**Technical Annex LCT Load Cycle Test (LCT)
of the Concept Additional Tests (CAT):**

Test Procedure „Hydraulic Load Cycle Test“

LCT 1 Introduction

The introduced procedure aims at guaranteeing highly reproducible load cycle tests. This is necessary to make results of various test laboratories or notified bodies usable for safety assessments.

Load cycle testing is a valid procedure for determining residual strength of composite pressure receptacles. Comparing interpretation of such results permits a quantification of degradation of design types or at least of a design variant. It is a prerequisite that load cycle tests lead to a quantification of residual strength with reasonable effort. To achieve this, the number of load cycles before leakage has to be reported. Recording the displaced volume of each load cycle (i. e. piston stroke) enables the determination of leakage.

The degradation behaviour of the residual strength of composite pressure receptacles can be derived from average values to a very limited degree. The common practice of assessing properties by single or very few results is much worse. Service related reduction of safety properties is identified best through a combined analysis of average strength and scatter of results. For this reason, the procedure introduced in the following is particularly suitable for the testing and assessment of samples of at least 5 specimens of similar properties (design type, age etc.).The procedure describes a single specimen test, which has to be repeated with each specimen of a sample.

LCT 2 Scope

The procedure described is suitable for all types and sizes of composite pressure receptacles produced in large numbers. In general, this is assumed for design types with a water volume of up to 450 litres.

In some cases, it may not be possible to perform the tests as described in this procedure for pressure receptacles with a volume of less than 450 litres. This depends on the properties of the individual design type and the available test equipment. In such cases deviating tests have to be agreed upon by the competent authority under consideration of the particular problem.

Design types not assessable according to the procedure described because of their limited production numbers shall be examined and monitored with an equivalent procedure in accordance with the competent authority.

Results from tests not meeting the requirements stated in the following, shall not be recognized in the statistical assessment according to CAT Annex SAS.

LCT 3 Data Recording

LCT 3.1 The following data has to be kept on file for identification and description of tested specimens:

a) Design type approval ID and third party, which issued the approval;

b) Manufacturer of pressure receptacle (address) and manufacturer ID;

c) Type of pressure receptacle;

d) Test date and test engineer (organisation and inspector);

e) Working pressure (PW), test pressure (PH); MSP (MAWP) – if applicable

f) Material of fibre and liner;

g) Identification number of each specimen;

h) Date of manufacturing or batch number of each specimen;

i) Details about intentional artificial aging or pre-conditioning of each specimen;

j) Details about previous usage (type of gas, intensity of usage, number of refills etc. as far as available) and service conditions (e. g. country of usage) of each specimen.

LCT 3.2 The following parameters have to be recorded and monitored continuously during each test:

k) Hydraulic pressure-time-trace inside of specimen[A]; at least 100 recordings per pressure cycle;

l) Temperature-time recording on surface of specimen and in test fluid;[B]

m) Piston stroke or volume of pumped pressure media during each pressure cycle, if technically feasible;

Pressure shall be controlled based on the continuous recording as described in LCT 3.2 (k).

LCT 3.3 Following data have to be recorded for description of each test:

n) Number of load cycles until failure, upper set pressure, lower set pressure and load cycle frequency;

o) Humidity in test chamber (only during LCT 5.1);

p) Employed test fluid;

q) Employed pressure transducer, temperature sensors and the equipment in this measurement chain; incl. accuracy class (for the sensor and the whole measurement chain);

r) Type of pressurization including list of employed equipment;

s) Each abnormality before, during and after test regarding specimen, test equipment etc;

t) Mode of failure (leak, burst or interruption without failure) incl. photo documentation.

[A] *Annotation: Pressure sensor has to be metered as close to specimen's pressure connector/valve thread as possible.*

[B] *Annotation: Fluid temperature sensor has to be metered as close to specimen's pressure connector/valve thread as possible.*

LCT 4 Test Procedure – General Requirements

The various types of load cycle tests introduced here, differ mainly regarding temperature and humidity in the test chamber. Common to all cycle test procedures is:

LCT 4.1 The specimen to be tested shall be completely filled with a non-corrosive fluid. It shall be connected to the pressure cycling equipment, purged from air and then exposed to a pulsating hydraulic load until failure as described below.

LCT 4.2 The upper set pressure level [C] to be achieved during each pressure cycle shall not be less than test pressure.
If the pressure receptacle is only to be approved for service with one dedicated gas a reduced set pressure level can be chosen. This shall be at least the maximum service pressure as defined in CAT 2: The pressure resulting from heating a pressure receptacle filled at 15°C to working pressure to the maximum expected settled temperature but not less than 65°C.

LCT 4.3 The lower pressure level to be undercut during each pressure cycle shall be 10% of test pressure, but not more than 20bar.[B]

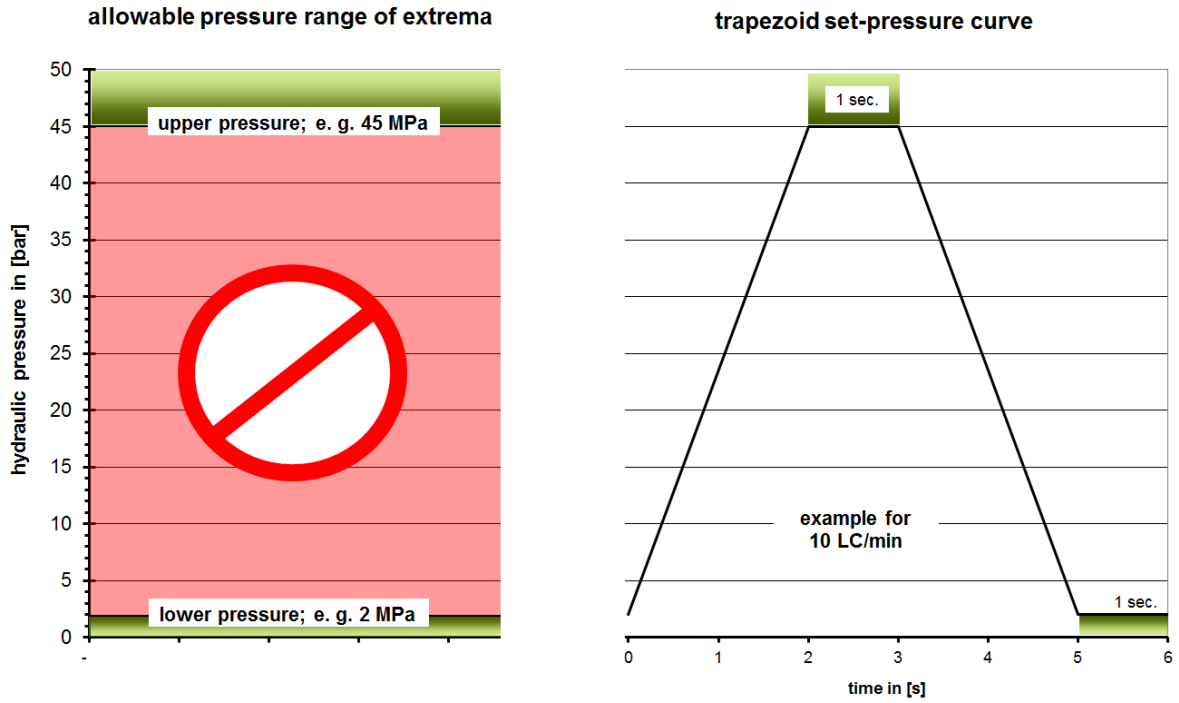

Fig. LCT-1: *Pressure area (extremes) for high reproducibility and a possible set pressure curve (Trapezoid)*

LCT 4.4 During cycling, pressure has to be metered as close to valve threads of tested specimens as possible. The upper and lower set pressure levels have to be exceeded respectively undercut during each pressure cycle regardless of pressure curve shape.
Deviating from this, extreme pressure values between the minimum and maximum set pressures may be accepted if it is proven that there are not more than 5% of the pressure cycles with non sufficient extreme pressures. Sufficient recording (pressure-time-trace, rain-flow-classification etc.) is required for documentation.

[C] *Annotation: The amount and occurrence of undercutting or exceeding the lower and upper pressure levels should be kept small. This improves reproducibility of results.*

LCT 4.5 Load cycle frequency must not be more than 5 cycles per minute. Load cycle frequencies up to 15 cycles per minute are acceptable if it is satisfactorily shown that the demanded pressures are effective inside the receptacle. In cases of receptacles with two connecting threads this can be achieved by measuring pressure opposite to the fluid feed connection. In case of receptacles with only one connecting thread, influences of load cycle frequency may be sensed through surface strain, fluid cycle volume or similar arrangements, assuming temperatures can be kept constant.

LCT 4.6 Tests have to continue until failure of the specimen. If a specimen does not show any signs of failure after 50 000 load cycles and the design type has already been classified as non-load-cycle-fatigue sensitive, tests may be stopped at this load cycle number. If the classification of cycle-fatigue sensitivity is not finalised the test may be interrupted in accordance with CAT 6.

LCT 4.7 Leakage at the connection thread during load cycle or burst testing is not considered as failure, testing shall continue after resealing.

LCT 4.8 After testing, all tested specimens shall be made unserviceable by its owner under supervision of the test engineer if testing did not lead to leakage or burst. Excepted from this are only specimen to be tested in a destructive procedure directly afterwards. In this case the preconditioning shall be taken into consideration to determine if the specimen is going to match the rest of the sample in case of a statistical assessment.

LCT 5 Test Procedures – Specific Requirements

If not demanded differently by procedure regulations or the respective competent authority each test procedure shall be performed with a sample of at least 5 specimens. The specimens of each sample shall have the same age and comparable service history.

Besides the general requirements found in LCT 3 and LCT 4 the following variations are possible.

LCT 5.1 Load Cycle Test at Ambient Temperature until Failure (ACF)

a) The ACF-Test shall be performed at regular ambient (air) temperature and initially settled temperature of specimen and pressure fluid between +15°C and +25°C.

b) During the test the pressure fluid temperature shall not exceed +40°C.

c) Ambient humidity shall be recorded during testing.

LCT 5.2 Load Cycle Test at Elevated Temperature until Failure (HCF)

a) The HCF-Test shall be performed at an initially settled temperature of air, specimen surface and pressure fluid between 65°C and 70°C.

b) Load cycling shall not start earlier than 24hours after ambient temperature in test containment has reached set temperature. Afterwards, the temperature shall not undercut 65°C neither in the pressure fluid nor at the surface of the specimen.

c) For good reproducibility, temperatures during the test should not exceed 70°C at any position of the specimen (surface, boss).

d) During the test the temperature of the pressure fluid should not deviate from the temperature of the specimen by more than 5K (5°C).

If the test is performed with elevated humidity the following has to be recognized:

e) The air inside of the test chamber has to be saturated with humidity to a level of at least 95% rel. hum during the whole test duration. This is deemed to be achieved by continuous fine spraying of water.

LCT 5.3 Load Cycle Test at Low Temperature until Failure (LCF)

a) The LCF-test is performed at an initially settled temperature of air, specimen surface and pressure fluid between -40°C and -45°C.

b) Load cycling shall not start earlier than 24 hours after air in test chamber has reached set temperature. Afterwards, the temperature shall stay below -40°C in the ambient air and at the surface of the specimen.

c) For good reproducibility temperatures during the test should not drop below -45°C at any position of the specimen.

d) The pressure fluid should be suitable to this temperature range (e. g. viscosity) and its temperature should not deviate more than 5K (5°C) from the tested specimen’s surface.

LCT Literature

[1] Mair, G. W.; Scherer, F.:
Statistische Bewertung von Prüfergebnissen zur Restfestigkeitsbetrachtung von Composite-Druckgefäßen
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[2] Mair, G. W.; Hoffmann, M.:
Statistic Evaluation of Sample Test Results to Determine Residual Strength of Composite Gas Cylinders;
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