Technical Annex Slow Burst Test (SBT):
of the Concept Additional Tests (CAT):

Test Procedure „Slow Burst Test“

SBT 1 Introduction

This document describes a standardised procedure for burst tests to ensure high process reproducibility. The main purpose is to ensure the comparability of burst test results from different test facilities or different test organizations for safety assessments.

The described procedure is based on a statistical evaluation of slow burst tests (SBT). The SBT is characterized by a very low pressurization rate compared to standard burst tests. This kind of test is used to provoke load-rate-dependent behaviour in pressure receptacles at a distinguishable level. This behaviour is used to accelerate relaxation and degradation effects in order to enhance the impact of damage in the composite structure on the burst strength of pressure receptacles. Therefore this procedure enables an assessment of the degradation of non-cycle- fatigue sensitive design types by residual burst strength testing. For this reason it replaces cycle testing until failure in cases where a lack of cycle sensitivity is proven and renders cycle testing infeasible to assess degradation effects in pressure receptacles.

SBT 2 Scope

The procedure 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.

Design types which are not assessable by this procedure because of their limited production numbers shall be examined and monitored with an equivalent procedure in accordance with the competent authority.

Results of tests not performed in full compliance with the procedure described in the following shall not be used for statistical assessment according to CAT Annex SAS!

SBT 3 Data Recording

SBT 3.1 The following data shall 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 re-fills etc. as far as available) and service conditions (e. g. country of usage) of each specimen.

SBT 3.2 Parameters to be under surveillance and recorded during testing:

k) Hydraulic pressure inside the specimen[A]; measured and recorded at least once per second;

Pressure control has be to be performed as described in (j) under continuous recording.

SBT 3.3 Data to be recorded for description of each test

l) Temperature of test environment or on specimen surface at beginning and end of each test;

m) Relative air humidity in test environment (chamber) at least at beginning of test;

n) Test fluid employed;

o) Applied pressure sensor (gauge) incl. accuracy class and further measurement equipment;

p) Information about pressure generation (type of pressure generator, pressurization rate e.g., steps, settings etc. if available);

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

r) Peak pressure, time to failure and mode of failure (burst or leak).

Note: *First failures with a consequence of a sudden pressure decrease of more than 5% of test pressure shall be discussed and validated individually. If the integrity of the specimens seems to be harmed critically the relevant pressure level shall be interpreted as burst pressure.*

[A] *Note: Pressure must be measured as close to specimen as possible*

SBT 4 Procedure of Burst Test

Slow Burst Test (SBT: pressure rate ṗ ≤ 20% PH/h)

All Tests have to be performed on a sample size of at least 5 specimens per design type of equivalent age and service history unless otherwise noted by the competent authority or stated in the procedure of SBT.

The procedure shall be applied identically to all specimens of a sample as described. During each test the following conditions have to be guaranteed:

SBT 4.1 Virgin specimens shall not be exposed to a pressure higher than 20% of test pressure after autofrettage or initial (proof) test otherwise the specimens shall not deemed as virgin.

SBT 4.2 Temperature of test fluid, surface of specimen and environment of specimen stays between 18 and 28°C;

SBT 4.3 Rel. air humidity in test chamber is between 40% and 60% rel. H;

SBT 4.4 Each specimen is completely filled and bled from air[B];

Note: *For safety reasons, a tightness test of the test arrangement performed in an opened test chamber shall be done carefully. The pressure level shall stay beyond a level, which is confirmed as being safe with respect to reduced strength by degradation during service or artificial aging.*

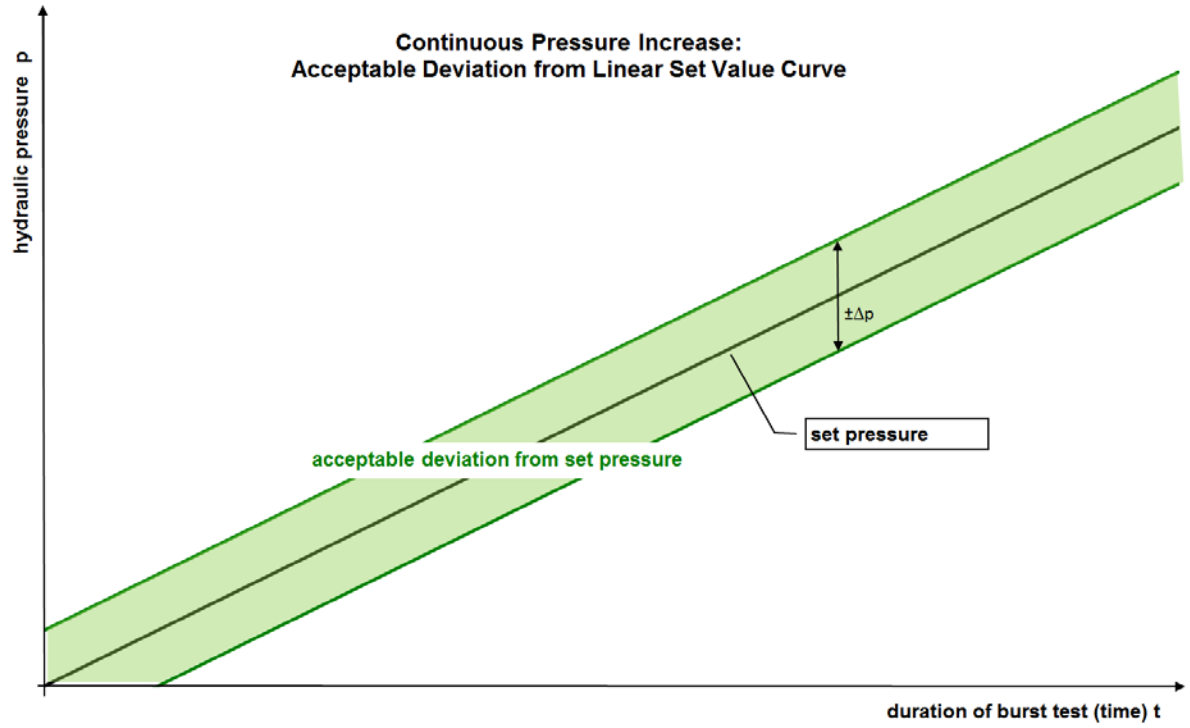

Fig SBT-1: *Range of pressure tolerance related to ideal set pressure curve*

[B] *Remark: Compatibility of test fluid with liner material has to be considered; temperature of fluid has to be similar to ambient and specimen temperature to prevent pressure change through warming.*

SBT 4.5 All specimens shall be loaded with a continuous pressure rate $\dot{p} = \Delta p/\Delta t \leq 20\%$ of PH per hour until failure (see also [1]). The starting point for continuous slow loading with $\dot{p}$ should be 0 MPa. [C]

SBT 4.6 Alternatively the starting point for slow pressure increase with a pressure rate $\dot{p} = \Delta p/\Delta t \leq 2$ % can be shifted up to PH. [C]

SBT 4.7 Pressure fluctuations are acceptable during an initial stabilization period of the pressure control system with a maximum pressure not higher than 20% of test pressure PH. After that, up to pressure of first failure, deviations from the target pressure rate shall be less than

$$\Delta p \leq 1.0\,\%\,PH \quad , \qquad \text{(Eq. 1)}$$

see green area in **Fig. SBT-1**; this condition guarantees reproducibility and comparability of test results. Examples for acceptable deviation are shown in **Table SBT-A**.

Table SBT-A: *Acceptable deviation from ideal set pressure*

PW	PH	Δp = 1% PH
200 bar	300 bar	3.0 bar
300 bar	450 bar	4.5 bar
700 bar	1050 bar	10.5 bar

SBT 4.8 Leakage at the connection thread during burst testing is not considered as failure. The test may be continued after resealing in case of interrupting the test below 20% of test pressure for virgin specimens or below 66% test pressure for used specimens. In case of a prohibited continuation of a burst testing an additional specimen with the specification in accordance with relevant requirements concerning age and service history has to be tested.

SBT 4.9 If a continuous pressure increase according to SBT4.6 and SBT 4.7 is infeasible, pressure can also be increased in steps according to the following guidelines.

SBT 5 Explanation for stepwise pressure increase

Each pressure step consists of two stages. The pressure increase stage Δp_s and the constant pressure stage with holding time of each step Δt_h. The second stage is necessary to stay close to the ideal set pressure according to Eq. 1, see also **Figure SBT-2**. All pressure increase steps have to be identical as far as technically possible. [D]

[C] *Remark: For the reason of comparability the set pressure curve has to be set identically for all specimens and all tests of a design type during its whole life cycle. It is selected and determined during type approval. This setting is mandatory for all tests independent from the individual notified body.*

[D] *Remark: Particularly for test equipment with only one driver piston performance is often limited by the tuning of maximum volume flow. This limits maximum pressure increase per step versus constant pressure stage (holding time), which is employed for retracting the driver piston.*

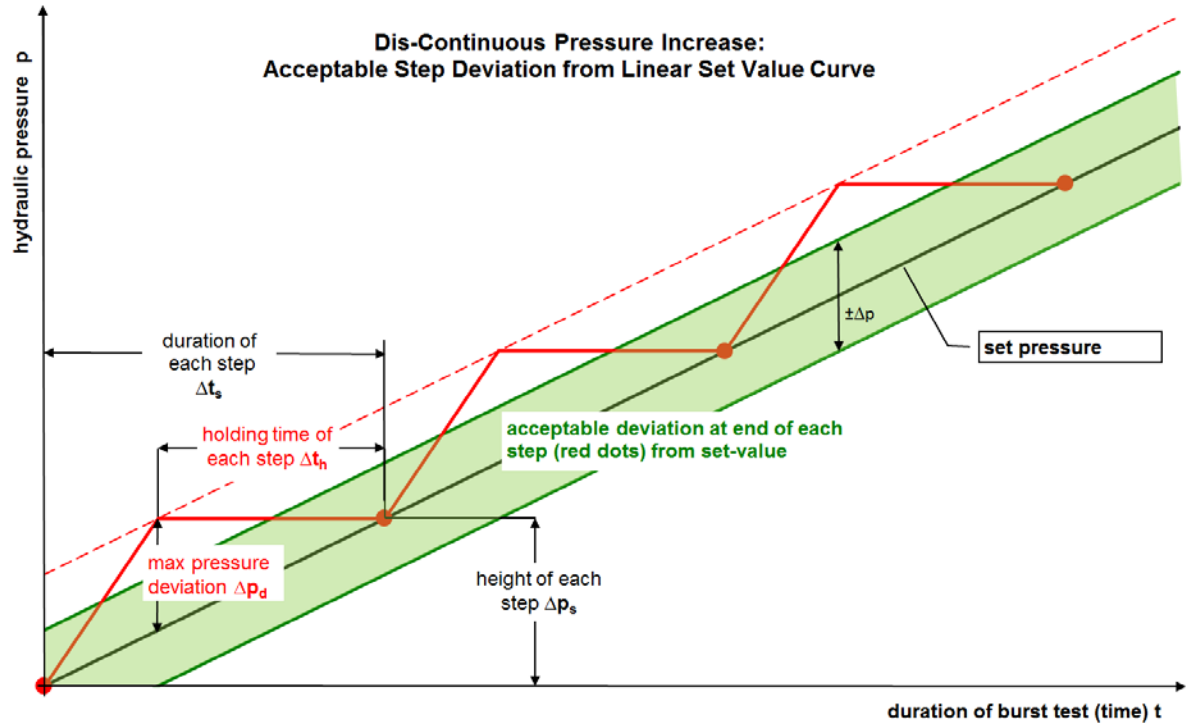

Fig SBT-2: *Range of pressure tolerance vs. ideal set pressure including details on stepwise pressure increase*

The acceptable pressure deviation at the end of each step according to SBT 4.7 has to be checked for each pressure step (red dots (Δt_s; Δp_s) in Fig SBT-2) in case of the stepwise procedure.

The amplitude of each step Δp_s and number of steps is not restricted. In reality, this number results from the measured pressure increase and the developing deviation from the target pressure rate curve. Assuming at least 100 steps to burst pressure, the maximum deviation Δp_d of the measured pressure at the end of the pressure increase phase of each step shall not be larger than:

$$\Delta p_d \leq 2.0\,\%\,PH \qquad \text{(Eq. 2)}$$

The pressure holding time t_h of each step can be derived from the target pressure increase rate and the maximum permitted deviation Δp_d:

$$t_h = \frac{\Delta p_d}{\dot{p}} \qquad t_{h\max}(\dot{p} = 20\%PH/h) = \frac{2\%PH}{20\%PH/h} = 6\,\text{min} \qquad \text{(Eq. 3)}$$

Table SBT-B shows examples of typical test pressures with their recommended and their maximum allowable pressure steps at a pressure increase rate of 20% PH/h. This equals 5 hours test time until PH and allows a maximum holding time of 360s per pressure step.

Errors of measurement and calibration have to be considered for the examination of the measured pressure curve.[E]

[E] *Remark: An accuracy class of 0.2 is sufficient if the measurement range of pressure transducer is smaller than twice the burst pressure. In other cases accuracy class 0.1 is required.*

Table SBT-B: *values of pressure increase in increase phase of each step*

recommended values for $\dot{p} = \Delta p/\Delta t$ = 20% PH/h						
PW	PH	$\dot{p}$ = 20% PH/h	t_h	Δp_s	Δt_s	Δp_d = 0,5% PH
200 bar	300 bar	1 bar/min	90 s	2.25 bar	2 ¼ min	1.50 bar
300 bar	450 bar	1.5 bar/min		3.38 bar		2.25 bar
700 bar	1050 bar	3.5 bar/min		7.88 bar		5.25 bar
maximum values for $\dot{p} = \Delta p/\Delta t$ = 20% PH/h						
PW	PH	$\dot{p}$ = 20% PH/h	t_h	Δp_s	Δt_s	$\Delta p_{d\,max}$ = 2% PH
200 bar	300 bar	1 bar/min	360 s	9 bar	9 min	6 bar
300 bar	450 bar	1.5 bar/min		13.5 bar		9 bar
700 bar	1050 bar	3.5 bar/min		21 bar		14 bar

SBT Background Literature

[1] Mair, G. W.; Hoffmann, M.; Schönfelder, T.:
The Slow Burst Test as a Method for Probabilistic Quantification of Cylinder Degradation
proceedings of the „International Conference on Hydrogen Safety ICHS 2013",
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[2] Mair, G. W., Hoffmann, M., Scherer, F., Schoppa, A., Szczepaniak, M.:
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[3] Mair, G. W.; Hoffmann, M.:
Statistic Evaluation of Sample Test Results to Determine Residual Strength of Composite Gas Cylinders;
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