BRITISH STANDARD

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IEC 1064:1991

Guide to

Acceptance tests for steam turbine speed control systems

The European Standard EN 61064:1993 has the status of a British Standard

UDC 621.165-531.6:621.3:620.1

Cooperating organizations

The European Committee for Electrotechnical Standardization (CENELEC), under whose supervision this European Standard was prepared, comprises the national committees of the following countries:

Austria	Italy
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Contents

National foreword

This British Standard has been prepared under the direction of the Machinery and Components Standards Policy Committee and is the English language version of EN 61064:1993 *Acceptance tests for steam turbine speed control systems* published by the European Committee for Electrotechnical Standardization (CENELEC). It is identical with IEC 1064:1991 published by the International Electrotechnical Commission (IEC).

For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to:

— IEC Publication 27: *Letter symbols to be used in electrical technology*;

— IEC Publication 617: *Graphical symbols for diagrams*

The symbols and signs contained in the present publication have either been taken from IEC Publications 27 or 617, or have been specifically approved for the purpose of this publication.

For general terminology, readers are referred to IEC Publication 50: *International Electrotechnical Vocabulary (IEV)*, which is issued in the form of separate chapters each dealing with a specific field, the General Index being published as a separate booklet. Full details of the IEV will be supplied on request.

The terms and definitions contained in the present publication have either been taken from the IEV or have been specifically approved for the purpose of this publication.

EN 61064 was produced as a result of international discussion in which the United Kingdom took an active part.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 30, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 61064

February 1993

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Descriptors: Steam turbine, control system, speed, overspeed protection, acceptance test

English version

Acceptance tests for steam turbine speed control systems

(IEC 1064:1991)

Essais de réception des sytèmes de régulation de vitesse des turbines à vapeur (CEI 1064:1991)

Abnahmeprüfungen für Dampfturbinen-Regelsysteme (IEC 1064:1991)

This European Standard was approved by CENELEC on 1992-12-09. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The CENELEC questionnaire procedure, performed for finding out whether or not the International Standard IEC 1064:1991 could be accepted without textual changes, has shown that no common modifications were necessary for the acceptance as European Standard.

The reference document was submitted to the CENELEC members for formal vote and was approved by CENELEC as EN 61064 on 9 December 1992.

The following dates were fixed:

- — latest date of publication of an identical national standard (dop) 1993-12-01
- — latest date of withdrawal of conflicting national standards (dow) 1993-12-01

For products which have complied with the relevant national standard before 1993-12-01, as shown by the manufacturer or by a certification body, this previous standard may continue to apply for production until 1998-12-01.

Annexes designated "normative" are part of the body of the standard. In this standard, Annex A and Annex ZA are normative.

Contents

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1 Scope and object

This International Standard applies primarily to constant-speed steam turbines driving a.c. generators at power stations, for testing speed control systems consisting of speed governing and overspeed protection systems. It may also be used, where appropriate, for other types of steam turbines.

The purpose of acceptance tests of steam-turbine speed governing and overspeed protection systems is to verify any criteria quoted in the manufacturer's guarantees. Such tests will generally be carried out to check compliance with IEC 45-1. The criteria may include:

a) steady-state speed regulation (speed governing droop);

b) steady-state incremental speed regulation (incremental speed governing droop);

c) range of speed at no-load corresponding to the extreme settings of the speed changer;

d) dead band of the speed governing system;

e) stability of the speed governing system;

f) maximum transient increase of speed following full load rejection and any partial load rejections, with the speed governing system in operation;

g) overspeed trip setting;

h) maximum transient overspeed following full load rejection on the failure of the speed governing system.

Selection of the tests to be carried out and procedures for other tests not covered by this specification shall be agreed upon between the manufacturer and the purchaser.

2 Normative reference

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

IEC 45:1991, *Steam turbines — Part 1: Specifications.*

3 Terms, symbols, definitions and units

Using these rules it is recommended to employ the symbols, definitions and units that are given in Table 1 and Table 2 and in Figure 1. Table 1 lists basic terms, symbols, and units, while Table 2 presents terms, symbols, definitions, and units of parameters specific to this standard. IEC 45-1 definitions are also applicable.

Table 1

No.	Term	Symbol	Unit
1	Power or load	L	MW or kW
2	Pressure	p	MPa or bar
3	Temperature	e	K or °C
4	Angular speed	ω	rad/s
5	Rotational speed	n	Hz, rev/s (rev/min)
6	Voltage	U	V
7	Current	I	A
8	Position or stroke of servomotors	s	mm, rad or (°)
9	Position or stroke of valves	h	mm, rad or (°)
10	Position or stroke of pilots	x	mm, rad or (°)
11	Time constant, characteristic time of element	T	s
12	Time as independent variable	t	s
13	Speed or load setting point	y	% or other

Table 2

No.	Term	Symbol	Definition	Unit
1	Rated speed	n_o	The speed at which the turbine is specified to operate at its rated output	Hz rev/s rev/min
2	Minimum controlled speed at no-load	n_1	The speed at no-load corresponding to the lower setting of the speed changer	Hz rev/s rev/min
3	Maximum controlled speed at no-load	n_2	The speed at no-load corresponding to the upper setting of the speed changer	Hz rev/s rev/min
4	Temporary speed rise		The transient increase in turbine speed following a load rejection, with the speed governing system in operation. The rated temporary speed rise applies if the rated output is rejected at rated speed	Hz rev/s rev/min
5	Maximum speed rise		The maximum transient increase in turbine speed following a load rejection, with the speed governing system inoperative. The rated maximum speed rise applies if the rated output is rejected at rated speed	Hz rev/s rev/min
6	Maximum transient speed	n_m	The maximum transient increase in turbine speed following rejection of maximum capability by disconnecting the generator from the electrical system (with auxiliary supplies previously disconnected) and the speed governing system in operation	Hz rev/s rev/min
7	Maximum transient overspeed	n_{ops}	The maximum rotational speed following rejection of maximum capability by disconnecting the generator from the electrical system (with auxiliary supplies previously disconnected) and the speed governing system inoperative	Hz rev/s rev/min
8	Overspeed trip setting	n_s	The speed at which the overspeed trip is set to operate	Hz rev/s rev/min
9	Maximum continuous rating (MCR) (electrical generating set)	L_o	The power output assigned to the turbine-generator by the supplier, at which the unit may be operated for an unlimited time, not exceeding the specified life, at the specified terminal conditions. This is the rating which will normally carry a guarantee of heat rate. The governing valves will not necessarily be fully open. (Also referred to as rated output, rated power or rated load)	MW or kW
10	Maximum capability	L_{max}	The maximum power output that the turbine can produce with the governing valves fully open and at the specified initial steam conditions. (Also referred to as valves-wide-open capability or maximum load)	MW or kW

Table 2

No.	Term	Symbol	Definition	Unit
11	Maximum overload capability	L_{ol}	The maximum power output that the unit can produce with the governing valves fully open, and with the terminal conditions specified for overload, e.g. with final feed water heater bypassed or with increased initial steam pressure	MW or kW
12	Dead band of the speed governing system	ε	The total magnitude of the change in steady-state speed (expressed as a percentage of rated speed), within which there is no resultant change in the position of the governing valves. The dead band is a measure of the sensitivity of the system	% (Dimension-less)
13	Steady-state speed regulation (speed governing droop)	δ	The steady-state speed change, expressed as a percentage of rated speed, when the load of an isolated unit is changed between rated load and zero load, with identical setting of the speed governing system, assuming a zero dead band	% (Dimension-less)
14	Steady-state incremental speed regulation (incremental speed droop)	δ_l	The rate of change of the steady-state speed with respect to load at a given steady-state speed and load, assuming a zero dead band. The value is the slope of the tangent to the steady-state speed/load curve at the load under consideration	% (Dimension-less)
15	Steam flow demand	d_c	The signal generated in the speed governing system which represents the required steam flow to the turbine	MPa V or A
16	Fluid pressure in control system	p_c	Fluid pressure at different points of the hydraulic control system	MPa
17	Stability		The capability of the speed governing system to reduce oscillations of the speed or load resulting from the action of the governing system to amplitudes within acceptable limits	

4 Guiding principles

4.1 Matters on which agreement shall be reached

a) The parties to the test shall, prior to the tests, reach agreement on the object of the tests and on the interpretation of the guarantees. Unless otherwise stated in the contract, the control system functions shall be verified in accordance with **1.2**.

b) Agreement shall be reached on the method of operation and on such matters as the means of maintaining constant steam conditions and output. If the test conditions differ from those specified in the test program, agreement shall be reached on the methods of conversion of experimental values.

c) Methods of testing other than those stated in this standard may be used by mutual agreement between the parties. For example, the methods given in national codes to determine steady-state speed regulation, dead band and other characteristics of the control system may be used. However, comparison of the quality of different control systems shall be accomplished only by using the methods stated in this standard. In the absence of such written agreement, it is understood that the provisions of this standard are to be applied.

d) Agreement shall be reached on the method and responsibilities for calibration of the instruments.

e) The parties to the test may designate a person to direct the test and another person to arbitrate in the event of disputes regarding test conditions and procedures, or accuracy of measurement and observations.

f) Accredited representatives of the purchaser and the manufacturer may be present at the tests to verify that they are conducted in accordance with this standard and the agreements made prior to the tests.

g) The test results shall be reported as calculated from the test observations, due account being taken of any corrections resulting from calibration of the instruments. Any tolerances or deviations from contractual values are a commercial matter between purchaser and manufacturer, and are not dealt with in this standard. Agreement shall be reached on the contents and the time period for preparation of the test report.

h) If not specified in the contract, the following items shall be agreed upon between the purchaser and manufacturer of the turbine, generator and control system:

1) supply of materials and special instrumentation to carry out the test;

2) provision of access to the necessary measuring points on the turbine, generator and control system;

3) time allowed for installing, pre-testing and disassembly of the test instrumentation;

4) tests to be carried out at the manufacturer's works and at the power plant;

5) provision of necessary additional personnel and definition of their duties;

6) liability in case of accidents, loss or damage to equipment and instruments;

7) liability for any damage due to testing of the turbine, generator or control system;

8) liability for any possible interruption of turbine service beyond that necessary to carry out the test;

9) insurance against any uncovered risk;

10) costs of equipment and manpower.

4.2 Time of carrying out tests

a) Any necessary adjustments to the speed governing and overspeed protection systems shall be completed before performing acceptance tests.

b) Acceptance tests of the overspeed protection system at no load shall be carried out as soon as the turbine is put into operation after installation.

c) All other agreed to acceptance tests shall be carried out within the period agreed between the purchaser and the manufacturer but not later than the end of the warranty period.

4.3 Preparation for acceptance tests

a) The test program shall be prepared by the parties to the tests. The program shall include a list of the tests to be carried out, the responsibilities of the parties, the operational conditions and test modes, instructions for the test personnel, safety measures and test procedures.

b) Before undertaking the tests, the lists and calibration curves for all instrument readings used during the tests should be compiled and checked.

c) Any special instruments not supplied for normal operation that are necessary for carrying out the tests shall be mounted on the unit.

d) When the parties concerned agree to perform tests on the turbine at standstill, the necessary simulation equipment shall be installed.

4.4 Instruments

a) The instruments used shall have the requisite accuracy and response characteristics to meet the test parameters and dynamic characteristics of the test processes.

In determining the dead band it is necessary to record the speed of the unit by means of a device having an accuracy of ± 0,02 % and a dead band less than 10 % of the dead band being measured. Also, the displacement of the servomotor and steam valves, and the change of the steam flow demand shall be measured with an accuracy of ± 0,5 % of the displacement or change which corresponds to the load change from no-load to rated load.

A precise frequency meter with a measurement accuracy of ± 0,1 % of the speed of the unit shall be used. Also, the values of the steam flow demand, the displacement of the main servomotor and the power at the generator terminals (measured or calculated) shall be obtained with an accuracy of ± 1 %. The measurement accuracy of the parameters used for converting the measured generator power to rated conditions (steam pressure and temperature upstream and within the turbine, steam flow, etc.) shall be adequate to obtain the above-mentioned accuracy.

b) When carrying out dynamic tests of the speed governing and overspeed protection systems, the pertinent values shall be recorded by fast recording instruments. The recording instruments cut-off frequency and chart speed should be suitable to obtain the required accuracy of the measured variables. For example, the speed measurement accuracy shall be ± 0,1 % for the load rejection test and overspeed protection test at no-load.

c) It is preferable to carry out test measurements with special test instruments. If this is not practicable or convenient, the normal station operational instruments may be calibrated and used. If they are used, it is necessary to reach an agreement about the tolerances for the test results.

4.5 Test report

After completion of the acceptance tests, the test report shall be prepared including the test results. Unless otherwise agreed between the parties, the report shall include the following items:

a) object and scope;

b) agreements between the test parties;

c) test program;

d) list of measurement points and instruments used, with information about their accuracy and other characteristics;

e) plots and tables of calibration and correction factors for the readings of test instruments;

f) test measurements in tabular, graphical or chart form;

g) results of the correction of test measurements to the specified conditions, if the test conditions differ from those specified:

h) calculations of the speed governing and overspeed protection systems characteristics, and their comparison with specifications and contractual requirements;

i) conclusions about the state of the speed governing and overspeed protection systems, and appropriate recommendations.

The test report shall be signed by those persons directing the tests and confirmed by the parties to the contract.

5 Speed governing system tests

Tests are carried out with three different operating conditions of the turbine:

a) turbine at standstill;

b) turbine at no-load;

c) turbine on load.

5.1 Turbine at standstill

The tests on the turbine at standstill demonstrate in advance whether the speed governing system is in its proper state, and allow for checking all the instruments and training the operating staff. With the exception of the test for obtaining the servomotor stiffness characteristic, all tests are for information only and should not be considered as acceptance tests. The servomotor stiffness characteristic is required for measuring the dead band by the method described in **5.3.5**. The test procedure is described in **A.1** of Annex A.

5.2 Turbine at no-load

5.2.1 ***Overview***

Tests are carried out with the generator disconnected from the network, and with the turbine speed and parameters set as listed subsequently.

Tests are carried out to determine:

a) the dependence of the steam flow demand and valve position on changes in the controlled parameters;

b) the dead band of the speed governor;

c) the dead band of the speed governing system with negligible or minimum steam forces on the control valves;

d) the range of speed corresponding to the extreme settings of the speed changer;

e) stability.

5.2.2 ***Test procedure for determination of static characteristics***

a) All parameters, which in changing their values may affect the test results, should be stabilized as closely as possible prior to the test. This condition should be maintained during the whole test with the accuracy defined by the equipment specifications or by the appropriate manuals. Possible acceptable deviations from the specified values are to be agreed by the parties prior to the tests.

b) Determination of the dependence of both the steam flow demand signal (for example, fluid control pressure) and the control valve position (or the position of the main servomotor actuating the valve) upon controlled parameter changes is carried out for three settings of the speed changer corresponding:

1) to turbine no-load at rated speed;

2) to turbine no-load at an increased speed between 1,03 n_o and 1,05 n_o;

3) to turbine no-load at a decreased speed between 0,96 n_o and 0,98 n_o.

c) When determining the static characteristics of the speed governing system at turbine no-load, the rated speed n_o is initially set by adjusting the speed changer and then, without changing this setting, the turbine steam flow is slowly decreased by one of the methods described in **A.2** of Annex A. This causes a speed reduction, following which the automatic action of the speed governing system causes the turbine control valves to open. Recording the steam flow demand signal and the positions of all the links of the speed governing system as a function of speed, the following functions of "n" are obtained for decreasing speed:

d_{c2} (n), s_2 (n), and also, as supplementary data:

h_2 (n) and x_2 (n).

The appropriate curves are shown in Figure 2.

The test is continued until the maximum possible valve stroke is reached, in most cases exceeding the rated valve stroke h_o which corresponds to rated loading. Subsequently, the steam admission to the turbine is increased and the speed starts to rise. The same measurements are recorded as with speed decreasing and the following functions of "n" are obtained for speed rising:

d_{c1} (n), s_1 (n), and also, as supplementary data:

h_1 (n) and x_1 (n).

d) When determining the dead band of the speed governor and of the speed governing system it is necessary to recognize that the displacement of any amplifying stage lags behind the control signal. Therefore, the changing of speed should be carried out slowly enough to exclude any distortion associated with the response time of the speed governing system.

5.2.3 ***Determination of dead band***

a) The dead band of the speed governor is defined as:

$$\varepsilon_g = \frac{\Delta n_{ig}}{n_o}$$

where Δn_{ig} is the difference of speed at the same values of steam flow demand between the two directions of speed change (see Figure 2a).

b) The dead band of the speed governing system with the turbine at no-load (with negligible or minimum steam forces on the control valves) will be:

$$\varepsilon = \frac{\Delta n_i}{n_o}$$

where Δn_i is the difference of speed at the same values of the servomotor final link position between the two directions of speed change (see Figure 2b).

5.2.4 ***Speed range determination***

In order to determine the speed range at no-load, corresponding to the extreme settings of the speed changer, the rotational speed is changed by adjusting the speed changer from its lower extreme setting point to the upper extreme setting point. The minimum (n_1) and maximum (n_2) values of the rotational speed, at which the turbine speed is controlled by the speed governing system, are recorded (see Figure 3).

5.2.5 ***Stability***

The speed stability can be checked with the turbine at no-load by initiation of any practicable perturbation, for example:

— step deviations on the speed changer, or

— connecting and disconnecting of auxiliaries on the generator.

The quantitative evaluation of the stability shall be agreed between the manufacturer and purchaser.

5.3 Turbine on load

5.3.1 *Overview*

Tests on the turbine on load are carried out in order to determine:

a) the dependence of the generated load on changes in steam flow demand or in the position of the main servomotor final link;

b) the dead band of the speed governing system taking account of the influence of steam forces on the control valves;

c) steady-state speed regulation;

d) incremental steady-state speed regulation;

e) stability.

5.3.2 *Test conditions*

When carrying out tests the following shall be observed:

a) The tests shall be carried out in strict compliance with the manufacturer's manuals.

b) The turbine shall be warmed up properly (preliminary operation at or near rated load until thermal equilibrium is achieved).

c) Main and exhaust steam conditions shall be as near as practicable to the rated values. No corrections to test results are required if the deviation of the main steam pressure does not exceed ± 1 % of the rated value and if the deviations of the main steam temperature and the temperature upstream of the reheat stop valves do not exceed ± 5 °C.

d) The feedwater heating system shall be in operation as specified in the manufacturer's manual.

e) The feedwater flow shall be maintained approximately the same as the main steam flow.

f) The thermal cycle of the turbine shall correspond to normal operation conditions.

g) The electrical network shall be substantially constant in frequency, except for tests **5.3.6** and **5.3.10**.

5.3.3 *Load-steam flow demand relationship*

a) With the turbine operating on load, the relationship $L(d_c)$ between the generated load and the steam flow demand signal, and the relationship L(s) between the generated load and the position of the main servomotor final link (or the position of servomotors in the case of several servomotors for the turbine) are determined. See Figure 4.

b) During the above test a), the load is changed by steps of approximately 0,05 L_o from rated load to the lowest practicable load.

An additional measurement may be made at minimum load at the highest temperature and pressure attainable by the steam supply system.

After attaining the next load level and the necessary steam conditions, the unit operational conditions shall be kept constant for 5 min to 10 min before the test. The observations shall be made at intervals of 2 min to 3 min. At each electrical load, 3 to 5 sets of observations shall be made.

The above tests shall be repeated with the turbine load increasing from lowest load to rated load. It may be desirable to carry out tests at electrical loads around the opening points of each turbine control valve.

If it is possible to maintain stable thermal steam conditions the tests may also be performed by continuously varying the load and simultaneously recording the indicated parameters.

For both methods all the parameters needed for correcting the results of the tests to the rated conditions shall be recorded.

5.3.4 *Dead band determination — Overview*

The dead band of the whole speed governing system, taking into account the effect of steam forces on the control valves can be determined by two different methods:

— method 1 is based on the measurements of the individual dead bands of the speed governor when the turbine is at no-load [**5.2.3** a)] and of the servomotor when the turbine is on load;

— method 2 is based on the direct measurement of the total dead band between frequency and load when the turbine is on load.

Method 1 may be used for all types of speed (frequency) governing systems. For systems with closed loop load control, the integral load governor shall be taken out of operation. This method gives the possibility of obtaining the speed governing systems' dead band for the whole steady state regulation range.

5.3.5 ***Dead band determination — Method 1***

a) The main servomotor dead band, taking into account the effect of steam forces, is determined with the turbine operating on load. With increasing load set point at several load levels (including the points of opening of each valve) the cylinder fluid pressure (or the fluid pressure on each side of the piston in the case of a double-acting servomotor) is recorded. The procedure is then repeated with decreasing load set point. The positions of the servomotor and the valve are simultaneously recorded. The dead band of the servomotor at any position (in absolute units) is the difference (Δp_s) between the cylinder pressure values at this position for increasing and decreasing the load set points (the sum of the absolute values of such pressure differences on both sides, in case of the double-acting servomotor) (Figure 5). The servomotor dead band percent is the ratio of the steam flow demand change Δd_c necessary to attain the above-mentioned pressure difference Δp_s with the motionless position, to the steam flow demand change $d_{c\delta}$, corresponding to the speed governing droop:

$$\varepsilon_s = \frac{\Delta d_c}{d_{c\delta}}$$

$d_{c\delta}$ is obtained from the static characteristic of Figure 8, curves A and B. The steam flow demand change Δd_c is plotted using the servomotor stiffness characteristic (Figure 6 and **A.1.6** and **A.1.7** of Annex A).

b) The dead band of the servomotor positioning loop ε_l is determined by using the load-steam flow demand relationship (**5.3.3** and Figure 4). The main servomotor dead band is the change of steam flow demand Δd_c, within which there is no change in load, relative to the range of steam flow demand $d_{c\delta}$. This method requires a precise measurement of the load-steam flow demand relationship.

c) The total dead band ε of the speed governing system when the turbine is on load is defined as:

$$\varepsilon = \varepsilon_g + \varepsilon_l \cdot \delta$$

where

ε_g is the dead band of the speed governor, measured throughout the test when the turbine is at no-load [**5.2.3** a)].

ε_l is the dead band of the servomotor positioning loop, taking into account steam forces [calculated according to **5.3.5** b)].

ε_l is taken for corresponding values of the steam flow demand on the static characteristic of the speed governing system. For the control systems with parallel or partially parallel movement of servomotors, the minimum dead band of these servomotors is taken for ε_l.

5.3.6 ***Dead band determination — Method 2***

The total dead band may also be determined on load. Throughout this test, the set point of the unit is maintained constant and the power loop taken out of operation.

The unit is operated connected to the network during periods when the network frequency can be expected to vary significantly. The signals to be recorded are the network frequency and either the position of the control valves or the generated load. If the load is measured, a correction should be applied to account for steam pressure deviations during the test, the corrected load signal being the measured load multiplied by the ratio of the rated and measured steam pressures. Since the item under investigation is a static characteristic of the governing system, low-pass filters should be used to process the recorded signals so that they do not unnecessarily attenuate effects due to network frequency variations. The signals may be recorded on *x*/*y* or time recorder charts. The recording period should be sufficiently long to obtain an amplitude of speed variations about three times as high as the specified dead band value. The speed governing system dead band on load is the maximum amplitude of frequency variation expressed as a percentage of rated frequency

$$\varepsilon = \frac{\Delta n_i}{n_o}$$

(Figure 7) which does not cause any change in load or in the position of the control valves. This test can be carried out for different settings of the speed changer, thus enabling a maximum value to be found for the dead band of the governing system.

5.3.7 ***Determination of steady-state speed regulation — Method 1***

The speed regulation (droop) is obtained by joint graphic plottings (Figure 8) of the characteristic d_c (n) (curve A) obtained when the turbine is at no-load for three settings of the speed changer (see Figure 2a) and the characteristic $L(d_c)$ (curve B) obtained when the turbine is on load (see Figure 4a).

According to the definition of speed regulation, where zero dead band is assumed, only the characteristics corresponding to a speed change in one direction are used. By combining the plots and eliminating the parameter d_c, as shown by arrows in Figure 8, the static characteristic of the speed governing system in the first quadrant (curve C) is obtained. In so doing, special attention is paid to the end points of the curves and to any points of change of slope.

The speed regulation for each setting of the speed changer is determined from:

$$\delta = \frac{n_A - n_B}{n_o} \cdot 100\ \%$$

where

n_A is the rotational speed at no-load

n_B is the rotational speed at rated load on the characteristic for the same setting of the speed changer

5.3.8 *Determination of steady-state speed regulation — Method 2*

Using this method, it is possible to determine the steady-state speed regulation for only one setting of the speed changer.

The speed regulation (governing droop) is determined by adjusting and measuring the setting of the speed changer Y_o to give rated load at rated steam conditions and rated network frequency, or any network frequency n at the time the tests are carried out. The frequency is measured accurately and compared with the value n_{11} obtained with the generator at no-load (disconnected from the network) at the same setting Y_o of the speed changer (Figure 3).

The operating conditions at no-load shall be stabilized and preferably be the same as for the test on load.

The speed regulation will then be:

$$\delta = \frac{n_{11} - n}{n_o} \cdot 100\ \%$$

5.3.9 *Determination of incremental speed regulation — Method 1*

The incremental speed regulation is obtained as the slope of the tangent to the load-speed curve (c) at a given point:

$$\delta_i = \frac{L_o}{L_B - L_A} \cdot \frac{n_{iA} - n_{iB}}{n_o} \cdot 100\ \%$$

where (see Figure 8)

L_A, L_B are two load points used for calculation

n_{lA}, n_{lB} are values of rotational speed, corresponding to loads L_A and L_B, and measured on the tangent

5.3.10 *Determination of incremental speed regulation — Method 2*

The incremental speed regulation for the speed range near the rated speed may be determined directly from the result of the test of **5.3.6** if a load signal is used. If the valve position is measured, then the desired characteristic may be determined using the results of test **5.3.3**, converting valve position into load.

The incremental steady-state speed regulation will then be (Figure 7):

$$\delta_i = \frac{n_{i1} - n_{i2}}{n_o} \cdot \frac{L_o}{L_2 - L_1} \cdot 100\ \%$$

5.3.11 *Stability*

The stability with the turbine on load is determined in the tests by applying step signals to the governing system through the electrical inputs of the system: either through the fast response input (electrohydraulic transformer or another type of device) or the slow response input (the speed changer motor), or both. The step signal value will correspond to the maximum change of load allowed by the manufacturer's specifications.

The quantitative evaluation of the stability shall be agreed upon between the manufacturer and the purchaser.

5.4 Dynamic tests of the speed governing system by sudden load rejection to no-load

5.4.1 *Overview*

These tests are carried out to verify the functional capability and coordination of the speed governing system components, so that the temporary increase of the speed on any sudden load rejection (particularly maximum load to no-load) remains below the overspeed trip setting.

5.4.2 *Operating conditions*

— main and exhaust steam conditions shall be the rated values;

— the thermal cycle of the turbine and feedwater heating system shall correspond to normal operational conditions;

— the electrical house load is switched to external supply;

— the turbine speed governing system has been previously tested according to the earlier procedures;

— the overspeed protection system shall previously have been tested according to the procedure in clause **6** and, in particular, the on-load test (**6.3**) shall have been carried out immediately beforehand.

5.4.3 ***Test procedure***

a) The tests shall be carried out in strict accordance with the test program, where all duties of those participating in the tests under emergency situations are specified.

b) Dynamic tests of the speed governing system are carried out by sudden disconnection of all loads from the generator.

c) Tests of the speed governing system of condensing turbines and back-pressure turbines without automatic steam extraction from intermediate tapping points, are carried out initially by sudden load rejection from approximately 50 % of rated load. A second test is then carried out by sudden load rejection from that corresponding to maximum capability.

When the control system contains an acceleration rate device, it is recommended to carry out load rejection tests at loads slightly below and above the threshold of operation of this device.

d) Dynamic test of the speed governing system of a turbine with automatic steam extraction are carried out:

1) For sudden load rejection from 50 % and then 100 % of maximum load, with no automatic steam extraction flow.

NOTE Blade loadings may not permit load rejection tests at 100 % operating conditions with no automatic steam extraction flow.

2) For sudden rejection of rated load at maximum automatic extraction steam flow.

e) The parameters recommended to be recorded during these tests are listed in Table 3.

Table 3

No.	Measured variable
1	Generator stator current
2	Electrical load
3	Speed
4	Steam flow demand
5	Servomotor displacement of high-pressure control valves
6	Servomotor displacement of reheat control valves
7	Movement of high-pressure stop valves
8	Movement of reheat stop valves
9	Any signal that commands rapid closure of control and/or intercept valves
10	Servomotor displacement of steam extraction control valves when testing control systems with steam extraction
11	Movement of bled-steam non-return valves or their servomotors
12	Protection system fluid pressure
13	Main steam pressure (initial value)
14	Steam pressure within the turbine

NOTE The moment of load rejection indicates the start of the test.

5.4.4 ***Test results***

a) Immediately after each test, a decision shall be made about the practicability of the next load rejection test.

b) The main result of the sudden maximum load rejection test is the maximum transient speed n_m, which shall be below the overspeed trip setting n_s:

$n_m < n_s$

c) The following test results should also be reported: the static increase of speed and its stability, the transient process to no load, the functional capability of control and non-return valves and other devices of the speed governing system, and the functional capability of plant elements.

5.4.5 ***Stability***

The stability of the speed-governing system may also be assessed after the sudden load rejection test. The quantitative evaluation of the stability shall be agreed upon between the manufacturer and purchaser.

6 Overspeed projection system tests

6.1 Turbine at standstill

a) The response time of the protection system with local manual initiation is checked. The time of operation from the moment of switch operation to the full closure of each control and stop valve is measured for comparison with the design operating time.

b) The same test is carried out as in **6.1** a), but using the remote initiation of the test.

c) The action of other turbine protection system devices leading to electrical initiation of the turbine protection system is checked.

6.2 Turbine at no-load

a) The overspeed trip device test is carried out with the turbine at no-load. The speed is gradually increased by actuating the speed governing system, if necessary using special facilities provided for the purpose. The speed at which the overspeed trip operates is recorded by suitable instruments. This test should be repeated until consistency to a standard agreed upon between the parties is achieved. The overspeed trip setting n_s is the highest among the consistent test values.

b) If the turbine has more than one independent overspeed trip device, then each of them is checked separately.

c) The consistent test values of speed at which the trip devices operate are compared with and shall be within the design limits for overspeed trip setting.

d) While conducting the tests all devices of the system which ensure overspeed protection (acceleration device, etc.) should be operational.

6.3 Turbine on load

If the overspeed protection system includes the facility for on-load testing without increasing the speed, then such a test shall be carried out on each separate trip device at rated speed.

6.4 Dynamic testing of overspeed protection system by turbine trip from maximum load

6.4.1 ***Overview***

The test is carried out to verify the functional capability and coordination of the overspeed protection system components (except overspeed trip devices) including the tightness of stop, control and non-return valves on all steam lines to the turbine, under the most onerous loading conditions. The turbine is not subjected to significant actual overspeed during this test and the maximum overspeed is estimated by calculation.

6.4.2 ***Operating conditions***

— The turbine operates at maximum load.

— The thermal cycle of the turbine and feedwater heating system corresponds to normal operating conditions.

— The electrical house load is switched to an external supply.

6.4.3 ***Test procedure***

a) For testing the overspeed protection system, instant closing of all stop, control and non-return valves is initiated by actuation of the remote or manual trip. When carrying out dynamic tests of the overspeed protection system, the generator is not disconnected from the mains, until the reverse power relay (or low forward power relay) trips the circuit breaker.

b) Recording of all the recommended variables of Table 3 is made during the test by fast recording instruments.

6.4.4 ***Test results***

a) The entire time from the moment of operation of the trip device to the full closure of each control, stop and non-return valve shall not exceed the design value.

b) The maximum rotational speed n_{ops} of the rotor, which will result after load rejection with the failure of the speed governing system and the operation of the overspeed trip, will exceed the overspeed trip setting n_s (measured according to the tests of **6.2**) by an amount Δn_{ps}.

$$n_{ops} = n_s + \Delta n_{ps}$$

Δn_{ps} is calculated according to the formula:

$$\Delta n_{ps} = \frac{\int_{t_1}^{t_2} L(t)\,dt}{4\pi^2 J n_o} \quad (s^{-1})$$

where

- $L(t)$ is the generator power output versus time, W
- J is the moment of inertia of the rotor train, kg · m²
- t_1 is the trip initiation time, s
- t_2 is the time at which the integral function of $L(t)$ reaches its maximum, s

The resulting overspeed n_{ops} should be less than the maximum speed level calculated as defined in IEC 45-1 or by the overspeed test of the turbine rotor made by the manufacturer. Because the formula tends to over-estimate the overspeed, no additional calculational tolerances are necessary.

Annex A (normative) General guidance

A.1 Speed governing system tests with the turbine at standstill

A.1.1 With the turbine at standstill, special equipment is used, if necessary, to simulate in real time the controlled variables which position the control valves. Thus the characteristic of control valve position accuracy is obtained.

A.1.2 Having obtained the characteristics described in **A.1.1** the dead band of part of the speed governing system is determined, without accounting for the dead bands of the speed governor or the speed transducer, or for the effect of steam forces on the valves or for the temperature effects of the unit on the control elements.

A.1.3 The dependence of valve displacement (h) upon the change of steam flow demand d_c is determined: h = h (d_c).

A.1.4 Alternatively, if the configuration of the system allows, the characteristics of the governor and speed transducer $x = x(n)$ or $d_c = d_c(n)$ may be determined by introducing a simulated speed signal or by simulating the primary element displacement. Eliminating d_c from the relationship obtained, the static characteristics of the speed governing system may be derived, including the speed regulation δ.

A.1.5 When applying the simulated speed signal, as for the other cases of separate determination of the static characteristics, the dead band of the speed governing system (ε) is the sum of the dead band of the governor (ε_g), and the dead band of the devices that convert and amplify the governor signal (ε_s), i.e.:

$$\varepsilon = \varepsilon_g + \varepsilon_s \cdot \delta$$

This value of the dead band obtained at standstill is for information purposes only.

A.1.6 The servomotor stiffness characteristic required for method 1 of dead band measurement (**5.3.5**) is obtained with the turbine at standstill. By means of the speed changer the servomotor is moved to its extreme position in such a way that the fluid pressure in its cylinder becomes maximum (maximum differential pressure for a double-acting servomotor). The servomotor position, fluid pressure in the cylinder (pressures for a double-acting servomotor), fluid supply pressure, steam flow demand (for example control pressure) and the servomotor pilot stroke (if possible) are recorded. Further, using the speed changer, different pressure values are generated in the servomotor cylinder (differential pressures for double-acting servomotors: right down to the lowest level, which takes place at the opposite extreme position. All the above mentioned parameters are recorded for each pressure level. Special attention is given to the points where the servomotor reaches its extreme positions.

According to the test results, the servomotor stiffness characteristic is plotted, i.e. the dependence of the cylinder pressure p_s (pressures for double-acting servomotors) on the steam flow demand d_c or pilot stroke $p_s = p_s(d_c)$ and the dependence of the cylinder pressure on the servomotor stroke $p_s = p_s(s)$.

The stiffness characteristic of the single-acting servomotor is shown on Figure 6.

A.1.7 To calculate the servomotor dead band ε_s, the change in steam flow demand Δd_c is required, which corresponds to the displacement of the servomotor pilot (in both directions from its middle position). This is necessary to obtain the cylinder pressure difference Δp_s (the dead band in absolute units) with the motionless piston.

To obtain Δd_{c1}, the component of the steam flow demand corresponding to the displacement of the servomotor pilot in the closing direction from its middle position, half of the cylinder pressure difference Δp_s is subtracted from the pressure level p_{s1} characterizing the lower extreme position of the servomotor (as shown by the arrow on Figure 6). Thus, Δd_{c1} is obtained on the abscissa of the servomotor stiffness characteristic.

Similarly, Δd_{c2}, the component of the steam flow demand which corresponds to the displacement of the servomotor pilot in the opening direction, is plotted.

The total change of the steam flow demand will thus be:

$$\Delta d_c = \Delta d_{c1} + \Delta d_{c2}$$

A.2 Methods of changing steam flow at no-load to change the rotational speed of the turbine

These methods differ according to the design features of the turbine and with the thermal cycle of the plant.

A.2.1 On turbines provided with a main-steam isolating valve and bypass, the turbine steam flow may be adjusted by changing the bypass valve opening with the main isolating valve closed.

A.2.2 For turbines with no main-steam isolating valve before the stop valve (and, naturally, no bypass), or by agreement between manufacturer and user, the speed can be decreased by partial closing of the turbine stop valve.

A.2.3 On those turbines with HP cylinder bypass system, the changing of the IP turbine steam flow is carried out by adjusting the HP turbine bypass valve, with the HP stop valvesclosed.

A.2.4 The following method is applicable for turbines provided with two or more sets of high pressure stop and control valves. In this case, all high pressure stop valves are closed, except one to feed the turbine with live steam. If the operational high pressure stop valve feeds the turbine through several control valves with individual servomotors, then only one of these control valves is left in operation. Others are closed by their individual control or test circuits. The steam flow is then changed by adjusting (with the help of the control or test circuit) the servomotor of the high pressure control valve feeding the turbine. The value of rotational speed deviation, corresponding to the change in steam flow, shall cover the whole movement range (between extreme positions) of the control valve servomotors associated with the closed high pressure stop valves. The stop valve of the other high pressure stop and control valves set is then opened and the stop valve of the operational valves set is closed. The test with the rotational speed changing is repeated by analogy with the method described above.

A.2.5 To obtain the relation between valve position and speed for the whole deviation of the servomotor it is possible to close all stop valves with the speed governing system in operation and the turbine running at a speed near rated speed. The natural speed decrease causes the control valves to open up to maximum opening. This speed-valve position's characteristic is obtained only in the direction of decreasing speed.

A.3 Schematic guide for clause numbers of acceptance tests of steam turbine control systems

Parameter or characteristic	Turbine operation mode			
	At standstill	At no-load	On load	
Preliminary — correct operation	**5.1**			
Common — static relationships		**5.2.2**, **A.2**		
Speed range		**5.2.4**		
Dead band			**Method 1**	**Method 2**
Speed governor		**5.2.3**		
Speed governing system without steam forces	**5.1**, **A.1**		**5.3.4**, **5.3.5**	
Speed governing system on load			**5.3.4**, **5.3.5**	**5.3.4**, **5.3.6**
Speed regulation				
Steady state speed regulation			**5.3.7**	**5.3.8**
Steady state incremental speed regulation			**5.3.9**	**5.3.10**
Dynamic properties				
Stability		**5.2.5**	**5.3.11**, **5.4.5**	
Maximum transient speed			**5.4.3**, **5.4.4**	
Overspeed protection				
Overspeed trip setting	**6.1**	**6.2**	**6.3**	
Maximum transient overspeed			**6.4**	

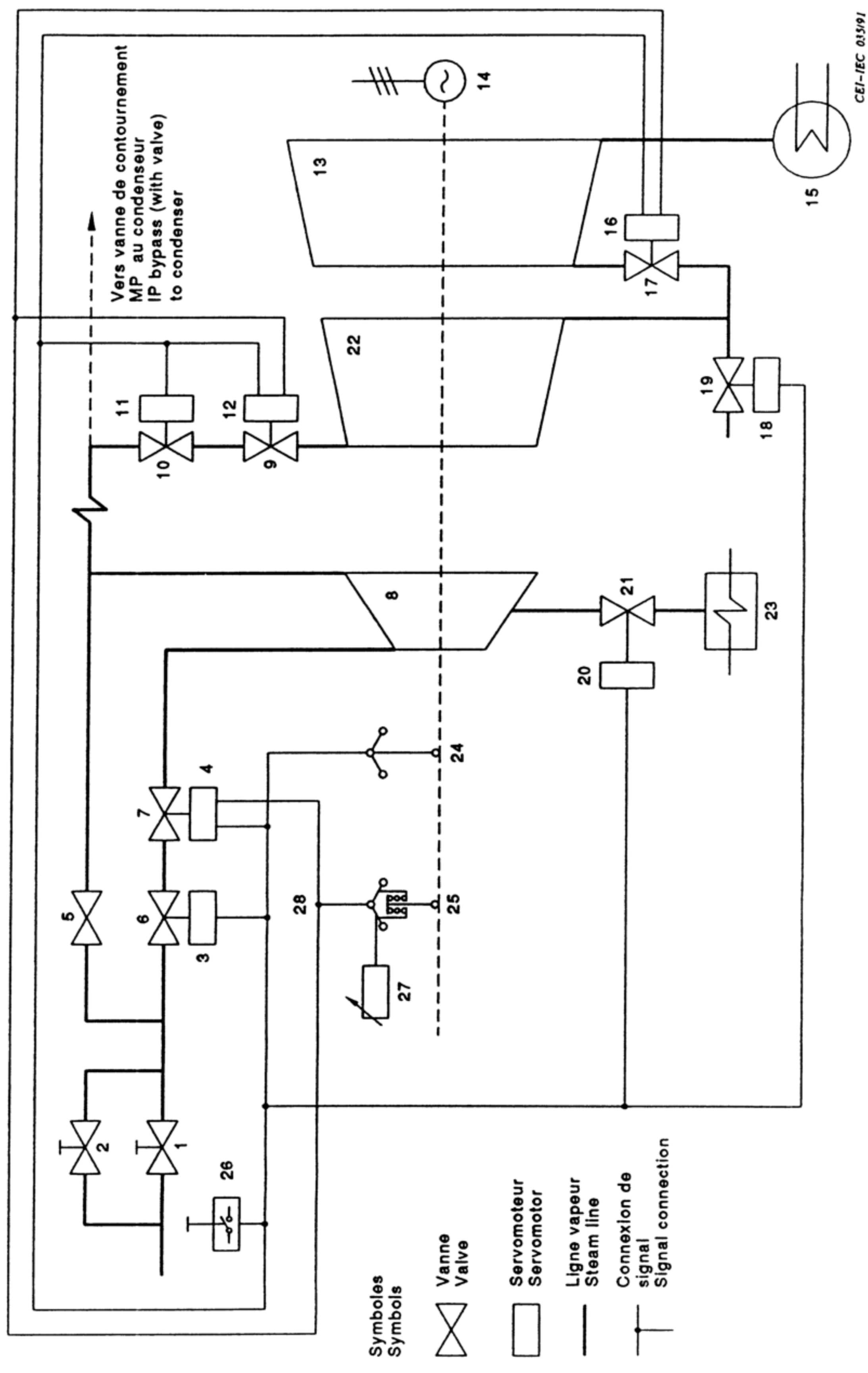

Figure 1 — Diagram of condensing reheat steam turbine set

1	=	main-steam isolating valve
2	=	main-steam isolating valve bypass valve
3	=	stop-valve servomotor
4	=	control-valve servomotor
5	=	high pressure cylinder bypass valve
6	=	turbine stop valve
7	=	turbine control valve
8	=	high pressure cylinder
9	=	reheat control (intercept) valve
10	=	reheat stop valve
11	=	reheat stop valve servomotor
12	=	reheat control (intercept) valve servomotor
13	=	low pressure cylinder
14	=	A.C. generator
15	=	condenser
16	=	steam-extraction control valve servomotor
17	=	steam-extraction control valve
18	=	steam-extraction stop valve servomotor
19	=	steam-extraction stop valve
20	=	bled (extraction) steam isolating valve servomotor
21	=	bled (extraction) steam isolating valve (non-return valve)
22	=	intermediate pressure cylinder
23	=	regenerative feed-water heater
24	=	overspeed trip
25	=	speed governor
26	=	remote turbine trip device
27	=	speed load changer
28	=	steam flow demand

Figure 1 — Nomenclature

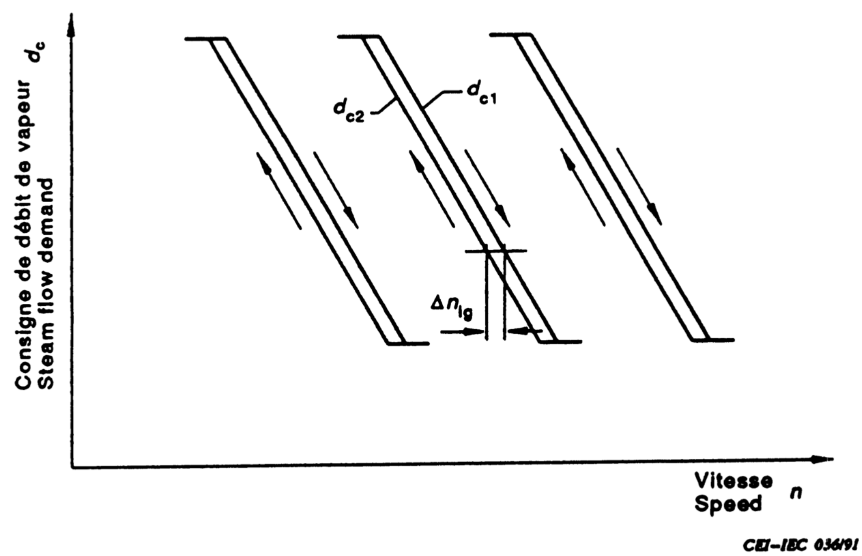

Figure 2a — Steam flow demand-speed relationship

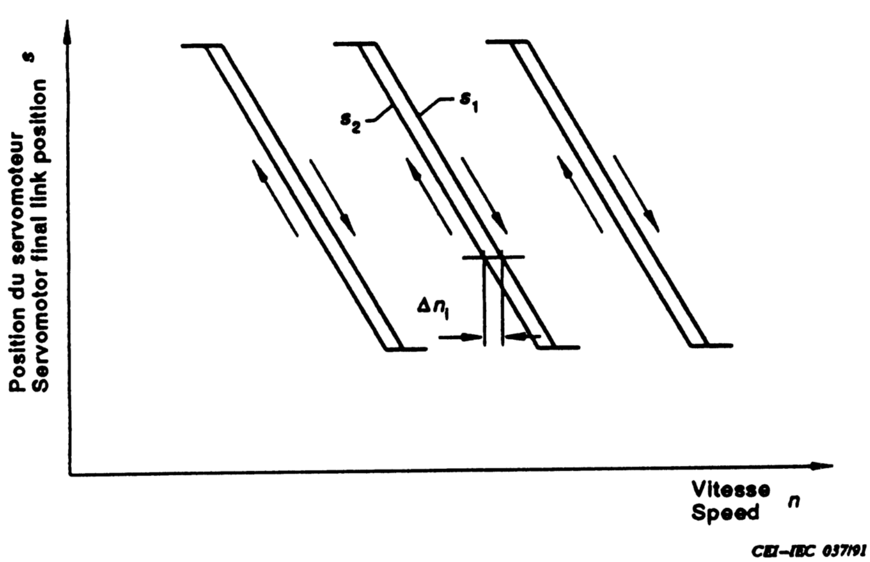

Figure 2b — Servomotor final link position-speed relationship

Figure 2 — Static characteristics at no-load

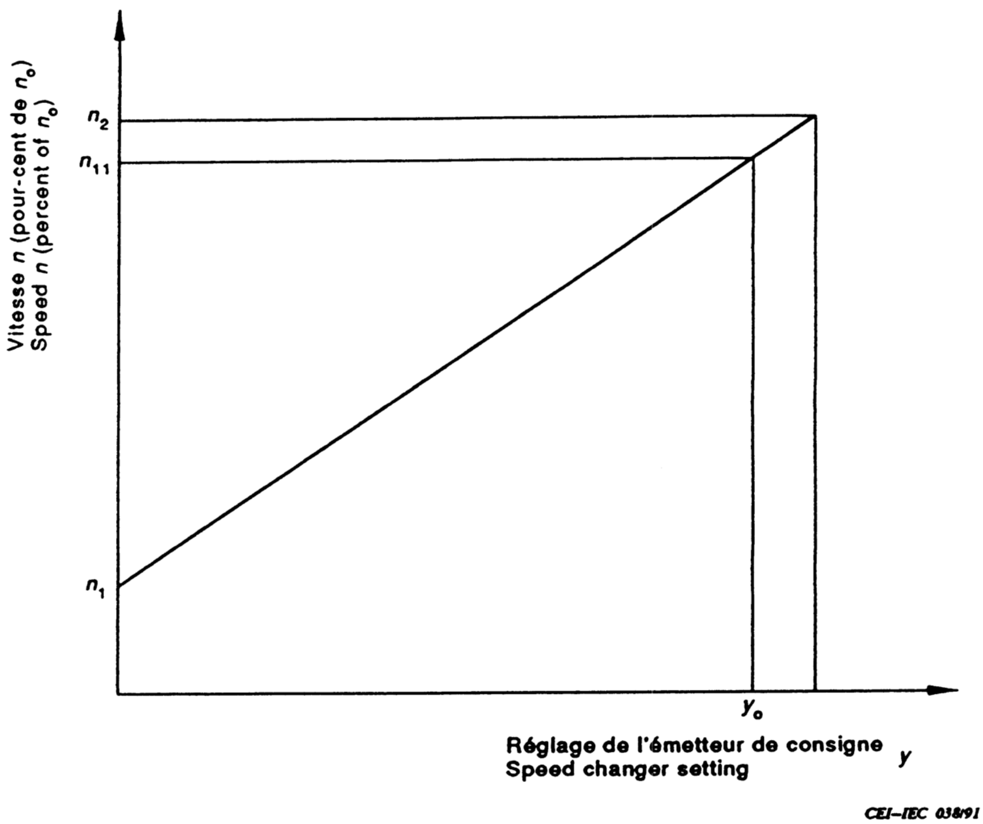

Figure 3 — Speed-speed changer setting relationship

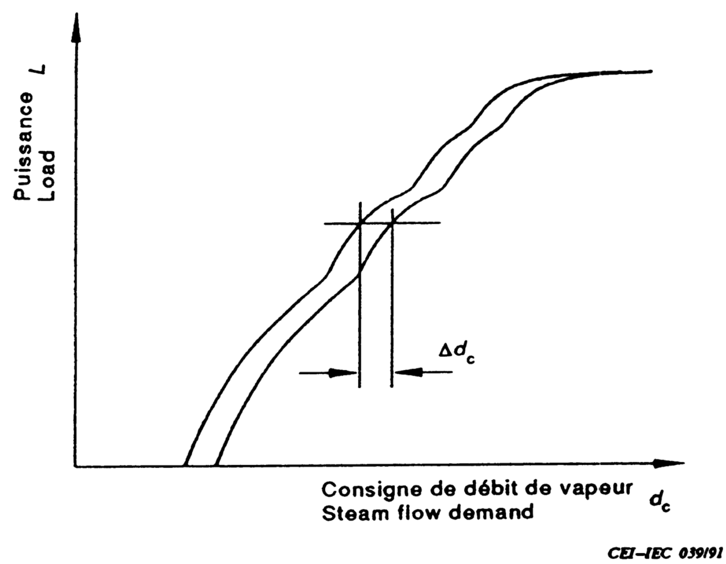

Figure 4a — Load-steam flow demand relationship

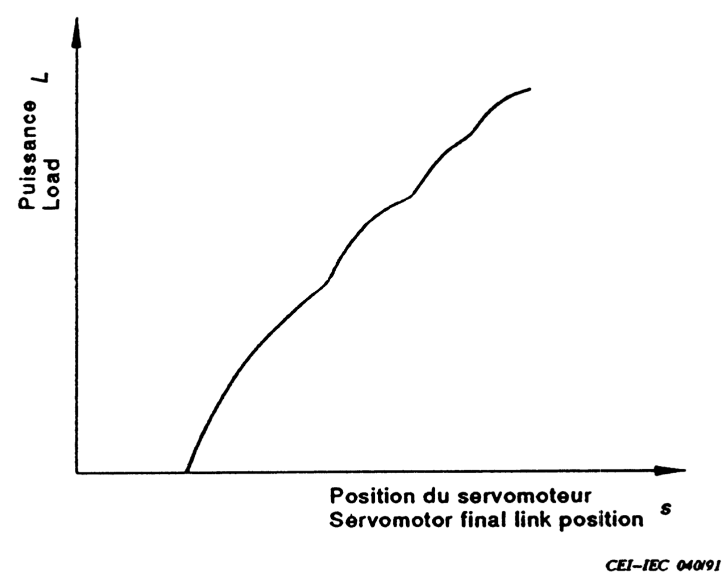

Figure 4b — Load-servomotor final link position relationship

Figure 4 — Static characteristics on load

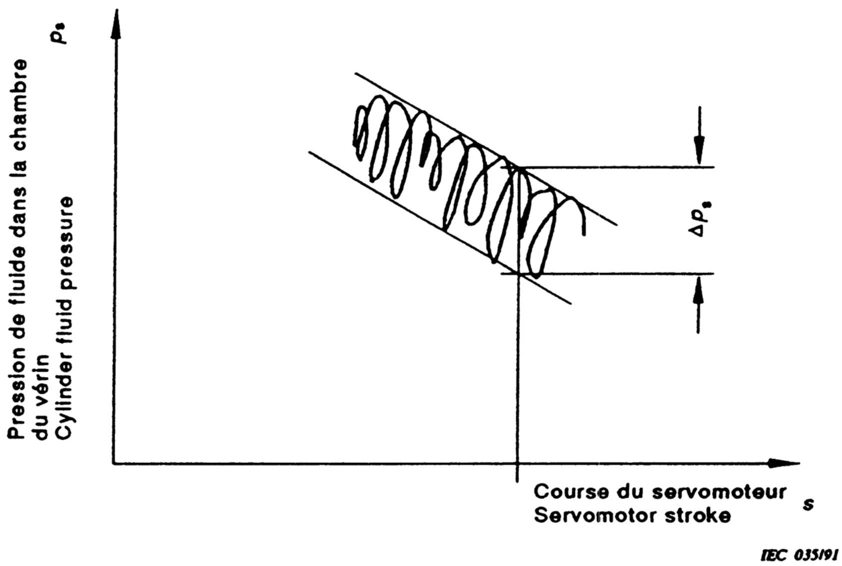

Figure 5 — Cylinder fluid pressure versus servomotor stroke

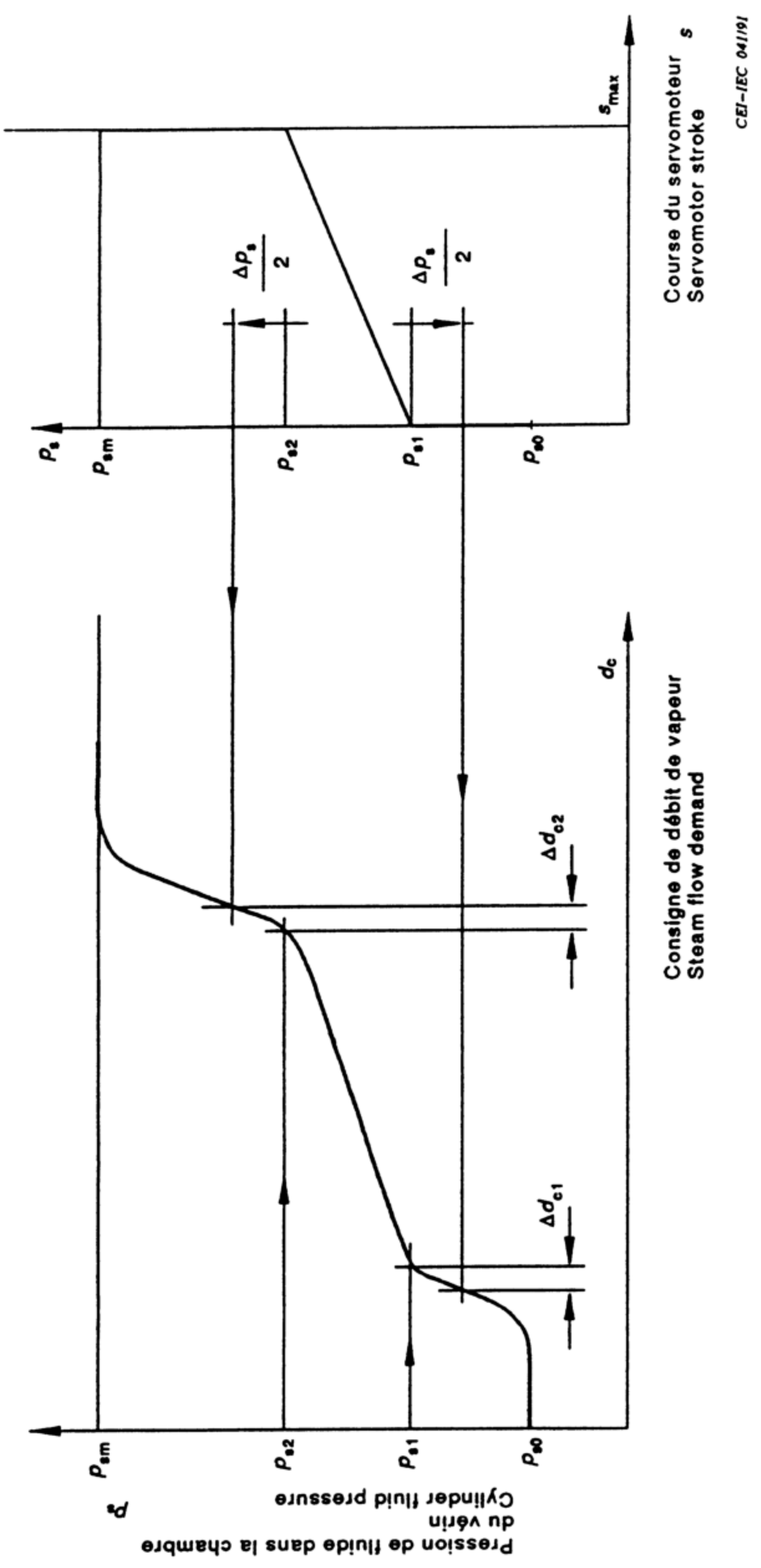

Figure 6 — Servomotor stiffness characteristic

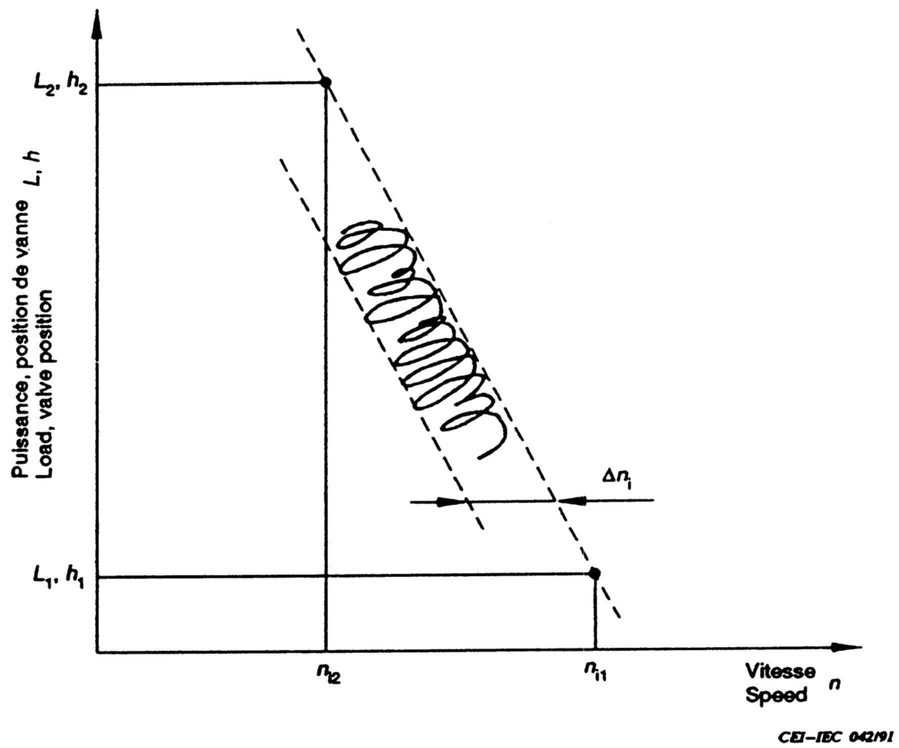

Figure 7 — Network frequency-load relationship

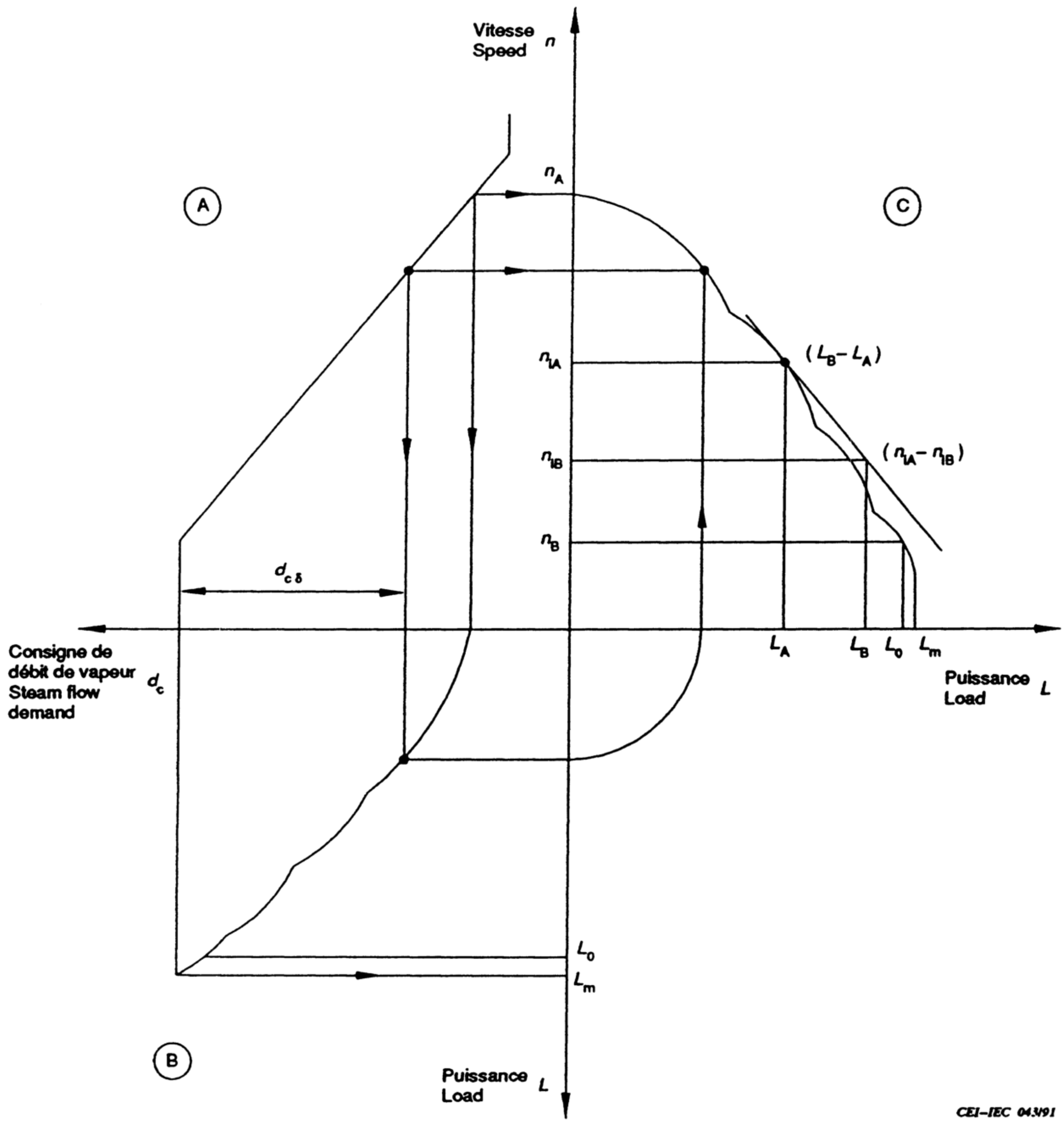

Figure 8 — Static characteristic of the speed governing system for one setting of the speed changer

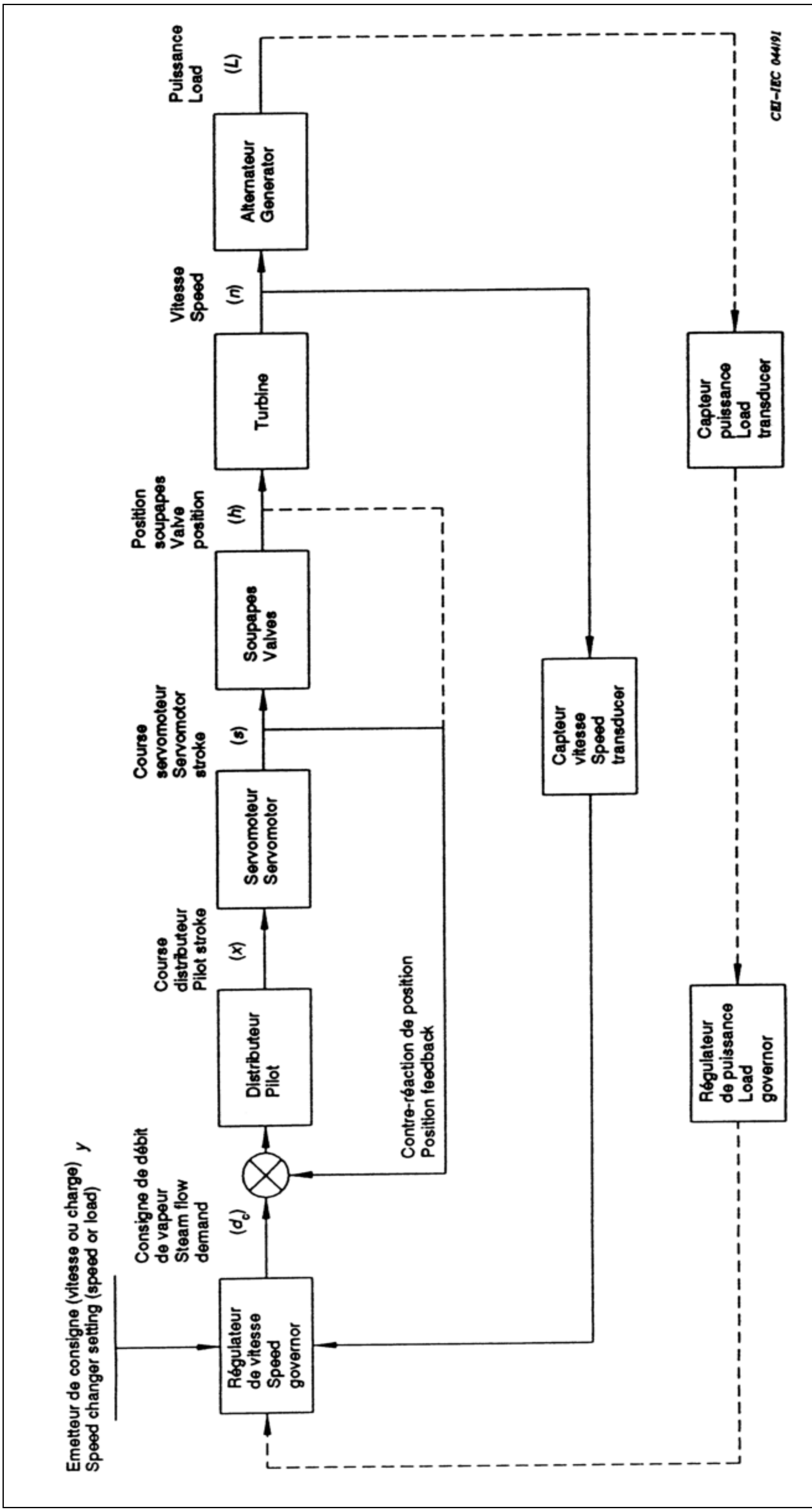

Figure 9 — Block-diagram of a typical speed governing system

Annex ZA (normative)
Other international publications quoted in this standard with the references of the relevant European publications

When the international publication has been modified by CENELEC common modifications, indicated by (mod), the relevant EN/HD applies.

IEC publication	Date	Title	EN/HD	Date
45-1	1991	*Steam turbines — Part 1: Specifications*	EN 60045-1	1993

National annex NA (informative) Committees responsible

The United Kingdom participation in the preparation of this European Standard was entrusted by the Machinery and Components Standards Policy Committee (MCE/-) to Technical Committee MCE/13 upon which the following bodies were represented:

Association of Consulting Engineers
Electricity Association
Electricity Supply Industry in England and Wales
North of Scotland Hydro-electric Board
Power Generation Association (BEAMA Ltd.)
South of Scotland Electricity Board
Coopted members

National annex NB (informative) Cross-references

Publication referred to	Corresponding British Standard
IEC 45-1:1991	BS EN 60045-1:1993 *Guide to steam turbine procurement*

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