INTERNATIONAL STANDARD

ISO 9091-1

First edition
1991-09-15

Refrigerated light-hydrocarbon fluids — Calibration of spherical tanks in ships —

Part 1: Stereo-photogrammetry

Hydrocarbures légers réfrigérés — Jaugeage des réservoirs sphériques à bord des navires —

Partie 1: Stéréo-photogrammétrie

Reference number
ISO 9091-1:1991(E)

Contents

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland
Printed in Switzerland

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9091-1 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*, Sub-Committee SC 5, *Measurement of light hydrocarbon fluids*.

ISO 9091 consists of the following parts, under the general title *Refrigerated light-hydrocarbon fluids — Calibration of spherical tanks in ships*:

— *Part 1: Stereo-photogrammetry*

— *Part 2: Triangulation measurement*

Annexes A, B, C, D, E and F of this part of ISO 9091 are for information only.

Introduction

Large quantities of light hydrocarbons consisting of compounds having 1 to 4 carbon atoms are stored and transported by sea as refrigerated liquids at pressures close to atmospheric. The liquids can be divided into two main groups: liquefied natural gas (LNG) and liquefied petroleum gas (LPG). Bulk transportation of these liquids requires a special technology in ship design and construction to enable shipborne transportation to be safe and economical.

Measurement of cargo quantities in ships' tanks for custody transfer purposes has to be of a high order of accuracy. The two parts of this International Standard, together with other standards in the series, specify methods of internal measurement of ships' tanks from which tank calibration tables can be derived.

For internal measurement, liquid calibration, physical measurement, optical measurement and stereo-photogrammetry are in general use. Liquid calibration cannot be used for large spherical tanks designed to operate at near atmospheric pressure with refrigerated light hydrocarbons because the hydrostatic pressure exerted by the calibrating liquid may exceed the design pressure when filled higher than a certain level. In view of its accuracy, the last-mentioned should be adopted as the referee method if calibration by another method is in doubt. Stereo-photogrammetry consists mainly of photographing targets on the tank wall and the analytical processing of the photographs in the laboratory.

This part of ISO 9091 specifically describes the method using a universal metric camera for the photographing and an analytical stereoplotter for the analysis.

Refrigerated light-hydrocarbon fluids — Calibration of spherical tanks in ships —

Part 1:
Stereo-photogrammetry

1 Scope

1.1 This part of ISO 9091 describes a stereo-photogrammetric procedure for the internal measurement of spherical tanks in liquefied-gas carriers.

1.2 In addition to the actual process of measurement, this part of ISO 9091 also sets out the calculation procedures for compiling the calibration tables.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 9091. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 9091 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7078:1985, *Building construction — Procedures for setting out, measurement and surveying — Vocabulary and guidance notes.*

ISO 8311:1989, *Refrigerated light hydrocarbon fluids — Calibration of membrane tanks and independent prismatic tanks in ships — Physical measurement.*

3 Definitions

For the purposes of this part of ISO 9091, the following definitions apply.

3.1 absolute orientation: The procedure of final correction of the stereoscopic models formed by inner and relative orientations, in which the scale in the stereoscopic model is converted to the actual length and the inclination of the model is adjusted to the actual condition of the tank.

3.2 calibration: The process of determining the total capacity or partial capacities of a tank corresponding to different levels.

3.3 calibration table (main gauge table): A table, often referred to as a tank table or a tank capacity table, showing the capacities of or volumes in a tank corresponding to various liquid levels measured from the gauge reference point, with the ship on an even keel and upright.

3.4 datum point: The south pole to which the tank table is referred.

3.5 deadwood: Any tank fitting which affects the capacity of a tank. Deadwood is referred to as "positive deadwood" when the capacity of the fitting adds to the effective capacity of the tank, or "negative deadwood" when the volume of the fitting displaces liquid and reduces the effective capacity.

3.6 equator: The largest horizontal circumference of a spherical shell.

3.7 floating mark: A mark seemingly occupying a position in the three-dimensional space formed by stereoscopic fusion of a pair of photographs and used as a reference mark in examining or measuring the stereoscopic model.

3.8 gauge reference point: The point from which the liquid depths are measured.

NOTE 1 In spherical tanks, this point may be either the zero of the level gauge or the south pole of the tank.

3.9 inner orientation: The process of determining, mathematically, the interior perspective of the photographs at the time of exposure in an analytical stereoplotter. The calibrated focal length, the location of the calibrated principal point and the calibrated lens distortion are the principal factors used in the calculation.

3.10 list: Transverse inclination of a ship.

3.11 north pole: The zenith, or highest point, of a spherical tank shell (an imaginary point in most spherical tanks due to the pipe tower or other appurtenances).

3.12 pipe tower: A large-diameter pipe coaxial with the tank's north-south axis, containing pipes for loading and discharging, measuring instrumentation, the ladder, wiring and other in-tank facilities designed to protect them from the effect of sloshing of the tank contents.

3.13 port: The left-hand side of a ship facing forward.

3.14 relative orientation: The process of determining the relative position and attitude of a pair of overlapping photographs by mathematical analysis to create a stereoscopic model.

3.15 south pole: The nadir, or lowest point, of a spherical shell.

3.16 starboard: The right-hand side of a ship facing forward.

3.17 stereoscopic model: Three-dimensional model formed by intersecting homologous rays of a pair of overlapping photographs.

3.18 stereoscopic photograph: A set of photographs of an object taken from two different positions so that they may form a stereoscopic model of the object depicting it as if it were in three-dimensional space.

3.19 targets: Predetermined positions distinctively marked on the inside surface of the tank for the stereo-photogrammetry.

3.20 trim: Longitudinal inclination of a ship.

4 Precautions

This clause outlines the precautions to be taken during measurement in order to ensure that the required calibration precision is obtained.

4.1 Utmost care and attention shall be exercised in taking measurements and during photographing, and any unusual occurrence during the measurement or photographing which might affect the results obtained shall be recorded. The calibration method described in this part of ISO 9091 may be applied to ships whether afloat or in a dry dock. However, its use in a dry dock may be preferable, because trim or list, if any, will remain the same throughout the measurement. Keep trim and list of the ship unchanged while an optical level or any other levelling device is being used.

4.2 If any unusual distortions are found in the tank shell, additional measurements shall be taken to obtain sufficient data for correct calculation in the calibration table, and the calibrator's notes shall be provided in connection with such extra measurements.

4.3 Measurements shall be taken in duplicate without interruption, and if they do not agree within the following tolerances, measurements shall be continued until two consecutive readings in duplicate agree within the specified tolerance:

Measurement	Tolerance
up to 20 m	± 2 mm
over 20 m	± 3 mm
for offset	± 0,5 mm

4.4 The reference scale shall have a damping device at its bottom and shall not be touched whilst taking photographs.

4.5 The paint used to mark the targets shall be manufactured from materials which are resistant to liquids at cryogenic temperatures.

4.6 When measurements are made with a measuring tape, the tension specified in the tape calibration certificate shall be applied.

4.7 Measurements in the analytical instrument shall be independently taken twice to check whether they agree within 0,01 mm on the scale of a negative or positive film and, if they do not agree, measurements shall be continued until two consecutive readings agree within 0,01 mm.

4.8 The targets shall be photographed when the tank is isothermal, either after dark or after the tank has been insulated.

5 Equipment

5.1 Analytical stereoplotter

A computerized instrument used to measure the coordinates of the targets in the photographs. It shall be capable of determining or distinguishing the position of each target by means of a three-dimensional coordinate system.

5.2 Camera platform

A platform having an area large enough to accommodate the photographer and a tripod for the camera and provided with adequate guard rails. It shall be mounted on a support structure of suitable strength and long enough to enable the camera to be installed at each photographing position. It shall be capable of being located at 360° around the pipe tower at one end, and along the tank wall at the other end.

5.3 End-to-end rule

A rule, graduated in centimetres and millimetres, to be used to measure deadwood, etc. The rule shall bear the identification of a recognized standardizing authority or a certificate of identification.

5.4 Measuring tape

A tape bearing the identification of a recognized standardizing authority or a certificate of identification.

5.5 Metric camera

A camera used for stereo-photogrammetry, calibrated in respect of principal distance, distortion and principal-point location, with clear and distinctive fiducial-mark separation.

5.6 Optical level

An optical level having an erect image, a magnification of × 20 or greater, capable of being focussed to 1,5 m or less and with a spirit level sensitivity of 40 s per 2 mm or better.

5.7 Reference scale

A steel scale with a plumb bob at its bottom and marked at several points to identify specified lengths. This is used to denote the reference length by which all photographic dimensions obtainable in the photogrammetric instrument are scaled to the actual lengths.

5.8 Remote thermometer

A thermometer used to measure the atmospheric temperature in the vicinity of the reference scale with an accuracy of ±0,5 °C in order to correct errors due to expansion or contraction of the scale.

5.9 Steel rule

The rule, to be used to measure clearances, etc., shall be graduated in millimetres. The rule shall bear the identification of a recognized standardizing authority or a certificate of identification.

5.10 Surface thermometer

A thermometer used to measure the temperature of the surface of the tank with an accuracy of ±0,5 °C in order to convert the coordinates of the targets at the temperature at the time of measurement to those at the certified reference temperature.

6 Preparation

6.1 Marking of targets

6.1.1 Each target shall consist of a square measuring 100 mm × 120 mm, painted black and with a distinguishing number, leaving a circle of 20 mm diameter with a cross at its centre. The paint used to mark the targets shall be manufactured from material resistant to hydrocarbon liquids at cryogenic temperatures.

6.1.2 During construction of the tank and prior to the installation of the pipe tower, targets shall be marked on the inside surface of the tank shell at each intersection of longitude and latitude at 20° intervals starting from the equator. The marking error shall be less than 10 mm in both vertical and horizontal directions.

6.2 Setting of reference scale

Suspend a reference scale, with a specified tension and marked at regular intervals, outside the pipe tower.

6.3 Setting of camera platform

See 5.2.

6.4 Fitting of thermometers

Set a thermometer around the pipe tower and a thermometer fixed on the tank wall.

7 Photographing

Take, across the centre of the tank, successive stereo pairs of photographs of the entire interior surface, overlapping each other at least 60 %, when the tank is in an isothermal condition.

8 Additional measurements

8.1 Temperature

Take the temperature around the reference scale with a remote thermometer, and take the temperature of the inside surface of the tank with a surface thermometer during the photographing operation.

8.2 Height of gauge reference point

If the gauge reference point and the datum point differ, measure the height of the gauge reference point from the datum point (south pole) of the tank by means of an optical level or any other levelling device.

8.3 Location of level gauge

For trim and list corrections, measure the horizontal deviations of the level gauge on the tank bottom from the vertical axis connecting the south and north poles.

8.4 Depth of south pole

Measure the depth of the south pole from a nearby target by setting a level on the tank bottom before the ship is launched.

8.5 Vertical diameter

If the tank has a dome with a built-in north pole, measure the distance between the north and south poles with a steel tape.

In the case of a dome that lacks the north pole and has only the grating top floor of the pipe tower, set an optical level by standing a theodolite in the middle of the above-mentioned floor, above the imaginary north pole, and measure with a steel tape the distance H between the above-mentioned optical level and the south pole.

Then measure the height h of the optical level from the bottom edge of the dome along the coaming of the dome and calculate the imaginary height Δh of the north pole from the above-mentioned edge by means of the curvature of the tank, which is obtainable from the design value of the vertical diameter.

The vertical diameter between the north and south poles is given by the formula

$$H - h + \Delta h$$

Other measurement and calculation methods may also be used to obtain the vertical diameter.

8.6 Deadwood

8.6.1 The volume of deadwood such as ladders, submerged pumps and any other structures in the tank shall be calculated from their dimensions, or any other suitable means of assessing their volumes.

8.6.2 The volume of internal piping containing cargo fluid shall be calculated as the difference between the internal and external volumes of the piping, i.e. the volume of the metal.

8.6.3 The volume of the deadwood shall be calculated at the respective heights where pipes and other fittings are present.

9 Processing of photographs

Develop the film used for photographing in the vicinity of the work site in order to ensure that the photographs are satisfactory and, if they are not, to allow repeat photography. The development shall be carried out with extreme care in order to avoid causing local expansion or contraction of the film.

10 Determination of coordinates

Determine the coordinates of the targets on the surface of the walls for each pair of stereoscopic photographs in accordance with the following procedure:

10.1 Set the stereoscopic photographs on the analytical stereoplotter.

10.2 Put the floating marks on the fiducial marks, targets and necessary points and record the coordinates of these points.

10.3 Process the measured coordinates from 10.2 through a series of photogrammetric programmes consisting of inner orientation, relative orientation and absolute orientation, using an on-line computer system to produce three-dimensional coordinates of the observed points. In the last-mentioned orientation, the stereoscopic models are completed.

10.4 The computed coordinates shall finally be scaled by application of an average scale factor, computed from comparison of thermally corrected actual distances with computed distances between the marks on the reference scale.

10.5 The accuracy of the analytical stereoplotter shall be verified by one of the following methods:

— using test data with known solutions;

— plotting known coordinates from a set of prepared photographs;

— cross-correlating with other equipment.

11 Data processing

Calculate each level's radius using the coordinates of the targets on each level and obtain the average radius of the best-fit circle of each level by the least-square method. The average radii obtained as above and their level heights are converted to those at the reference temperature at which calibration tables are certified, calculated from the certified coefficient of linear expansion of the tank material.

12 Calculation procedure

12.1 Calculation of tank volume

Compute the fractional volume of the space encircled by a spherical band between the two adjoining levels comprising the targets marked on the tank surface by using the radii of the respective levels, and obtain the total volume of the spherical tank at the certified reference temperature of the calibration table by adding up the above-mentioned fractional volumes. The fractional volumes for the remainder of the tank, below the lowest targets and above the highest targets, are calculated from the data of the appropriate sub-divided level obtained in 10.3. Then the volumes at one-centimetre intervals, starting from the south pole, the volume of deadwood being deducted, are also obtained by computation to compile a main gauge table.

12.2 Calculation of liquid head

Calculate the volume of the tank in the loaded condition with the contents of the designated density, then compare it with that of the empty condition. Deal with the difference in volume as deadwood.

12.3 Trim correction

Trim corrections shall be given as an addition to or subtraction from the apparent liquid level measured by the tank gauge. Trim corrections are calculated by comparison of the liquid levels given by the same volume of liquid in the tank with the ship upright and on even keel and with the ship in trimmed condition and upright for the condition of trim under consideration.

12.4 List correction

List corrections shall be given as an addition to or subtraction from the apparent liquid level measured by the tank gauge. List corrections are calculated by comparison of the liquid levels given by the same volume of liquid in the tank with the ship on even keel and upright and with the ship listed and on even keel for the list condition under consideration.

12.5 Combined trim and list correction

The trim and list corrections compiled in accordance with 12.3 and 12.4 may be combined in one table.

12.6 Correction for tank shell expansion or contraction

Corrections for the tank shell expansion or contraction due to the temperature in the loaded condition deviating from the reference temperature at which the tank table was certified shall be made by means of the coefficient of expansion of the material of the tank shell.

NOTE 2 The coefficient of expansion is not constant, but varies with temperature.

13 Calibration tables

Calibration tables shall consist of the following report and tables:

13.1 Calibration report

A tank calibration report shall include the following items:

a) name of the calibrator;

b) place of calibration;

c) date of calibration;

d) tank configuration;

e) measurement method applied;

f) reference temperature of the tank table;

g) average temperature of the tank during measurement;

h) total capacity of the tank including dome capacity;

i) description of the deadwood;

j) tank calibration accuracy;

k) method of use of the main gauge table and the correction tables;

l) any other information.

13.2 Main gauge table

The tank volume at the calibration reference temperature is tabulated against the gauge readings at suitable intervals, and for ease of interpolation a second column shall give the differences between the readings. An example of a typical format for the gauge table is given in annex C.

13.3 Trim correction table

The corrections to be applied to gauge readings are tabulated at suitable intervals of gauge reading for various conditions of trim both by head and by stern. An example of a typical format for a trim correction table is given in annex D.

13.4 List correction table

The corrections to be applied to gauge readings are tabulated at suitable intervals of gauge reading for conditions of list at 0,5° intervals. An example of a typical format for a list correction table is given in annex E.

13.5 Correction table for tank shell expansion or contraction

Correction factors to be applied to the indicated volume of the tank contents to compensate for the volume change of the tank shell between the reference temperature and the actual temperature at which the volume of the contents is measured are tabulated at intervals of 0,1 °C for a range of temperatures on either side of the reference temperature. An example of a typical format for a tank shell expansion or contraction correction table is given in annex F.

Correction factor $F_V = 1 - 3\alpha_t(t_1 - t_2)$

where

α_t is the mean coefficient of linear expansion of the metal from which the tank is constructed;

t_1 is the certified reference temperature of the tank table;

t_2 is the arbitrary temperature of the liquid or vapour.

13.6 Correction for float-type level gauges

13.6.1 Correction table for difference in temperature

Gauge-reading correction due to expansion of a tape which is calibrated at certified temperature shall be made by means of the temperature in the vapour phase of the tank.

13.6.2 Correction table for difference in density

A float shall be adjusted with the reference density. For different densities, e.g. those of different LNGs or propane and butane, float immersion shall be corrected.

Annex A
(informative)

Safety precautions

In addition to the general precautions (see ISO 7507-1) required for the ordinary tank calibration, the following should also be observed:

a) suitable footwear with non-slip soles should be worn on slippery tank surfaces;

b) a mercury thermometer should not be used in an aluminium tank.