) only applicable for systems powered by internal battery

- 4) only applicable for systems powered by AC mains

- 5) only applicable for systems powered by road vehicle battery

However, the applicant for type approval may indicate specific (more severe) environmental conditions in the documentation supplied to the metrology service, based on the intended use of the tanker. In this case, the metrology service shall carry out performance tests at severity levels corresponding to the corresponding environmental conditions. If type approval is granted, the data plate shall indicate the corresponding limits of use. Manufacturers shall inform potential users of the conditions of use for which the tanker is approved.

3.4 Performance tests

The following tests need only be carried out where, as a result of the physical principle of the measuring system or a part of it, a significant influence may be expected. If a test is not carried out the reason shall be noted in the test report.

Note: The test procedures have been given in condensed form, for information only, and are adapted from the referenced IEC-publications. Before conducting the test, the applicable publication should be consulted.

3.4.1 Dry heat

| | |
|-------------------------------|---|
| Test method: | Dry heat (non condensing) |
| Object of the test: | To verify compliance with the provisions in 5.7.1.1 of R 80-1 under conditions of high ambient air temperature. |
| References: | IEC 60068-2-2 [3]. IEC 60068-3-1 [4]. IEC 60068-1 [5]. |
| Test procedure in brief: | <p>The test consists of exposure of the EUT to the specified high temperature (+ 55 °C) under “free air” conditions for a 2-hour period, after the EUT has reached temperature stability.</p> <p>The change of temperature shall not exceed 1 °C/min during heating up and cooling down.</p> <p>The absolute humidity of the test atmosphere shall not exceed 20 g/m³. When testing is performed at temperatures lower than 35 °C, the relative humidity shall not exceed 50 %.</p> <p>The EUT shall be tested at the reference temperature after 1 hour conditioning,</p> <ul style="list-style-type: none">- at the specified high temperature, 2 hours after temperature stabilization,- after 1 hour recovery of the EUT at the reference temperature. <p>During tests, the EUT shall be in operation.</p> <p>Simulated inputs are permitted.</p> |
| Test severity: | Severity level 3: 55 °C |
| Number of test cycles: | One cycle |
| Maximum allowable variations: | All functions shall operate as designed and all the errors measured during the application of the influence factor shall be within the maximum permissible errors. |

3.4.2 Cold

| | |
|---------------------------|---|
| Test method: | Cold |
| Object of the test: | To verify compliance with the provisions in 5.7.1.1 of R 80-1 under conditions of low ambient air temperature. |
| References: | IEC 60068-2-1 [6]. IEC 60068-3-1 [4]. IEC 60068-1 [5]. |
| Test procedure in brief : | The test consists of exposure of the EUT to the specified low temperature (- 25 °C) under “free air” conditions for a 2-hour period, after the EUT has reached temperature stability. |

The EUT shall be tested

- at the reference temperature after 1 hour conditioning,
- at the specified low temperature, 2 hours after temperature stabilization
- after 1 hour recovery of the EUT at the reference temperature.

During tests, the EUT shall be in operation, simulated inputs are permitted.

| | |
|-------------------------------|--|
| Test severity: | Severity level 3: - 25 °C |
| Number of test cycles: | One cycle |
| Maximum allowable variations: | All functions shall operate as designed and all the errors measured during the application of the influence factor shall be within the maximum permissible errors. |

3.4.3 Damp heat, cyclic (condensing)

| | |
|--------------------------|--|
| Test method: | Damp heat, cyclic (condensing) |
| Object of the test: | To verify compliance with the provisions in 5.7.1.2 of R 80-1 under conditions of high humidity when combined with cyclic temperature changes. |
| References: | IEC 60068-2-30 [7]. IEC 60068-3-4 [8] |
| Test procedure in brief: | <p>The test consists of exposure of the EUT to cyclic temperature variations between 25 °C and the upper temperature of 55 °C, maintaining the relative humidity above 95 % during the temperature changes and during the phases at low temperature, and at 93 % at the upper temperature phases.</p> <p>A 24 h cycle consists of:</p> <ul style="list-style-type: none">- temperature rise during 3 h- temperature maintained at upper value until 12 h from the start of the cycle- temperature lowered to lower value within 3 h to 6 h, the rate of fall during the first hour and a half being such that the lower value would be reached in 3 h- temperature maintained at lower value until the 24 h cycle is completed. <p>The stabilizing period before and recovery after the cyclic exposure shall be such that all parts of the EUT are within 3 °C of their final temperature.</p> <p>The electrical power is turned off when the influence factor is applied.</p> |
| Test severities: | Severity level 2: 55 °C |
| Number of test cycles: | Two cycles |

Maximum allowable variations: After the application of the disturbance and recovery, all functions shall operate as designed and either significant faults do not occur, or significant faults are detected and acted upon by means of a checking facility.

3.4.4 Vibration (random)

Test method: Random vibration

Object of the test: To verify compliance with the provisions in 5.7.1.1 of R 80-1 under conditions of random vibrations.

References: IEC 60068-2-47 [9]
IEC 60068-2-64 [10]

Test procedure in brief: The EUT shall, in turn, be tested in three, mutually perpendicular axes, mounted on a rigid fixture by its normal mounting means.

The EUT shall normally be mounted so that the gravitational force acts in the same direction as it would in normal use.

The electrical power is turned off when the influence factor is applied.

Test severities: Severity level 2

| | | |
|-----------------------|-----------|---------------------------------|
| Total frequency range | 10 -150 | Hz |
| Total RMS level | 7 | m.s ⁻² |
| ASD level 10 –20 Hz | 1 | m ² .s ⁻³ |
| ASD level 20 –150 Hz | - 3 | dB/octave |
| Number of axes | 3 | - |
| Duration per axis | 2 minutes | |

Maximum allowable variations: After the application of the influence factor, all functions shall operate as designed and all errors shall be within the maximum permissible errors.

3.4.5 Radiated radio frequency electromagnetic fields

Test method: Radiated electromagnetic fields

Object of the test: To verify compliance with the provisions in 5.7.1.2 of R 80-1 under conditions of electromagnetic fields.

References: IEC 61000-4-3 [11]

Test procedure in brief: The EUT shall be exposed to electromagnetic field strength as specified by the severity level and a field uniformity as defined by the referred standard.

The EM field can be generated in different facilities, however the use of which is limited by the dimensions of the EUT and the frequency range of the facility.

The frequency ranges to be considered are swept with the modulated signal, pausing to adjust the RF signal level or to switch oscillators and antennas as necessary. Where the frequency range is swept incrementally, the step size shall not exceed 1 % of the preceding frequency value.

The dwell time of the amplitude modulated carrier at each frequency shall not be less than the time necessary for the EUT to be exercised and to respond, but shall in no case be less than 0,5 s. The sensitive frequencies (e.g. clock frequencies) shall be analyzed separately (Usually, these sensitive frequencies can be expected to be the frequencies emitted by the EUT).

During tests, the EUT shall be in operation, simulated inputs are permitted.

Test severities:

Severity level 3:

- 10 V/m for the frequency range: 26 – 2 000 MHz.

Modulation: 80 % AM, 1 kHz sine wave

Maximum allowable variations:

During the disturbance, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it in accordance with 5.7.3 of R 80-1 when significant faults occur.

Notes:

1) IEC 61000-4-3 only specifies test levels above 80 MHz. For frequencies in the lower range the test methods for conducted radio frequency disturbances are recommended (test 3.4.6)

2) However, for EUT having no mains or other input port available the lower limit of radiation test should be 26 MHz, taking into account that the test specified in 3.4.6 cannot be applied (refer to Annex H of IEC 61000-4-3). In all other cases both 3.4.5 and 3.4.6 shall apply

3.4.6 Conducted radio frequency fields

Test method:

Conducted electromagnetic fields

Object of the test:

To verify compliance with the provisions in 5.7.1.2 of R 80-1 under conditions of conducted radio frequency fields.

References:

IEC 61000-4-6 [12]

Test procedure in brief:

Radio frequency EM current, simulating the influence of EM fields shall be coupled or injected into power ports and I/O ports of the EUT using coupling/decoupling devices as defined in the referred standard.

During tests, the EUT shall be in operation, simulated inputs are permitted.

| | |
|-------------------------------|---|
| Test severities: | Severity level 3: 10 V (e.m.f.) for the RF amplitude (50 Ω) Frequency range 0.15 – 80 MHz |
| Maximum allowable variations: | During the disturbance, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it in accordance with 5.7.3 of R 80-1 when significant faults occur. |
| Notes: | 1) If the EUT is composed of several elements, the tests shall be performed at each extremity of the cable if both of the elements are part of the EUT. 2) For the frequency range 26 - 80 MHz, the testing laboratory can either carry out test according to 3.4.5 or according to 3.4.6. But in case of a dispute, the results according to 3.4.6 shall prevail. |

3.4.7 Electrostatic discharge

| | |
|-------------------------------|--|
| Test method: | Electrostatic discharge (ESD) |
| Object of the test: | To verify compliance with the provisions in 5.7.1.2 of R 80-1 under conditions of direct and indirect electrostatic discharge. |
| References: | IEC 61000-4-1 [13] IEC 61000-4-2 [14] |
| Test procedure in brief: | An ESD generator shall be used with a performance as defined in the referred standard. At least 10 discharges shall be applied. The time interval between successive discharges shall be at least 10 seconds, during the same measurement or simulated measurement. Contact discharge is the preferred test method. Air discharges shall be used were contact discharge cannot be applied. |
| Test severities: | Severity level 3: 8 kV for air discharges 6 kV for contact discharges |
| Number of test cycles: | At each test point, at least ten direct discharges shall be applied at intervals of at least ten seconds between discharges, during the same measurement or simulated measurement. For indirect discharges, a total of ten discharges shall be applied on the horizontal coupling plane and a total of ten discharges for each of the various positions of the vertical coupling plane. |
| Maximum allowable variations: | During the disturbance, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it |

in accordance with 4.7.3 of R 80-1 when significant faults occur.

3.4.8 Power frequency magnetic field

| | |
|-------------------------------|---|
| Test method: | Power frequency magnetic field (50 Hz or 60 Hz) |
| Object of the test: | To verify compliance with the provisions in 5.7.1.2 of R 80-1 under conditions of power frequency magnetic field (50 Hz or 60 Hz). References: IEC 61000-4-8 [15] |
| Test procedure in brief: | The test consists of exposure to power frequency magnetic field (50 Hz or 60 Hz) |
| Test severities: | Severity level 4: Magnetic field strength 30 A/m for continuous field Magnetic field strength 300 A/m for short duration (1 – 3 s) |
| Maximum allowable variations: | During the disturbance, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it in accordance with 5.7.3 of R 80-1 when significant faults occur. |

3.4.9 Burst (transients) on signal, data and control lines

| | |
|--------------------------|---|
| Test method: | Electrical bursts |
| Object of the test: | To verify compliance with the provisions in 5.7.1.2 of R 80-1 under conditions where electrical bursts are superimposed on input/output and communication ports. References: IEC 61000-4-1 [13] IEC 61000-4-4 [14] |
| Test procedure in brief: | A burst generator shall be used with the performance characteristics as specified in the referred standard. The test consist of exposure to bursts of voltage spikes for which the repetition frequency of the impulses and peak values of the output voltage on 50 Ω and 1 000 Ω load are defined in the referred standard. Both positive and negative polarity of the bursts shall be applied. The duration of the test shall not be less than 1 min for each amplitude and polarity. For the coupling of the bursts into the input/output and communication lines, a capacitive coupling clamp as defined in the standard shall be used. |

The bursts are applied during all the time necessary to perform the test; to that purpose more bursts than indicated above may be necessary.

During tests, the EUT shall be in operation, simulated inputs are permitted.

Test severities:

Severity level 3:

1 kV for the amplitude (peak value), repetition rate: 5 kHz.

Maximum allowable variations:

During the disturbance, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it in accordance with 5.7.3 of R 80-1 when significant faults occur.

3.4.10 AC mains voltage variation

| | | |
|--|--|-------------------|
| Applicable standards | IEC/TR3 61000-2-1 [17], IEC 61000-4-1 [13] | |
| Test method | Variation in AC mains power voltage (single phase) | |
| Object of the test | To verify compliance with the provisions in 5.7.1.1 under conditions of varying AC mains power voltage. | |
| Test procedure in brief | The test consists of exposure to the specified power condition for a period sufficient for achieving temperature stability and for performing the required measurements. | |
| Test severity | Severity level: 1 | |
| Mains voltage ⁽¹⁾ , ₍₂₎ | Upper limit | $U_{nom} + 10 \%$ |
| | Lower limit | $U_{nom} - 15 \%$ |
| Maximum allowable variations: | All functions shall operate as designed and all the errors measured during the application of the influence factor shall be within the maximum permissible errors. | |
| Notes | ⁽¹⁾ In the case of three phase mains power, the voltage variation shall apply for each phase successively. ⁽²⁾ The values of U_{nom} are those marked on the measuring instrument. In case a range is specified, the “-” relates to the lowest value and the “+” to the highest value of the range. | |

3.4.11 Surges on AC lines

| | |
|-------------------------|---|
| Applicable standard | IEC 61000-4-5 [18] |
| Test method | Electrical surges |
| Object of the test | To verify compliance with the provisions in 5.7.1.2 under conditions where electrical surges are superimposed on the mains voltage |
| Test procedure in brief | <p>A surge generator shall be used with the performance characteristics as specified in the referred standard. The test consists of exposure to surges for which the rise time, pulse width, peak values of the output voltage/current on high/low impedance load and minimum time interval between two successive pulses are defined in the referred standard.</p> <p>On AC mains supply lines at least 3 positive and 3 negative surges shall be applied synchronously with AC supply voltage in angles 0°, 90°, 180° and 270°.</p> |

| | |
|-------------------------------|--|
| | The injection network depends on the lines the surge is coupled into and is defined in the referred standard. |
| Test severities | Severity level 3: line to line 1.0 kV, line to earth 2.0 kV |
| Maximum allowable variations: | After the disturbance, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it in accordance with 5.7.3 of R 80-1 when significant faults occur. |

3.4.12 AC mains voltage dips, short interruptions and voltage variations

| | | | | | |
|-------------------------------|---|-------------------------------|-----------------------------|-----------------------------|--------|
| Applicable standards | IEC 61000-4-11 [19], IEC 61000-6-1 [20], IEC 61000-6-2 [21] | | | | |
| Test method | Short-time reductions in mains voltage | | | | |
| Object of the test | To verify compliance with the provisions in 5.7.1.2 under conditions of short time mains voltage reductions | | | | |
| Test procedure in brief | A test generator suitable to reduce for a defined period of time the amplitude of the AC mains voltage is used. The mains voltage reductions shall be repeated 10 times with an interval of at least 10 seconds. | | | | |
| Test severities | Severity level 3: | | | | |
| | Voltage dips | Test a | Reduction | 0 | % |
| | | | Duration | 0.5 | cycles |
| | | Test b | Reduction | 0 | % |
| | | | Duration | 1 | cycles |
| | | Test c | Reduction | 40 | % |
| | | | Duration | 10/12 ⁽²⁾ | cycles |
| | Test d | Reduction | 70 | % | |
| | | Duration | 25/30 ⁽²⁾ | cycles | |
| | Test e | Reduction | 80 | % | |
| Duration | | 250/300 ⁽²⁾ | cycles | | |
| Short interruptions | Reduction | 0 | % | | |
| | Duration | 250/300 ⁽²⁾ | cycles | | |
| Notes | ⁽¹⁾ For the voltage dips, all tests within the severity level can be applicable (refer to 8.4.7 of OIML D 11 [2]). ⁽²⁾ These values are for 50 Hz / 60 Hz respectively | | | | |
| Maximum allowable variations: | During the disturbance, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it in accordance with 5.7.3 of R 80-1 when significant faults occur. | | | | |

3.4.13 Bursts (transients) on AC mains

| | |
|-------------------------|---|
| Applicable standards | IEC 61000-4-1 [13], IEC 61000-4-4 [16] |
| Test method | Electrical bursts |
| Object of the test | To verify compliance with the provisions in 5.7.1.2 under conditions where electrical bursts are superimposed on the mains voltage |
| Test procedure in brief | <p>A burst generator shall be used with the performance characteristics as specified in the referred standard.</p> <p>The test consist of exposure to bursts of voltage spikes for which the output voltage on 50 Ω and 1 000 Ω load are defined in the referred standard.</p> <p>Both positive and negative polarity of the bursts shall be applied.</p> <p>The duration of the test shall not be less than 1 min for each amplitude and polarity.</p> <p>The injection network on the mains shall contain blocking filters to</p> |

| | |
|-------------------------------|---|
| | prevent the burst energy being dissipated in the mains. |
| Test severities | Severity level 3: Amplitude (peak value) 2 kV, Repetition rate 5 kHz |
| Maximum allowable variations: | During the disturbance, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it in accordance with 5.7.3 of R 80-1 when significant faults occur. |

3.4.14 Low voltage of internal battery (not connected to mains power)

| | |
|-------------------------------|---|
| Applicable standards | There is no reference to standards for this test. |
| Test method | Variation in supply voltage |
| Object of the test | To verify compliance with the provisions in 5.7.1.1 under conditions of low battery voltage |
| Test procedure | <p>The test consists of exposure to the specified condition of the battery(s) for a period sufficient for achieving temperature stability and for performing the required measurements.</p> <p>If an alternative power source (standard power supply with sufficient current capacity) is used in bench testing to simulate the battery, it is important that the internal impedance of the specified type of battery also be simulated.</p> <p>The maximum internal impedance of the battery is to be specified by the manufacturer of the instrument.</p> <p>Test sequence: Stabilize the power supply at a voltage within the defined limits and apply the measurement and/or loading condition. Record the following data:</p> <ul style="list-style-type: none"> a) date and time b) temperature c) power supply voltage d) functional mode e) measurements and/or loading condition f) indications (as applicable) g) errors h) functional performance <p>Reduce the power voltage to the EUT until the equipment clearly ceases to function properly according to the specifications and metrological requirements, and note the following data:</p> <ul style="list-style-type: none"> i) power supply voltage j) indications k) errors l) other relevant responses of the instrument |
| Test severities | Severity level 1: Lower limit of the voltage is the lowest voltage at which the EUT functions properly according to the specifications. |
| Number of cycles | At least one test cycle for each functional mode |
| Maximum allowable variations: | All functions shall operate as designed and all the errors measured during the application of the influence factor shall be within the maximum permissible errors. |

3.4.15 Tests for power from road vehicle batteries

3.4.15.1 Voltage variations

Test method: Variation in supply voltage

Object of the test: To verify compliance with the provisions in 5.7.1.1 of R 80-1 under conditions of varying battery voltage.

References: The voltage limits specified in this clause are in accordance with ISO 16750-2 [22] code C, respectively code F.

Test procedure in brief: The test consists of exposure to the specified supply voltage for a period sufficient for achieving temperature stability and for performing the required measurements.

If a standard power supply unit (with sufficient current capacity) is used in bench testing to simulate the battery, it is important that the low internal impedance of the battery also be simulated.

The continuous supply source shall have an internal resistance R_i less than 0.01 Ω dc and an internal impedance $Z_i = R_i$ for frequencies less than 400 Hz.

During tests, the EUT shall be in operation, simulated inputs are permitted.

Test severities:

| | | | |
|---------|--------------------------|-------------|------|
| Voltage | 12 V battery (Code C) | lower limit | 9 V |
| | | upper limit | 16 V |
| | 24 V battery (Code F) | lower limit | 16 V |
| | | upper limit | 32 V |

Maximum allowable variations: At supply voltage levels between upper and lower limit, all functions shall operate as designed and all errors shall be within the maximum permissible errors.

3.4.15.2 Electrical transient conduction along supply lines

Test method: Electrical transient conduction along supply lines

Object of the test: To verify compliance with the provisions in 4.7.1.2 of R 80-1 under the following conditions:

- transients due to a sudden interruption of currents in a device connected in parallel with the device under test due to the inductance of the wiring harness (pulse 2a);
- transients from DC motors acting as generators after the ignition is switched off (pulse 2b)¹⁾;
- transients on the supply lines, which occur as a result of the switching processes (pulses 3a and 3b);
- voltage reductions caused by energizing the starter-motor circuits of internal combustion engines (pulse 4)

References:

ISO 7637-2 [23]

§ 5.6.2: Test pulse 2a + 2b ⁽¹⁾

§ 5.6.3: Test pulse 3a + 3b

§ 5.6.4: Test pulse 4

Test procedure in brief:

The test consists of exposure to disturbances on the power supply by direct coupling on supply lines.

During tests, the EUT shall be in operation, simulated inputs are permitted.

Test severities:

Severity level IV:

| Test pulse | Pulse voltage U_s | |
|-------------------|-------------------------|-------------------------|
| | $U_{nom} = 12\text{ V}$ | $U_{nom} = 24\text{ V}$ |
| 2a | + 50 V | + 50 V |
| 2b ⁽¹⁾ | + 10 V | + 20 V |
| 3a | - 150 V | - 200 V |
| 3b | + 100 V | + 200 V |
| 4 | - 7 V | - 16 V |

¹⁾ Test pulse 2b is only applicable if the measuring instrument may be connected to battery via the main (ignition) switch of the car, i.e. if the manufacturer of the measuring instrument has not specified that the instrument is to be connected directly (or by its own main switch) to the battery.

Maximum allowable variations:

During the disturbances 2a, 3a, 3b, and 4 and after the disturbance 2b, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it in accordance with 5.7.3 of R 80-1 when significant faults occur

3.4.15.3 Electrical transient conduction via lines other than supply lines

Test method:

Electrical transient conduction along lines other than supply lines

Object of the test:

To verify compliance with the provisions in 5.7.1.2 of R 80-1 under conditions of transients which occur on other lines than supply lines as a result of the switching processes (pulses a and b)

References: ISO 7637-3 [24]

Test procedure in brief:

The test consists of exposure to bursts of voltage spikes by capacitive and inductive coupling via lines other than supply lines.

During tests, the EUT shall be in operation, simulated inputs are permitted.

Test severities:

Severity level IV:

| | | | | |
|--------------|---------|-------|------|---|
| 12 V Battery | Pulse a | U_s | - 60 | V |
| | Pulse b | U_s | + 40 | V |
| 24 V Battery | Pulse a | U_s | - 80 | V |
| | Pulse b | U_s | + 80 | V |

Maximum allowable variations: During the disturbance, either significant faults do not occur or checking facilities detect a malfunctioning and act upon it in accordance with 5.7.3 of R 80-1 when significant faults occur.

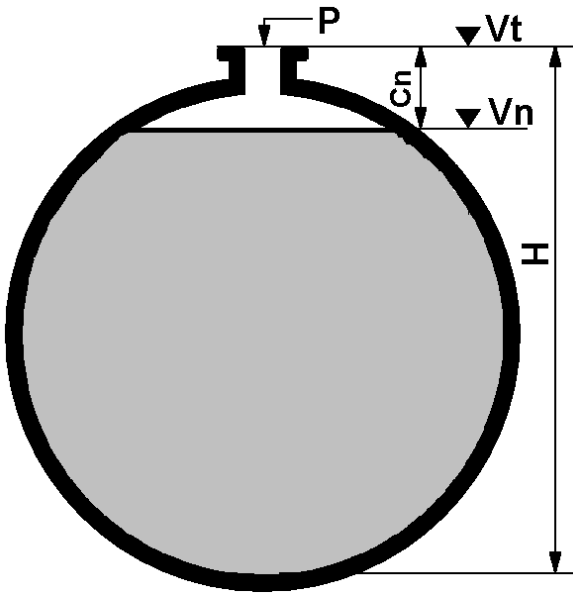
4 Bibliography

- [1] Guide to the expression of uncertainty in measurement. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML. International Organization for Standardization, Geneva, 1995
- [2] OIML International Document D 11. General Requirements for electronic measuring instruments. OIML, Paris, 2004
- [3] IEC 60068-2-2 (1974-01). Amendments IEC 60068-2-2-am1 (1993-02) and IEC 60068-2-2-am2 (1994-05). Environmental testing. Part 2. Tests. Test B. Dry heat. Section 4 - Test Bd: Dry heat for heat-dissipating specimen with gradual change of temperature. International Electrotechnical Commission, Geneva.
- [4] IEC 60068-3-1 (1974-01). First Supplement: IEC 60068-3-1A (1978-01). Basic environmental testing procedures. Part 3: Background information. Section one - Cold and dry heat tests. International Electrotechnical Commission, Geneva
- [5] IEC 60068-1 (1988-06). Amendment IEC 60068-1-am1 (1992-04). Environmental testing. Part 1: General and guidance. International Electrotechnical Commission, Geneva
- [6] IEC 60068-2-1 (1990-05). Amendments IEC 60068-2-1-am1 (1993-02) and IEC 60068-2-1-am2 (1994-06). Environmental testing. Part 2.1 Tests. Test A. Cold. Section three - Test Ad: Cold for heat-dissipating specimen with gradual change of temperature. International Electrotechnical Commission, Geneva
- [7] IEC 60068-2-30 (1980-01). Amendment IEC 60068-2-30-am1 (1985-08). Basic environmental testing procedures. Part 2: Tests. Test Db and guidance: Damp heat, cyclic (12 + 12-hour cycle). International Electrotechnical Commission, Geneva
- [8] IEC 60068-3-4 (2001-08). Environmental Testing. Part 3-4: Supporting documentation and guidance – Damp heat tests. International Electrotechnical Commission, Geneva
- [9] IEC 60068-2-47 (1999-10). Environmental testing. Part 2-47: Test methods. Mounting of components, equipment and other articles for vibration, impact and similar dynamic tests. International Electrotechnical Commission, Geneva
- [10] IEC 60068-2-64 (1993-05). Environmental testing. Part 2: Test methods. Test Fh: Vibration, broad-band random (digital control) and guidance. International Electrotechnical Commission, Geneva

- [11] IEC 61000-4-3 (1998-11). Amendment IEC 61000-4-3-am2 (2000-11). Electromagnetic Compatibility (EMC). Part 4-3: Testing and measurement techniques. Radiated, radio-frequency, electromagnetic field immunity tests. International Electrotechnical Commission, Geneva
- [12] IEC 61000-4-6 (2003-05) Electromagnetic compatibility (EMC) Part 4: Testing and measurement techniques, Section 6: Immunity to conducted disturbances, induced by radio frequency fields. International Electrotechnical Commission, Geneva
- [13] IEC 61000-4-1 (2000-04). Electromagnetic compatibility (EMC). Part 4-1: Testing and measurement techniques. Overview of IEC 61000-4 series. International Electrotechnical Commission, Geneva
- [14] IEC 61000-4-2 (1995-01) with amendment 1 (1998-01) Electromagnetic compatibility (EMC) Part 4: Testing and measurement techniques, Section 2: Electrostatic discharge immunity test. Consolidated Edition: IEC 61000-4-2 (2001-04) Ed. 1.2. International Electrotechnical Commission, Geneva
- [15] IEC 61000-4-8 (1993-06) with amendment 1 (2000-11) Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test. Consolidated Edition: IEC 61000-4-8 (2001-03) Ed. 1.1. International Electrotechnical Commission, Geneva
- [16] IEC 61000-4-4 (2004-07) Electromagnetic compatibility (EMC) – Part 4-4: Testing and Measurement techniques – Electrical fast transient/burst immunity test. International Electrotechnical Commission, Geneva
- [17] IEC/TR 61000-2-1 (1990-05) Electromagnetic compatibility (EMC) - Part 2: Environment Section 1: Description of the environment - Electromagnetic environment for low frequency conducted disturbances and signalling in public power supply systems
- [18] IEC 61000-4-5 (2001-04) consolidated edition 1.1 (Including Amendment 1 and Correction 1) Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques - Surge immunity test
- [19] IEC 61000-4-11 (2004-03) Electromagnetic compatibility (EMC) - Part 4-11: Testing and measuring techniques - Voltage dips, short interruptions and voltage variations immunity tests
- [20] IEC 61000-6-1 (1997-07) Electromagnetic compatibility (EMC) - Part 6: Generic standards - Section 1: Immunity for residential, commercial and light-industrial environments
- [21] IEC 61000-6-2 (1999-01) Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
- [22] ISO 16750-2: 2003 Road vehicles – Environmental conditions and testing for electrical and electronic equipment; Part 2: Electrical loads. International Electrotechnical Commission, Geneva
- [23] ISO 7637-2: 2004, Road vehicles - Electrical disturbances from conducting and coupling, Part 2: Electrical transient conducting along supply lines only. International Electrotechnical Commission, Geneva

[24] ISO 7637-3 (1995) with correction 1 (1995), § 4.5: Test pulses a and b. Road vehicles - Electrical disturbance by conducting and coupling - Part 3: Passenger cars and light commercial vehicles with nominal 12 V supply voltage and commercial vehicles with 24 V supply voltage - Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines. International Electrotechnical Commission, Geneva

**ANNEX 1
 CALIBRATION TABLE**



P : reference point
 H : reference height
 V_t : total contents (to brim)
 V_n : capacity corresponding to normal filling in use
 C_n : ullage corresponding to a normal filling in use
 V : contained volume corresponding to the ullage C

figure 1-1

| Compartment No. | H mm | V_t dm ³ | V_n dm ³ | C_n mm |
|-----------------|---------|--------------------------|--------------------------|-------------|
| 1 | 1953 | 5530 | 5496 | 160 |
| 2 | 1958 | 5625 | 5580 | 170 |
| 3 | 1967 | 5573 | 5532 | 170 |
| 4 | 1963 | 5700 | 5663 | 170 |

| Compartment No. | Ullage (C) , cm | | | | |
|-----------------|---------------------------------------|------|------|------|------|
| | 19.0 | 18.0 | 17.0 | 16.0 | 15.0 |
| | Contained Volume (V), dm ³ | | | | |
| 1 | 5460 | 5473 | 5485 | 5496 | 5504 |
| 2 | 5557 | 5569 | 5580 | 5590 | ~ |
| 3 | 5508 | 5521 | 5532 | 5541 | ~ |
| 4 | 5640 | 5652 | 5663 | 5672 | ~ |

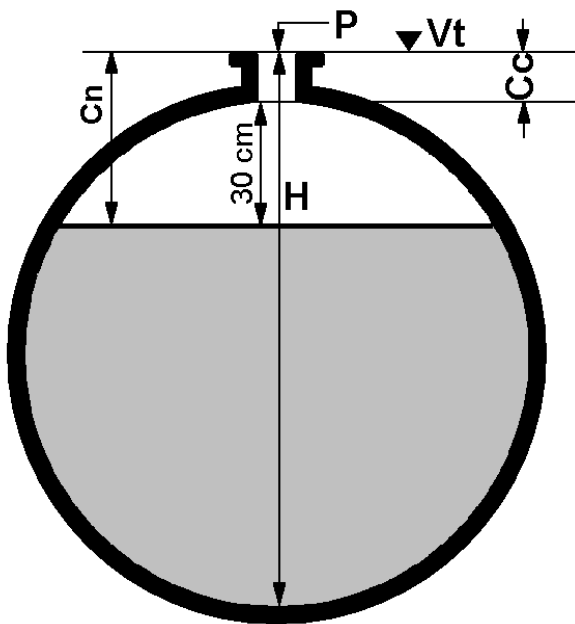
Calibrated at date

by

ANNEX 2

EXAMPLE OF CALIBRATION OF A RAIL TANKER

A standard installation is used with two proving tanks, each of 2 000 dm³, and a volumetric measure with a window and scale graduated from 1 to 550 dm³ (scale interval 1 dm³).



1. During the first stage of calibration the values obtained for the data on the drawing (Fig. 1) are shown on the test sheet given below. The volume of the proving tank of 2000 dm³ was used 23 times to fill to $C_n = 45$ and then a further 20 dm³ by means of the 550 dm³ measure.
2. The second stage of calibration was carried out by means of the 550 dm³ measure, a measuring device, and an electric signal for each centimetre; the results and calculated values are shown on the test sheet given below.

CALIBRATION TEST SHEET

Calibration Station

Rail tanker No.

First stage calibration

Date

$H = 3\,955\text{ mm}$ $C_c = 14.2\text{ cm}$

$C_n = 45\text{ cm}$

$V_n = 23 \times 2000 + 20 = 46\,020\text{ dm}^3$

Temperature of ambient air: + 17 °C

Temperature of water in the rail tanker (final) : + 17.5 °C

Mean temperature of water in the proving tanks : + 18 °C

Second stage calibration

Date:

| Number of use of proving tank | Partial volumes (on scale) | Volume per cm | Volume total | C_i |
|-------------------------------|----------------------------|-----------------|-----------------|-------|
| | dm ³ | dm ³ | dm ³ | cm |
| 1 | | | 46020 | 45 |
| 2 | 195 | 195 | 46215 | 44 |
| | 362 | 167 | 46382 | 43 |
| | 512 | 150 | 46532 | 42 |
| 3 | 147 | 147 | 46679 | 41 |
| | 286 | 139 | 46818 | 40 |
| | 416 | 130 | 46948 | 39 |
| | 549 | 133 | 47081 | 38 |
| 4 | 130 | 130 | 47211 | 37 |
| | 263 | 133 | 47344 | 36 |
| | 388 | 125 | 47468 | 35 |
| | 516 | 128 | 47597 | 34 |
| 5 | 127 | 127 | 47724 | 33 |
| | 237 | 110 | 47834 | 32 |
| | 350 | 113 | 47947 | 31 |
| | 460 | 110 | 48057 | 30 |
| 6 | 106 | 106 | 48163 | 29 |
| | 213 | 107 | 48270 | 28 |
| | 314 | 101 | 48371 | 27 |
| | 418 | 104 | 48475 | 26 |
| | 510 | 92 | 48567 | 25 |
| 7 | 80 | 80 | 48647 | 24 |
| | 154 | 74 | 48721 | 23 |
| | 225 | 71 | 48792 | 22 |
| | 291 | 66 | 48858 | 21 |
| | 357 | 66 | 48924 | 20 |
| | 415 | 58 | 48982 | 19 |
| | 471 | 56 | 49038 | 18 |
| | 509 | 38 | 49076 | 17 |
| | 521 | 12 | 49088 | 16 |
| | 531 | 10 | 49098 | 15 |

Calibrated by:.....

ANNEX 3

EXAMPLES FOR TESTS OF 2.3 THROUGH 2.5

(Informative for Measuring systems for partial delivery and accuracy class 0.5)

A3.1 Preparations for the volumetric test of the individual measuring compartments

Each measuring compartment of the measuring tank shall be separately tested by stepwise discharge.

If possible, tests shall be performed with a product for which the measuring system is intended (preferably fuel oil or diesel oil). Initially, the compartment shall be filled with about 90 % of the permissible loading quantity and connected to a volume standard or reference meter via the gravity outlet of the compartment (if present). The filling quantity should be selected that it is sufficient for all testing steps as well as the initial flushing (if required) so that pumping back of product can be avoided.

Note: The initial flushing ensures that the pipes and hoses are filled completely.

A3.2 Testing of a measuring compartment using a volume standard

The volume standards used should have a volume of less than twice the minimum measured quantity of the smallest compartment to be tested.

The test can be carried out at any flow rate, but sufficiently small (especially for the last discharge steps) so that no air enters into the pipe system by way of swirl formation.

Each filling step consists of a delivery during which the volume standard is filled from the respective measuring compartment. After each delivery, the delivery temperature, the operating volume and the converted volume are read from the indication of the level gauging system and the measured standard volume from the volume standard, and documented. Subsequently, the errors are calculated (see example). The compartment shall be completely emptied during the test. If the residual quantity cannot be measured with the volume standard, gravimetric methods may be used. In this case, the verification of the converted volume may be dispensed with. For the assessment, it may be necessary to add the volumes of several steps so that at least 0,8 times the minimum delivery is obtained. The maximum permissible error shall be applied to these summation values (see example).

Example: Volumetric test

Nominal loading volume of tank compartment: 15 000 litre
 Minimum measured quantity of tank compartment = 1/10 of loading volume: 1 500 litre
 Nominal volume of volume standard used: 1 000 litre
 Maximum permissible error
 Minimum specified volume deviation $E_{\min} = 2 \times 0.3\% \cdot V \leq 2 \times V_{\min}$: ± 9 litre
 Maximum permissible error for $V > 2 \times V_{\min}$: $0.3\% \cdot V$

| No. of measurement | Compartment contents before measurement | Indication of level gauging system | Indication of standard | Error of current measurement | | Error for volume between 1 x and 2 x MMQ (from sum of two individual measurements) | | Error for volume > 2 x MMQ (from sum of three individual measurements) | |
|--------------------|---|------------------------------------|------------------------|------------------------------|---------------|--|---------------|--|------------------------------------|
| | | | | absolute | relative | absolute | relative | absolute | relative |
| | litre | litre | litre | litre | % | litre | % | litre | % |
| 1 | 15 015 | 1 000 | 1 002.4 | - 2.4 | - 0.24 | | | | |
| 2 | 14 015 | 1 001 | 1 000.2 | + 0.8 | + 0.08 | + 0.8 | + 0.08 | | |
| 3 | 13 014 | 1 003 | 1 000.1 | + 2.9 | <u>+ 0.27</u> | + 2.9 | <u>+ 0.27</u> | + 1.3 | + 0.04 |
| 4 | 12 011 | 1 004 | 1 002.5 | + 1.5 | + 0.15 | + 1.5 | + 0.15 | + 5.2 | + 0.17 |
| 5 | 11 007 | 997 | 1 002.5 | - 5.5 | - 0.55 | - 5.5 | - 0.55 | - 1.1 | - 0.03 |
| 6 | 10 010 | 996 | 998.9 | -2.9 | - 0.29 | -2.9 | - 0.29 | - 6.9 | - 0.23 |
| 7 | 9 014 | 999 | 1 000.6 | -1.6 | -0.16 | -1.6 | -0.16 | -10 | -0.33 |
| | | | | | | check: values must be ≤ 9 litres | | | check: values must be $\leq 0,3\%$ |

Note: In the example, the error determined for measurement No. 5 is - 0.55 %, but the 5.5 L are smaller than the minimum specified volume deviation.
 In measurement No. 7, the maximum permissible error for the minimum measured quantity is exceeded. The compartment shall be rejected.

A3.3 Testing of the temperature sensors

The temperature sensors shall be tested during the delivery by determining the mean temperature of the delivered product for a quantity of at least 1 000 litre and comparing it with the mean temperature calculated by the system. As an alternative, the temperature can also be measured and directly compared in a well situated next to the temperature sensor. The deviation must not exceed ± 0.5 °C. Testing of the temperature sensors may be done during the volume tests of the respective measuring compartments.

A3.4 Testing of the compartment using a reference meter

The standard used may be a reference meter suitable for the product used for testing. Prior to the first measurement, the meter shall be tested using a volume standard. During testing, the flow rates used shall comply with the specification of the reference meter.

The test procedure is the same as in A3.2, except that the volume steps may now be equal to the minimum measured quantity of the compartment under test.

A3.5 Test of the pipework volumes for delivery by gravity

The volume of the pipework between the bottom valve of each measuring compartment and the respective transfer point for delivery by gravity (e.g. pneumatic API coupler or pneumatic valve) are stored as calibration parameters of the measuring system in the level gauging system and are tested as follows:

The measuring compartment and the pipework are filled via the loading coupler with at least 200 litre of product. After a waiting time of approx. five minutes, the bottom valve shall be closed and the pipework will be emptied by gravity via the delivery outlet. The quantity may be determined by gravimetry or volumetrically and must agree with the value entered into the measuring system to within ± 1 litre.

A3.6 Test of delivery via collector

The compartment with the smallest MMQ of the measuring container shall be selected for this test. Each available delivery path (full and/or empty hose(s)) are to be tested separately in two steps, each time delivering a test volume of 1 000 litre or the smallest delivery quantity of the selected compartment, whichever is smaller. For an initial flushing, the compartment is filled with at least 200 litre and subsequently emptied through the collector and the selected delivery path. The quantities used and indicated during flushing are irrelevant.

A3.6.1 Measuring systems with gas separator or level sensor for the cut-off point

After flushing, the compartment is filled with twice the test volume.

In a first step, the test volume is discharged through the originally empty collector line and the same delivery path as during initial flushing, using a volume standard or reference meter. In the second step, the remaining product is delivered through the same delivery path until the system stops. The maximum permissible error for this deviation is ± 0.5 % of the minimum measuring quantity of the compartment used for the test.

A3.6.2 Measuring systems with level sensor for the pipework system

After flushing, the test volume plus approximately half the volume of the collector pipework is filled into the compartment. The test volume (NOT including the added volume for the pipework) shall then be delivered into/through the volume standard or reference meter.

In the second step, the test volume minus the pipework volume which had been added before, is filled into the compartment, and subsequently delivered into/through the standard/reference meter, until the system shuts off.

The maximum permissible error for these deviations is ± 0.5 % of the minimum measuring quantity of the compartment used for the tests.

A3.7 Test of the inclination correction

This test shall be performed for each measuring compartment, once with a filling volume of approx. 15 to 30 % and once with approx. 70 to 90 % of its nominal volume. It is recommended to simultaneously test all compartments in two runs, with an arbitrary combination and

sequence of filling states. The centre of gravity of the partially loaded truck should be carefully checked for each loading state.

The first measurement for each filling state shall be performed in normal position, i.e. within $\pm 0,2^\circ$ in the longitudinal and in the transverse direction: After a settling time of approx. five minutes, the filling volumes of all compartments shall be read. They are the reference values for the subsequent tests in inclined positions.

Then the tank is successively brought into the following positions:

- in the longitudinal direction, inclined by $+ 2^\circ$ to $+ 3^\circ$ ("front up")
- in the longitudinal direction, inclined by $- 2^\circ$ to $- 3^\circ$ ("rear up")
- in the transverse direction, inclined by $+ 2.5^\circ$ to $+ 5^\circ$ ("right up")
- in the transverse direction, inclined by $- 2.5^\circ$ to $- 5^\circ$ ("left up"),

whereby the inclination must not be greater than $\pm 0.5^\circ$ in the direction not considered.

After a settling time of approx. five minutes, the filling volumes of all compartments shall be read.

For each of the filling states, and for each of the measuring compartments, the volume indication in each of the four inclined positions shall be equal to the reference values determined in normal position within $\pm 0.3 \%$ of the minimum measuring quantity of the respective compartment (see example below).

Example: Inclined position test

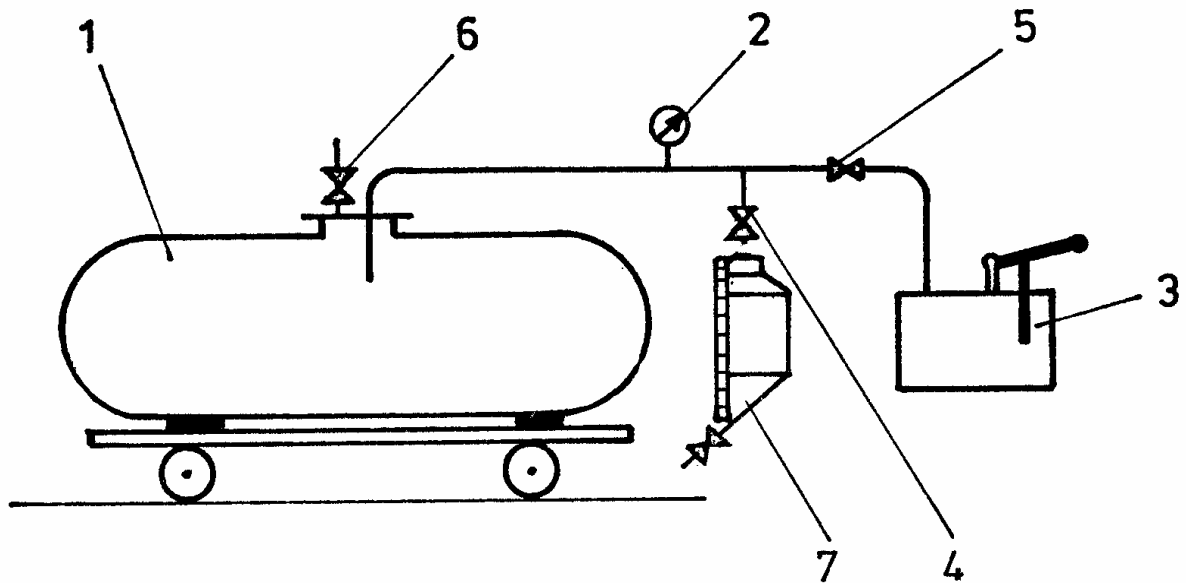
Tanker with three compartments

- compartment volume 10 000 litre each
- minimum measuring quantity (1/5 of the permissible compartment volume): 2 000 litre per compartment
- maximum permissible errors for inclined position test ($\pm 0.3 \%$ of minimum measuring quantity): ± 6 litre

Procedure:

- (1) filling of compartments 1 and 3 with 2 000 litre of fuel oil each and compartment 2 with 8 000 litre of fuel oil
- (2) horizontal alignment of tank and recording of reference measurement values
- (3) inclination of tank front upwards, recording of measurement values
- (4) inclination of tank rear upwards, recording of measurement values
- (5) inclination of tank right upwards and recording of measurement values
- (6) inclination of tank left upwards and recording of measurement values
- (7) evaluation of the recorded measurement results
- (8) filling up of compartments 1 and 3 with 8 000 litre of fuel oil each and emptying of compartment 2 to 2 000 litre of fuel oil
- (9) horizontal realignment of tank and recording of reference measurement values
- (10) repetition of measurement at inclinations "front upwards", "rear upwards", "right upwards" and "left upwards" and recording of the measurement results
- (11) evaluation of the recorded measurement results.

A3.8 Influence of internal pressure



- (1) tank under test
- (2) pressure gauge
- (3) hydraulic pump
- (4) ball valve
- (5) separation valve
- (6) vent
- (7) standard capacity measure

While ensuring, by means of vent 6, that there are no air pockets, the pressure is increased by means of pump 3 up to p_{\max} (indicated on pressure gauge 2). Valve 5 is then closed and, by opening valve 4, water is stepwise withdrawn and its volume is measured using the volumetric measure 7; the volume is indicated on the graduated rule of the measure 7, and the corresponding pressure is read from the pressure gauge 2.

The calculated volume changes ΔV_i are recorded in tabular form:

| Pressure in tank p (bar) | Increase of tank volume ΔV (litres) |
|-------------------------------|--|
| p_1 | ΔV_1 |
| p_2 | ΔV_2 |
| | |
| p_{\max} | ΔV_{\max} |

or presented in the form of a graph dependency $\Delta V = \Delta V(p)$.