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Thermal Acceptance Tests of Steam Turbines

DIN 1943

Wärmetechnische Abnahmeversuche an Dampfturbinen (VDI-Dampfturbinenregeln)

This Standard has been prepared by the Ausschuss Dampfturbinenregeln der VDI-Gesellschaft Energietechnik.

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N o t e : In some instances direct translations have, for better understanding, been somewhat interpreted. In these cases, such explanations or interpretations are given in brackets ( ) behind the word(s) in question.

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1 General definitions

1.1 Scope

This Standard is intended to apply to thermodynamic acceptance tests on steam turbines of every type of design, size and use. The types of steam turbines are defined in DIN 4304 (reference 4).

1.2 Object

This Standard defines uniform rules for the preparation for and conduct of acceptance tests and evaluation of the results. Details of the conditions under which acceptance tests shall take place are also included.

The Standard makes possible clear unambiguous agreements between the customer and supplier and shall therefore be recognized as binding by the parties to the contract. Deviations and additions shall be mutually agreed.

1.3 Purpose of the acceptance tests

The purpose of the acceptance test is to measure the thermodynamic performance of the turbine and compare it with the performance guaranteed by the supplier. In order to facilitate such a comparison, the guarantee should be complete and precise and be expressed so as to avoid any misunderstanding. The acceptance tests may also include such measurements as are necessary to establish the performance of the whole installation (including the feed heating system but excluding the steam generator), and to ensure correct results and correct correction to guarantee conditions (see also comparative measurements, Section 4.2.2.1)).

2 Symbols and units

2.1 Latin letters

Symbol	Description	SI units and permissible alternative units
a	Sonic velocity	m/s
b	Range of scatter due to all unknown correction influences	–
b^*	Allowance for output correction for back pressure turbines	–
b^{**}	Allowance for output correction for extraction back pressure turbines	–
b_1	Thermodynamic properties	–
c	Absolute velocity	m/s
c_2	Absolute exhaust velocity	m/s
c_n	Coefficients	–
D_m	Mean diameter of last rotor blade row	m, mm
d	Specific steam consumption	kg/Ws kg/kWs kg/kWh
f_x	Wetness loss factor also called *"Baumann"* correction	–
G	Known limit of error (class of accuracy)	–
h	Specific enthalpy	J/kg, kJ/kg
$\Delta h_{V,a}$	Changed exhaust loss due to change in cooling water inlet temperature at correction conditions for checking correction curves	kJ/kg
$\Delta h_{s,a}$	Changed isentropic enthalpy drop due to particular influence at correction conditions for checking correction curves	kJ/kg
I	Content	
k	Correction factor	–
$k_{b\,max}$	Upper deviation limit for a particular influence	–
$k_{b\,min}$	Lower deviation limit for a particular influence	–
$\dot{m}$	Mass flow	kg/s, t/h
n	Speed	s^{-1}, min^{-1}
P	Output	W, kW, MW
P_a	Changed output due to particular influence considering the isentropic expansion and known efficiency influence for checking correction curves	W, kW, MW
P	Pressure (absolute)	N/m^2, bar
$\dot{Q}$	Heat flow	J/s = W kW, MW
s	Specific entropy	J/kgK kJ/kgK
T	Temperature (Kelvin)	K
t	Temperature (Centigrade)	°C
t_S	Saturation temperature for pressure at condenser inlet (per saturation line)	°C
t_{W1}	Cooling water inlet temperature	°C
t_{W2}	Cooling water outlet temperature	°C
$\Delta t = t_S - t_{W2}$	Condenser terminal temperature difference	K
t_{Sp}	Final feed water temperature	°C
t_K	Condensate temperature at condenser outlet	°C
u	Peripheral speed	m/s
V	Measuring uncertainty	–
V_x	Confidence limit of the error of a particular measurement	–
v	Specific volume	m^3/kg
w	Specific heat consumption	J/Ws kWh/kWh
w_2	Relative exhaust velocity	m/s
w_a	Changed specific heat rate due to a particular influence considering isentropic expansion and known efficiency influence for checking correction curves	J/Ws kWh/kWh
x	Dryness fraction	kg/kg
x_j	Measured variable	–
z	Time	s, h

2.2 Greek letters

Symbol	Description
β_2	Relative exit angle
Δ,δ	Difference
η	Efficiency
ζ	Ratio of theoretical output of exhaust flow to theoretical output of total flow
σ_z	Standard deviation of complete sample
τ	Relative measuring uncertainty

2.3 Subscripts[1)]

Subscript	Meaning
A	Bleeding
a	Consideration of the change in the isentropic heat drop and the known efficiency influence for checking correction curves
ae	Exterior
Abd	Exhaust steam
ax	Axial components
B	Correction of mass flow balance
D	Leakage flow
E	Extraction
EW	Injection water
FD	Inlet steam
G	Back-pressure
ges	Total
HD	High pressure
i	Interior
j, l, n, m	sequential numbering of several values
Kl	Generator terminals
K	Condenser, condensate
kor	corrected
kZÜ	At steam turbine outlet flange before the reheater
M	Measured value
MD	Intermediate pressure
S	Saturation
s	Isentropic
Sp	Feed water
T	Steam turbine
U	Corrected value
u	Circumferential component of velocity
V	Loss
VB	Before blading
W	Cooling water
w	Specific heat consumption
x	With wetness influence
Z	Guaranteed value, guarantee reference value
ZÜ	At steam turbine inlet flange after reheater
1, 2, 3, ...	At particular point and pipe section, respectively
γ	Weighted mean value

1) Further subscripts which are identical with symbols have the same meaning as the symbol.

3 Terms of contract

3.1 Place and time of acceptance tests

Acceptance tests on site shall be carried out, within 6 months after commissioning the turbines. Acceptance tests of smaller units can be performed on the test rig of the supplier, if mutually agreed.

3.2 Supervision of acceptance tests

The supervision of the acceptance tests shall be agreed upon in time between the customer and the supplier. An independent expert may be appointed.

The appointed supervisor(s) shall be responsible for conducting the tests and evaluating the results properly and correctly. The supervisor(s) has (have) the right and duty to obtain all detail information necessary for the test.

Other parties to the contract who are not engaged in the supervision of the acceptance test must be given the possibility of access to all detail information in time.

When an automated data collecting and processing system is to be used the operator of such system has to prove that it is appropriate for this application. A control of all calculations performed must be possible.

A judgement of the test results according to clauses 6.3 and 6.4 must be possible. The measured values must be printed out in sufficiently short intervals to detect long-term variations and trends.

3.3 Further agreements

Prior to the tests, agreement shall be reached between customer and supplier on the programme of the tests, the variables to be measured, measuring instruments and measuring points. In addition, where the tests are to take place at the erection site, the operating and observation personnel to be provided shall also be agreed. Further agreement has to be reached ahead of time about comparative tests (see Section 4.2.2.1).

An independent expert may be employed to assist in reaching agreement on any matter.

3.4 Repetition of acceptance tests

The acceptance tests shall be repeated at the request of the customer, if, subsequent to the test, the supplier has made or caused to be made, some correction or alteration to the turbine which could have a significant effect on the performance, for any other reason than at the specific request of the customer.

A repetition may also be requested by one of the parties to the contract if he has reasonable grounds to doubt the validity of the result.

3.5 Costs of the acceptance tests

It shall be clearly stated in the contract who has the responsibility for bearing the costs of the acceptance tests and any possible repetition.

3.6 Steam tables

If no agreement has been made on the steam tables to be used the steam tables on which the guarantee is based shall be used.

4 Preparation for and implementation of acceptance tests

4.1 Location of measuring points

The measuring points and measuring devices for the measurement shall be considered when designing steam turbine equipment and piping.

In the case of site tests, in order that the acceptance tests may be carried out without impeding the normal operation of the plant, the parties to the contract shall agree in advance of construction on additional special instrument connections (e.g. taps for installation of thermocouples without pockets) for the measured variables essential for verifying the guarantee.

In nuclear power stations, any necessary penetrations or conduits shall be provided so that the signals from any measuring points within a radiation controlled area can be transmitted by suitable cables or impulse lines to an area which is exposed to no radiation or to minor radiation only. For this purpose, the maximum acceptable radiation level in the area in which the measuring instruments are located shall be that which is legally or contractually permitted in areas accessible to operating staff without restriction. For the exit points of measuring cables from rooms exposed to relatively large radiation, shafts or penetrations shall be provided.

4.2 Condition of the plant

4.2.1 Preliminary work

At the beginning of the acceptance tests, the plant must be in good, clean, "as-supplied" condition. The important points being the condition of the steam turbine and the driven machine, the cleanliness and leak tightness of the condenser, feed water heaters and piping and the correct operation of the sealing steam system. Further, with saturated steam turbines in nuclear power stations, the effective operation of any water separators or superheaters should be checked to the satisfaction of all parties.

For an acceptance test on the erection site, the supplier shall be given facilities for checking the condition of the plant before the acceptance tests begin, if necessary by making his own preliminary tests. Any deficiencies discovered shall be rectified before the acceptance test.

Any pipe connections to that portion of the plant which is the subject of the test and which are not required during the test shall whenever possible, be positively isolated by blind flanges. Otherwise the leak-tightness of the system shall be proved in some other way (see Section 4.2.4).

In nuclear power stations with contaminated steam, the responsible radiological safety officer (1st Radiation Protection Edict (SSVO) para. 20) shall be consulted on the planning, preparation and implementation of acceptance tests.

4.4.2 Condition of the steam turbine

The condition of the steam turbine is dependent on the effects of surface deterioration [2] (see Section 7.4), on minor damage [3] and on deposits [4].

The condition of the turbine and possible changes may be checked either by internal examination or by making comparison measurements.

4.2.2.1 Comparison measurements

In making comparison measurements as distinct from the full acceptance tests only the measurements necessary for controlling the condition of the steam turbine will be made. However, the measuring accuracy should be comparable to that of an acceptance test. The first comparison measurement is to be made as early as possible at repeatable operating conditions. This measurement is called reference measurement.

The type and scope of the comparison measurements as well as the allocation of the costs shall be agreed by the customer and the supplier (see Section 3.3). The comparative measurements shall be conducted jointly.

For the comparison measurements it is suggested to measure the internal efficiency, the expansion line (pressure and temperature values), steam flow rates through shaft glands and balance pistons, the condenser terminal temperature difference and the vibration level at suitable points.

4.2.2.2 Timing of the comparison measurements

The comparison measurements should be undertaken:

a) as reference measurements immediately after the machine has been commissioned, if necessary also with partial load,
b) in good time prior to the acceptance tests,
c) following any attempt to clean the turbine by flushing,
d) within the framework of the acceptance test,
e) when necessary before and after internal inspection.

4.2.2.3 Consideration of the measurement results

If the results of the initial reference measurement indicate that the performance of the turbine differs significantly from the guarantee performance, remedial action should be agreed between customer and supplier.

Should the results of a subsequent comparison measurement suggest the presence of deposits which may be removable by flushing, the supplier may require the operator to flush the turbine. If, after flushing, a further comparison measurement reasonably agrees with the initial reference measurement then the full acceptance test may be undertaken. On the other hand, should this further comparison measurement still indicate a significant deterioration in the condition of the turbine, the parties to the contract shall agree whether to proceed with the acceptance test or attempt further remedial work. This is especially the case where the defect believed to be the cause of the deterioration requires further investigation or otherwise cannot be quickly corrected.

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2) Surface deterioration is, providing proper operation, any change in the condition of the surface of parts in the steam flow path (e.g. nozzles and blades etc.) during operation or shutdown due to erosion and corrosion.

3) Minor damage is damage to or changes in critical clearances associated with blading, balance pistons, shafts seals, wear of valve spindles or bushes, and leakage in valve glands or seats.

4) Deposits: Salts or metal on the steam side, and slime, ashes, bacteria, algae etc. on the cooling water side.

4.2.2.4 Opening the steam turbine

Opening the steam turbine or individual casings or components of the turbine to determine the internal condition should be considered when:

a) the cost of making adequate comparison measurements would be greater than the cost of opening the machine,

b) larger or inexplicable deviations from the expected performance appear during comparison measurements.

4.2.3 Condition of the condenser

The internal condition of the condenser can be determined by opening the water boxes for visual examination and for water flow tests or by comparative measurements of the terminal temperature difference. When such examinations or tests indicate the presence of deposits [4], the supplier may request that the condenser be cleaned before the acceptance tests.

4.2.4 Condition of water drain facilities in saturated steam turbines

The water drain facilities (condensate drains) necessary for the proper operation of a saturated steam turbine remain in function.

Properly operating draining facilities are an integral part of the mass flow balance of the turbine, i.e. they have been taken into account in determining the guaranteed heat rate and they shall not be regarded as leakages.

Prior to the acceptance tests (e.g. as part of a routine inspection) the condensate steam traps shall be checked for satisfactory functioning and optimum adjustment.

In the case of incorrect operation the mass flows can be established with the aid of mass flow calibration curves of the condensate steam traps (see Section 5.1).

4.2.5 Tests for leak-tightness

Before the acceptance tests, and in any case of doubt again after the test, the condenser, the feed heaters and associated piping, the shaft glands and any moisture separators or superheaters for saturated steam turbines shall be checked for leak tightness. During the test, the contractually agreed operating conditions of sealing devices shall be maintained [5].

4.2.6 Cleanliness of steam strainers and water separators

If necessary, the steam strainers and water separators shall be cleaned before the acceptance tests.

4.3 Preliminary tests

Prior to the acceptance tests, the test supervisor shall be given the opportunity to conduct preliminary tests for the purpose of training the observers and checking the instruments.

By mutual agreement, the preliminary test may subsequently be considered as the acceptance test, provided that the conditions in Section 4.4 have been fulfilled and the results are computed in accordance with Section 6.

4.4 Acceptance tests

4.4.1 Steady conditions during test

Before commencement of the acceptance test all measured values which may affect the result of the test, shall be constant as nearly as possible and shall be maintained within the allowed range of deviation (see Section 4.4.2) during the whole test.

4.4.2 Maintenance of the agreed operating conditions

The test conditions of pressures, temperatures, cooling water flow, rotational speed etc. shall be maintained as close as possible to the conditions stated in the contract. However, deviations from the contract values, due to variations in conditions for which the supplier is not responsible, are permissible provided the mean test values do not deviate from the contract values by more than the extent given in Table 1.

Table 1. Maximum permissible deviations of the mean test values from the contract values.

Variable	Symbol	Maximum Permitted Deviation	
Initial steam pressure	p_{FD}	± 5 %	
Initial steam temperature	t_{FD}	± 15 K	
Extraction pressure	p_E	± 5 %	
Exhaust pressure	p_{Abd}		
for back-pressure turbines		± 5 %	
for condensing turbines		± 25 %,	if condenser is not included in guarantee
Reheat temperature	t_{ZU}	± 15 K	
Isentropic Enthalpy drop	Δh_s	± 7 %	
Power output	P	± 7 %	
Cooling water flow	$\dot{m}_W$	± 15 %,	if condenser is included in guarantee
Cooling water inlet temperature	t_{W1}	± 5 K	if condenser is included in guarantee
Final feed water temperature	t_{Sp}	± 10 K	
Rotational speed	n	± 5 %	
Maximum permissible unaccounted leakage losses in closed circuit- percent of the inlet steam flow		0,6 %	in conventional power stations
	$\dot{m}_V$	0,4 %	in nuclear power stations [6]

The maximum permissible fluctuation around the mean value during an acceptance test shall not exceed one half of the deviations given in Table 1, except that the power output may vary by no more than ± 5 %.

Should the above requirements not be satisfied, the test shall only serve as information unless, in a particular case, a special agreement has been made as to the influence of the deviating operating condition in consideration of Section 8.

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[5] In the case of turbines handling contaminated steam, it is particularly important that agreed values are not exceeded with respect to the exhaust system.

[6] This value may be reduced in the event of the 1st Radiation Protection Edict stipulating a maximum permissible concentration of contaminated matter in the air (see Section 6.2.3.4).