

# **Hydraulic machines — Acceptance tests of small hydroelectric installations**

**National foreword**

This British Standard is the UK implementation of EN 62006:2011. It is identical to IEC 62006:2010.

The UK participation in its preparation was entrusted to Technical Committee MCE/15, Hydraulic turbines.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© BSI 2011

ISBN 978 0 580 54423 1

ICS 27.140

**Compliance with a British Standard cannot confer immunity from legal obligations.**

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 June 2011.

**Amendments issued since publication**

| Amd. No. | Date | Text affected |
|----------|------|---------------|
|----------|------|---------------|

EUROPEAN STANDARD  
NORME EUROPÉENNE  
EUROPÄISCHE NORM

**EN 62006**

February 2011

ICS 27.140

English version

**Hydraulic machines -  
Acceptance tests of small hydroelectric installations  
(IEC 62006:2010)**

Machines hydrauliques -  
Essais de réception des petits  
aménagements hydroélectriques  
(CEI 62006:2010)

Hydraulische Maschinen -  
Abnahmemessungen an Kleinwasserkraft-  
Anlagen  
(IEC 62006:2010)

This European Standard was approved by CENELEC on 2011-01-02. 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.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

# CENELEC

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

**Management Centre: Avenue Marnix 17, B - 1000 Brussels**

© 2011 CENELEC - All rights of exploitation in any form and by any means reserved worldwide for CENELEC members.

Ref. No. EN 62006:2011 E

**Documents**  
Document Sharing Hub

## Foreword

The text of document 4/254/FDIS, future edition 1 of IEC 62006, prepared by IEC TC 4, Hydraulic turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 62006 on 2011-01-02.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

- latest date by which the EN has to be implemented  
at national level by publication of an identical  
national standard or by endorsement (dop) 2011-10-02
- latest date by which the national standards conflicting  
with the EN have to be withdrawn (dow) 2014-01-02

Annex ZA has been added by CENELEC.

---

## Endorsement notice

The text of the International Standard IEC 62006:2010 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

|                 |      |                                                 |
|-----------------|------|-------------------------------------------------|
| IEC 60994       | NOTE | Harmonized as EN 60994.                         |
| IEC 61116       | NOTE | Harmonized as EN 61116.                         |
| IEC 61260       | NOTE | Harmonized as EN 61260.                         |
| ISO 4373        | NOTE | Harmonized as EN ISO 4373.                      |
| ISO 5167 series | NOTE | Harmonized in EN ISO 5167 series (not modified) |

---

## Annex ZA (normative)

### Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

| <u>Publication</u> | <u>Year</u> | <u>Title</u>                                                                                                                                                                                                                             | <u>EN/HD</u> | <u>Year</u> |
|--------------------|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|-------------|
| IEC 60041          | 1991        | Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines                                                                                                                     | EN 60041     | 1994        |
| IEC 60193          | -           | Hydraulic turbines, storage pumps and pump-turbines - Model acceptance tests                                                                                                                                                             | EN 60193     | -           |
| IEC 60308          | -           | Hydraulic turbines - Testing of control systems                                                                                                                                                                                          | EN 60308     | -           |
| IEC 60609          | Series      | Hydraulic turbines, storage pumps and pump-turbines - Cavitation pitting evaluation                                                                                                                                                      | EN 60609     | Series      |
| IEC 60651          | -           | Sound level meters                                                                                                                                                                                                                       | EN 60651     | -           |
| IEC 61362          | -           | Guide to specification of hydraulic turbine control systems                                                                                                                                                                              | EN 61362     | -           |
| ISO 1680           | -           | Acoustics - Test code for the measurement of airborne noise emitted by rotating electrical machines                                                                                                                                      | EN ISO 1680  | -           |
| ISO 1940-1         | 2003        | Mechanical vibration - Balance quality requirements for rotors in a constant (rigid) state -<br>Part 1: Specification and verification of balance tolerances                                                                             | -            | -           |
| ISO 3746           | -           | Acoustics - Determination of sound power levels of noise sources using sound pressure - Survey method using an enveloping measurement surface over a reflecting plane                                                                    | EN ISO 3746  | -           |
| ISO 4412           | Series      | Hydraulic fluid power - Test code for determination of airborne noise levels                                                                                                                                                             | -            | -           |
| ISO 5168           | -           | Measurement of fluid flow - Estimation of uncertainty of a flow-rate measurement                                                                                                                                                         | -            | -           |
| ISO 7919-5         | -           | Mechanical vibration - Evaluation of machine vibration by measurements on rotating shafts - Part 5: Machine sets in hydraulic power generating and pumping plants                                                                        | -            | -           |
| ISO 10816-3        | -           | Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts -<br>Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ | -            | -           |

| <u>Publication</u> | <u>Year</u> | <u>Title</u>                                                                                  | <u>EN/HD</u> | <u>Year</u> |
|--------------------|-------------|-----------------------------------------------------------------------------------------------|--------------|-------------|
| ANSI/IEEE 810      | -           | Hydraulic Turbine and Generator Integrally Forged Shaft Couplings and Shaft Runout Tolerances | -            | -           |

## CONTENTS

|        |                                                              |    |
|--------|--------------------------------------------------------------|----|
| 1      | Scope.....                                                   | 9  |
| 2      | Normative references .....                                   | 9  |
| 3      | Terms, definitions and schematic layout .....                | 10 |
| 3.1    | Terms and definitions .....                                  | 10 |
| 3.2    | Schematic layout of a hydroelectric installation .....       | 10 |
| 4      | Nature and extent of guarantees .....                        | 11 |
| 4.1    | Grouping of classes A, B, C .....                            | 11 |
| 4.1.1  | General .....                                                | 11 |
| 4.1.2  | Contract conditions .....                                    | 13 |
| 4.2    | Scope of performance guarantee .....                         | 13 |
| 4.2.1  | General .....                                                | 13 |
| 4.2.2  | Class A: Maximum power output .....                          | 13 |
| 4.2.3  | Class B: Index test .....                                    | 13 |
| 4.2.4  | Class C: Turbine efficiency .....                            | 13 |
| 4.2.5  | Interpretation of losses .....                               | 13 |
| 4.3    | Scope of tests .....                                         | 14 |
| 4.3.1  | Safety tests .....                                           | 14 |
| 4.3.2  | Trial run and reliability tests .....                        | 14 |
| 4.3.3  | Performance test .....                                       | 14 |
| 4.4    | Aptitude .....                                               | 15 |
| 4.5    | Warranty .....                                               | 15 |
| 5      | Safety tests (commissioning) .....                           | 16 |
| 5.1    | Pre-start tests .....                                        | 16 |
| 5.2    | Closing devices .....                                        | 16 |
| 5.2.1  | General .....                                                | 16 |
| 5.2.2  | Intake gate or valve .....                                   | 17 |
| 5.2.3  | Turbine inlet valve .....                                    | 17 |
| 5.2.4  | Guide vanes (Francis and Kaplan turbines) .....              | 17 |
| 5.2.5  | Needle valve and deflector (Pelton and Turgo turbines) ..... | 18 |
| 5.3    | First run operation and control .....                        | 19 |
| 5.4    | Bearing run at rated speed .....                             | 19 |
| 5.5    | Emergency shutdown (no load) .....                           | 20 |
| 5.6    | Electrical protection .....                                  | 20 |
| 5.7    | Overspeed test .....                                         | 21 |
| 5.8    | Runaway test .....                                           | 21 |
| 5.9    | Overpressure, emergency trip and load rejection tests .....  | 22 |
| 5.9.1  | General conditions .....                                     | 22 |
| 5.9.2  | Testing the guide vanes or needle valves .....               | 23 |
| 5.9.3  | Testing the turbine inlet valve .....                        | 23 |
| 5.9.4  | Testing the pressure relief valve .....                      | 23 |
| 5.9.5  | Pressure rise .....                                          | 23 |
| 5.10   | Measured quantities .....                                    | 25 |
| 5.10.1 | Pressure .....                                               | 25 |
| 5.10.2 | Speed .....                                                  | 25 |
| 5.10.3 | Control components .....                                     | 25 |

|       |                                                                              |    |
|-------|------------------------------------------------------------------------------|----|
| 6     | Trial operating and reliability tests (commissioning).....                   | 25 |
| 6.1   | General .....                                                                | 25 |
| 6.2   | Temperature stability of rotating parts .....                                | 25 |
| 6.2.1 | General .....                                                                | 25 |
| 6.2.2 | Temperature guarantees .....                                                 | 26 |
| 6.3   | Speed controller system .....                                                | 26 |
| 6.3.1 | General .....                                                                | 26 |
| 6.3.2 | Unit operating without regulation .....                                      | 26 |
| 6.3.3 | Unit operating with a speed governor.....                                    | 27 |
| 6.3.4 | Unit operating with a voltage governor.....                                  | 28 |
| 6.3.5 | Unit operating with a controller .....                                       | 28 |
| 6.3.6 | Measurements when testing the control system .....                           | 28 |
| 6.4   | Control of cam correlation .....                                             | 29 |
| 7     | Performance guarantees and tests .....                                       | 29 |
| 7.1   | General .....                                                                | 29 |
| 7.2   | Maximum generator (transformer) power output as a function of net head ..... | 30 |
| 7.2.1 | Guarantee .....                                                              | 30 |
| 7.2.2 | Instrumentation.....                                                         | 30 |
| 7.3   | Index test .....                                                             | 30 |
| 7.3.1 | General .....                                                                | 30 |
| 7.3.2 | Index discharge measurement .....                                            | 31 |
| 7.3.3 | Shape control .....                                                          | 31 |
| 7.3.4 | Index plant efficiency.....                                                  | 32 |
| 7.3.5 | Optimizing cam correlation .....                                             | 33 |
| 7.4   | Turbine efficiency .....                                                     | 33 |
| 7.4.1 | Efficiency test by absolute discharge measurement.....                       | 33 |
| 7.4.2 | Efficiency test by thermodynamic method .....                                | 34 |
| 7.5   | Correcting the efficiency using the model curve.....                         | 34 |
| 8     | Computation of results and comparison to the guarantee .....                 | 36 |
| 8.1   | General .....                                                                | 36 |
| 8.1.1 | Site data .....                                                              | 36 |
| 8.1.2 | Measured values (readings) .....                                             | 36 |
| 8.1.3 | Scale effect due to water temperature .....                                  | 37 |
| 8.1.4 | Shifting of the plant characteristic .....                                   | 37 |
| 8.2   | Power output .....                                                           | 37 |
| 8.2.1 | Plant power output measurement .....                                         | 37 |
| 8.2.2 | Generator power output measurement.....                                      | 38 |
| 8.2.3 | Turbine power output measurement.....                                        | 38 |
| 8.3   | Relative turbine efficiency (index test) .....                               | 38 |
| 8.3.1 | General .....                                                                | 38 |
| 8.3.2 | Relative discharge .....                                                     | 38 |
| 8.3.3 | Guarantee of the shape of the plant characteristics .....                    | 39 |
| 8.3.4 | Relative index plant efficiency .....                                        | 40 |
| 8.4   | Absolute turbine efficiency .....                                            | 40 |
| 8.4.1 | General .....                                                                | 40 |
| 8.4.2 | Absolute discharge .....                                                     | 40 |
| 8.4.3 | Guarantee of the plant efficiency and comparison to the results .....        | 40 |
| 9     | Error analysis .....                                                         | 40 |

|                       |                                                                                 |     |
|-----------------------|---------------------------------------------------------------------------------|-----|
| 9.1                   | General .....                                                                   | 40  |
| 9.2                   | Estimation of systematic (bias) uncertainties .....                             | 41  |
| 9.2.1                 | General .....                                                                   | 41  |
| 9.2.2                 | Typical systematic uncertainties .....                                          | 41  |
| 9.2.3                 | Systematic uncertainty for turbines used to indicate discharge .....            | 42  |
| 9.3                   | Estimation of random (precision) uncertainties .....                            | 42  |
| 9.3.1                 | Measurement at a single operation point .....                                   | 42  |
| 9.3.2                 | Measurement over a range of operating condition .....                           | 44  |
| 9.4                   | Evaluation of the uncertainties .....                                           | 45  |
| 9.4.1                 | General .....                                                                   | 45  |
| 9.4.2                 | Head .....                                                                      | 45  |
| 9.4.3                 | Power output .....                                                              | 47  |
| 9.4.4                 | Index test measurement .....                                                    | 49  |
| 9.4.5                 | Efficiency test by absolute discharge measurement .....                         | 51  |
| 9.4.6                 | Efficiency test by the thermodynamic method .....                               | 51  |
| 10                    | Other guarantees .....                                                          | 51  |
| 10.1                  | Cavitation .....                                                                | 51  |
| 10.1.1                | General .....                                                                   | 51  |
| 10.1.2                | Measurement methods .....                                                       | 52  |
| 10.1.3                | Comparison with specified guarantees .....                                      | 52  |
| 10.2                  | Noise .....                                                                     | 53  |
| 10.2.1                | General .....                                                                   | 53  |
| 10.2.2                | Measurement methods .....                                                       | 53  |
| 10.2.3                | Comparison with specified guarantees .....                                      | 54  |
| 10.3                  | Vibration .....                                                                 | 54  |
| 10.3.1                | General .....                                                                   | 54  |
| 10.3.2                | Measurements and measurement methods .....                                      | 54  |
| 10.3.3                | Comparison with specified guarantees .....                                      | 55  |
| Annex A (normative)   | Terms, definitions, symbols and units .....                                     | 56  |
| Annex B (normative)   | Head definition .....                                                           | 64  |
| Annex C (normative)   | Method of speed measurements .....                                              | 77  |
| Annex D (normative)   | Power output measurement .....                                                  | 78  |
| Annex E (normative)   | Methods of discharge measurement .....                                          | 82  |
| Annex F (informative) | Plant condition .....                                                           | 95  |
| Annex G (informative) | Commissioning .....                                                             | 97  |
| Annex H (informative) | Performance test efficiency calculation .....                                   | 99  |
| Annex I (informative) | Cam correlation test .....                                                      | 106 |
| Bibliography.         | .....                                                                           | 109 |
| Figure 1              | – Schematic layout of a hydroelectric installation (water to wire system) ..... | 11  |
| Figure 2              | – Warranty period .....                                                         | 16  |
| Figure 3              | – Vanes and blades servomotors force measurements (Kaplan on line) .....        | 17  |
| Figure 4              | – Evaluation of the guide vane (GV) closing characteristic .....                | 18  |
| Figure 5              | – Needle servomotor force .....                                                 | 18  |
| Figure 6              | – Automatic start – Synchronization – No load test (Kaplan turbine) .....       | 19  |
| Figure 7              | – Emergency shutdown from no load test (Kaplan turbine) .....                   | 20  |

|                                                                                                                                                             |    |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 8 – Runaway test (Kaplan turbine) .                                                                                                                  | 21 |
| Figure 9 – Emergency shutdown due to an electrical fault .                                                                                                  | 22 |
| Figure 10 – Emergency shutdown due to a mechanical fault .                                                                                                  | 23 |
| Figure 11 – Emergency shutdown due to the governor failure .                                                                                                | 24 |
| Figure 12 – Evaluation of the maximum overpressure .                                                                                                        | 24 |
| Figure 13 – Temperature stability, recording at no load up to stable conditions .                                                                           | 26 |
| Figure 14 – Speed governor check at no load .                                                                                                               | 27 |
| Figure 15 – Maximum power output: procedure to compare measured power output at actual net head to the guarantee .                                          | 30 |
| Figure 16 – Comparison of the shape of the turbine characteristic to the guarantee .                                                                        | 32 |
| Figure 17 – Example of an optimized switch band for 1 and 2 turbine operation .                                                                             | 33 |
| Figure 18 – Efficiency test: procedure to compare guaranteed turbine efficiency to the prototype measurement results, including the overall uncertainties . | 34 |
| Figure 19 – Hill chart – Showing head loss examples with one and two units in operation using the same penstock .                                           | 35 |
| Figure 20 – Shifting of the performance curves .                                                                                                            | 37 |
| Figure 21 – Variation of factor k and exponent x on turbine index efficiency .                                                                              | 39 |
| Figure 22 – Random uncertainties of a single operation point, example for penstock pressure variation and fluctuation .                                     | 43 |
| Figure 23 – Detection of outlier errors: example to find out offset and reading errors by plotting in linear and logarithmic form with the same data .      | 44 |
| Figure 24 – Example of scattered points with function of second order .                                                                                     | 44 |
| Figure 25 – Scattered points smoothed by individual fitting on adjacent sections .                                                                          | 45 |
| Figure 26 – Overall uncertainty of head for free water level for low head turbines .                                                                        | 46 |
| Figure 27 – Overall uncertainty of head in a closed conduit .                                                                                               | 47 |
| Figure 28 – Estimated overall uncertainties of the discharge by index measurement versus full scale differential pressure .                                 | 50 |
| Figure 29 – Operation range and cavitation limits .                                                                                                         | 52 |
| Figure A.1 – Transient pressure fluctuation at the turbine high pressure reference section, when a specified load is suddenly rejected .                    | 61 |
| Figure A.2 – Transient pressure fluctuation at the turbine high pressure reference section, when a specified load is suddenly accepted .                    | 62 |
| Figure B.1 – High pressure reference and measuring sections .                                                                                               | 65 |
| Figure B.2 – Measuring section at tail water .                                                                                                              | 66 |
| Figure B.3 – Measuring section at draft tube .                                                                                                              | 66 |
| Figure B.4 – Definition of measuring sections .                                                                                                             | 67 |
| Figure B.5 – Kaplan turbine with horizontal shaft .                                                                                                         | 68 |
| Figure B.6 – Kaplan turbine with vertical shaft .                                                                                                           | 68 |
| Figure B.7 – Francis open flume turbine with vertical shaft .                                                                                               | 69 |
| Figure B.8 – Francis turbine with horizontal shaft .                                                                                                        | 69 |
| Figure B.9 – Francis turbine with vertical shaft, with stagnation probe .                                                                                   | 70 |
| Figure B.10 – Francis turbine with horizontal shaft with pressure on suction side .                                                                         | 70 |
| Figure B.11 – Pelton turbine with horizontal shaft .                                                                                                        | 71 |
| Figure B.12 – Pelton turbine with vertical shaft .                                                                                                          | 71 |
| Figure B.13 – Turgo turbine with horizontal shaft .                                                                                                         | 72 |
| Figure B.14 – Turgo turbine with vertical shaft .                                                                                                           | 72 |

|                                                                                                                                               |     |
|-----------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Figure B.15 – Crossflow turbine with horizontal shaft, with draft tube .....                                                                  | 73  |
| Figure B.16 – Crossflow turbine with horizontal shaft, without draft tube .....                                                               | 73  |
| Figure B.17 – Specifications for static pressure taps .....                                                                                   | 74  |
| Figure B.18 – Example: discharge versus guide vane opening .....                                                                              | 76  |
| Figure C.1 – Overspeed and runaway .....                                                                                                      | 77  |
| Figure D.1 – Typical losses of a synchronous generator .....                                                                                  | 79  |
| Figure D.2 – Asynchronous generator: typical power factor and slip factor .....                                                               | 80  |
| Figure D.3 – Power measurement using the two wattmeter method .....                                                                           | 80  |
| Figure D.4 – Power measurement using the three wattmeter method .....                                                                         | 81  |
| Figure E.1 – Typical arrangements of acoustic transducers .....                                                                               | 84  |
| Figure E.2 – Arrangement for pressure time method .....                                                                                       | 85  |
| Figure E.3 – Example of pressure-time diagram for a uniform conduit .....                                                                     | 86  |
| Figure E.4 – Example of pressure-time diagram for a non-uniform conduit .....                                                                 | 86  |
| Figure E.5 – Example of pressure-time diagram for a combination of uniform and non<br>uniform conduits between several sections .....         | 87  |
| Figure E.6 – Location of taps for differential pressure method of discharge measurement .....                                                 | 93  |
| Figure E.7 – Location of taps for differential pressure measurement of discharge in a<br>bulb turbine .....                                   | 93  |
| Figure E.8 – Location of taps for Winter-Kennedy method of discharge measurement<br>through a turbine equipped with a steel spiral case ..... | 94  |
| Figure H.1 – Comparison of measured index efficiency with the guaranteed values .....                                                         | 105 |
| Figure I.1 – Index measurement to optimize the efficiency .....                                                                               | 107 |
| Figure I.2 – Two dimensional cam correlation .....                                                                                            | 108 |
| Table 1 – Scope of classes A, B, and C .....                                                                                                  | 12  |
| Table 2 – Maximum runaway speeds ( $n_{run}$ ) expressed as a percentage of rated speed .....                                                 | 21  |
| Table 3 – Performance test parameters .....                                                                                                   | 29  |
| Table 4 – Index discharge measurement methods .....                                                                                           | 31  |
| Table 5 – Site data .....                                                                                                                     | 36  |
| Table 6 – Systematic uncertainties at full load .....                                                                                         | 41  |
| Table 7 – Systematic uncertainties of discharge versus turbine opening .....                                                                  | 42  |
| Table 8 – Overall uncertainties of the shape of turbine characteristics with respect to<br>the guaranteed efficiency .....                    | 49  |
| Table 9 – Data used in Figure 28 .....                                                                                                        | 51  |
| Table 10 – Limits for cavitation damage .....                                                                                                 | 53  |
| Table A.1 – Density of water .....                                                                                                            | 62  |
| Table E.1 – Selection of flow measurement method .....                                                                                        | 82  |
| Table E.2 – Evaluation of the penstock factor with estimation of the systematic uncertainty .....                                             | 91  |
| Table H.1 – Plant index efficiency guarantee .....                                                                                            | 99  |
| Table H.2 – Transformer data .....                                                                                                            | 100 |
| Table H.3 – Data measurements (not all tests included) .....                                                                                  | 101 |
| Table H.4 – Calculation of results .....                                                                                                      | 102 |

## HYDRAULIC MACHINES – ACCEPTANCE TESTS OF SMALL HYDROELECTRIC INSTALLATIONS

### 1 Scope

This International Standard defines the test, the measuring methods and the contractual guarantee conditions for field acceptance tests of the generating machinery in small hydroelectric power installations. It applies to installations containing impulse or reaction turbines with unit power up to about 15 MW and reference diameter of about 3 m. The driven generator can be of synchronous or asynchronous type.

This International Standard contains information about most of the tests required for acceptance of the hydraulic turbine such as safety approval tests, trial operating and reliability tests, as well for verification of cavitation, noise and vibration conditions, if required.

This standard represents the typical methods used on smaller hydroelectric installations, and is divided into three classes as follows (see Table 1 for more detail):

|                |                                                                                                       |                    |
|----------------|-------------------------------------------------------------------------------------------------------|--------------------|
| <b>Class A</b> | Normal test program (panel measurement)<br>To determine the maximum power output of the installation. | <b>Default</b>     |
| <b>Class B</b> | Extended test program<br>To determine the performance characteristics of the installation.            | <b>Recommended</b> |
| <b>Class C</b> | Comprehensive test program<br>To determine the absolute efficiency of the installation.               | <b>Optional</b>    |

NOTE All classes contain safety tests, trial operating tests, and reliability tests.

This standard gives all necessary references for the contract in order to execute the test, evaluate, calculate and compare the result to the guarantee for all the classes A, B and C.

The manufacturer or consulting engineer is responsible for ensuring that standardized connections are installed for performing these tests. This standard does not cover the structural details of a hydroelectric installation or its component parts.

### 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60041:1991, *Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump turbines*

IEC 60193, *Hydraulic turbines, storage pumps and pump-turbines – Model acceptance tests*

IEC 60308, *Hydraulic turbines – Testing of control systems*

IEC 60609 (all parts), *Hydraulic turbines, storage pumps and pump-turbines – Cavitation pitting evaluation*

IEC 60651, *Specification for sound level meters*

IEC 61362, *Guide to specification of hydraulic turbine control systems*

ISO 1680 *Acoustics – Test code for the measurement of airborne noise emitted by rotating electrical machinery*

ISO 1940-1:2003, *Mechanical vibration – Balance quality requirements for rotors in a constant (rigid) state – Part 1: Specification and verification of balance tolerances*

ISO 3746, *Acoustics – Determination of sound power levels of noise sources using sound pressure – Survey method using an enveloping measurement surface over a reflecting plane*

ISO 4412 (all parts), *Hydraulic fluid power – Test code for determination of airborne noise levels*

ISO 5168, *Measurement of fluid flow – Procedures for the evaluation of uncertainties*

ISO 7919-5, *Mechanical vibration – Evaluation of machine vibration by measurements on rotating shafts – Part 5: Machine sets in hydraulic power generating and pumping plants*

ISO 10816-3, *Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts – Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ*

ANSI/IEEE 810, *Hydraulic Turbine and Generator Integrally Forged Shaft Couplings and Shaft Runout Tolerances*

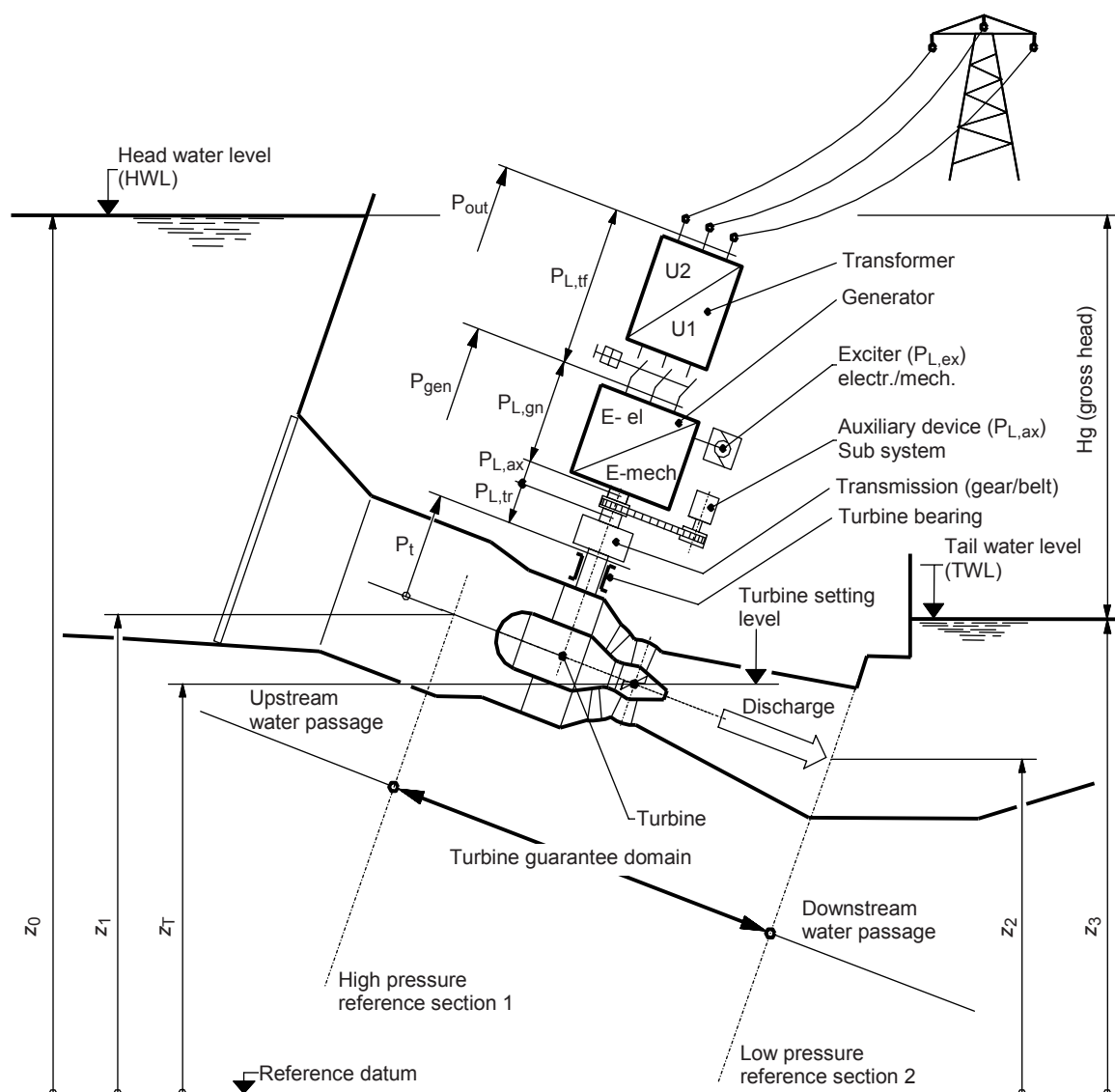
### **3 Terms, definitions and schematic layout**

#### **3.1 Terms and definitions**

A complete list of terms and definitions is given in Annex A.

#### **3.2 Schematic layout of a hydroelectric installation**

In general, there are three connected hydraulic regimes in a hydroelectric installation as shown in Figure 1 below. These are the upstream water passage, the turbine guarantee domain, and the downstream water passage.



NOTE The losses in the upstream and downstream water passage are not part of the turbine losses. Nevertheless, they may influence the hydraulic conditions in the turbine guarantee domain and lower the efficiency of the turbine. Only the energy losses in the turbine guarantee section are to be considered when measuring the efficiency of a turbine. If it is not possible to measure the energy in the reference section 1 and 2, the measuring section should be changed in agreement with all parties.

The definition of the reference section 1 and 2 and that of net head and specific energy for the most common small turbines is given in Annex B.

**Figure 1 – Schematic layout of a hydroelectric installation (water to wire system)**

## 4 Nature and extent of guarantees

### 4.1 Grouping of classes A, B, C

#### 4.1.1 General

The scope of the measurement classes for hydroelectric installations is shown in Table 1.

**Table 1 – Scope of classes A, B, and C**

| Class A Normal (panel measurement) test program                                                                                                                                                                                                                                                                                                  |         |         |         |        |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|---------|---------|--------|
| Class B Extended test program                                                                                                                                                                                                                                                                                                                    |         |         |         |        |
| Class C Comprehensive test program                                                                                                                                                                                                                                                                                                               |         |         |         |        |
| Measurement of class                                                                                                                                                                                                                                                                                                                             | C       | B       | A       | Clause |
| Safety tests (commissioning)                                                                                                                                                                                                                                                                                                                     |         |         |         | 5      |
| Pre-start tests (dry test)                                                                                                                                                                                                                                                                                                                       | yes     | yes     | yes     | 5.1    |
| Closing devices (dry and wet tests)                                                                                                                                                                                                                                                                                                              | yes     | yes     | yes     | 5.2    |
| First run operation and control (wet tests)                                                                                                                                                                                                                                                                                                      | yes     | yes     | yes     | 5.3    |
| Bearing run at rated speed                                                                                                                                                                                                                                                                                                                       | yes     | yes     | yes     | 5.4    |
| Emergency shutdown (no load)                                                                                                                                                                                                                                                                                                                     | yes     | yes     | yes     | 5.5    |
| Electrical protection                                                                                                                                                                                                                                                                                                                            | yes     | yes     | yes     | 5.6    |
| Overspeed test                                                                                                                                                                                                                                                                                                                                   | yes     | yes     | yes     | 5.7    |
| Runaway test                                                                                                                                                                                                                                                                                                                                     | no/opt  | no/opt  | no/opt  | 5.8    |
| Overpressure, emergency trip and load rejection tests                                                                                                                                                                                                                                                                                            | yes     | yes     | yes     | 5.9    |
|                                                                                                                                                                                                                                                                                                                                                  |         |         |         |        |
| Trial operating and reliability tests (commissioning)                                                                                                                                                                                                                                                                                            |         |         |         | 6      |
| Temperature stability of rotating parts                                                                                                                                                                                                                                                                                                          | yes     | yes     | yes     | 6.2    |
| Speed controller system                                                                                                                                                                                                                                                                                                                          | yes/opt | yes/opt | yes/opt | 6.3    |
| Control of cam correlation (double regulated turbines)                                                                                                                                                                                                                                                                                           | yes     | yes     | yes     | 6.4    |
|                                                                                                                                                                                                                                                                                                                                                  |         |         |         |        |
| Performance guarantees and tests                                                                                                                                                                                                                                                                                                                 |         |         |         | 7      |
| Maximum generator (transformer) power output                                                                                                                                                                                                                                                                                                     | a       | a       | yes     | 7.2    |
| Index test                                                                                                                                                                                                                                                                                                                                       |         |         |         | 7.3    |
| - Shape control                                                                                                                                                                                                                                                                                                                                  | a       | yes     | –       | 7.3.3  |
| - Index plant efficiency                                                                                                                                                                                                                                                                                                                         | a       | yes     | –       | 7.3.4  |
| - Optimizing cam correlation                                                                                                                                                                                                                                                                                                                     | a       | a       | a       | 7.3.5  |
| Turbine efficiency                                                                                                                                                                                                                                                                                                                               |         |         |         | 7.4    |
| - Absolute discharge measurement                                                                                                                                                                                                                                                                                                                 | yes     | –       | –       | 7.4.1  |
| - Thermodynamic method                                                                                                                                                                                                                                                                                                                           | yes     | –       | –       | 7.4.2  |
|                                                                                                                                                                                                                                                                                                                                                  |         |         |         |        |
| Computation of results and comparison to the guarantee                                                                                                                                                                                                                                                                                           | yes     | yes     | yes     | 8      |
| Error analysis                                                                                                                                                                                                                                                                                                                                   | yes     | yes     | yes     | 9      |
| Other guarantees                                                                                                                                                                                                                                                                                                                                 |         |         |         | 10     |
| Cavitation                                                                                                                                                                                                                                                                                                                                       | yes/opt | yes/opt | yes/opt | 10.1   |
| Noise                                                                                                                                                                                                                                                                                                                                            | no/opt  | no/opt  | no/opt  | 10.2   |
| Vibration                                                                                                                                                                                                                                                                                                                                        | no/opt  | no/opt  | no/opt  | 10.3   |
| <p>NOTE Definitions used in Table 1 are the following:</p> <p>yes – may be required.</p> <p>yes/opt(ional) – normally yes, but depends on the turbine type and site conditions.</p> <p>no/opt(ional) – normally no, but depends on the turbine type and site conditions.</p> <p><sup>a</sup> included in other tests.</p> <p>– not required.</p> |         |         |         |        |

#### 4.1.2 Contract conditions

The contract specifies the guarantees, and includes the scope of the tests, and the classification of measuring instruments. Safety tests shall always be included. The condition of the plant, water quality, and setting levels shall all be specified (see Annex F).

### 4.2 Scope of performance guarantee

#### 4.2.1 General

All guarantees concern the hydraulic passage between reference section 1 and 2 (turbine guarantee domain) and the corresponding net head. The guaranteed data required for each class is given below:

#### 4.2.2 Class A: Maximum power output

- a) Maximum power output of the generator, including losses a) to d) of 4.2.5  $P_{\text{gen, max}} = f(H)$
- b) Maximum power output of the transformer, including losses a) to e) of 4.2.5  $P_{\text{out, max}} = f(H)$ 
  - Power output versus net head, see Figure 15
  - Discharge versus turbine opening, see Figure B.18
  - Electrical connection sheet, see Annex D

#### 4.2.3 Class B: Index test

Shape control of turbine characteristic for newly commissioned turbines, and for refurbishment projects to compare pre- and post- refurbishment measurements.

- a) Shape control  $\eta_{ix} = f(P_t)$ 
  - Expected shape of plant efficiency, see Figure 16
  - Possible deviation to the shape, see Figure 16
  - Hill chart if the head differs by more than 3 %, see Figure 19
- b) Index plant efficiency  $\eta_{\text{plant ix}} = f(P_{\text{out}})$ 
  - Hill chart, see Figure 19
  - Generator losses, see Annex D
  - Electrical connection sheet, see Annex D
- c) Optimizing of cam correlation for double regulated turbines
  - Pre-adjusted opening of guide vane versus runner blade opening as a function of static head, see Annex I

#### 4.2.4 Class C: Turbine efficiency

- a) Absolute discharge measurement  $\eta_t = f(P_t)$
- b) Thermodynamic method  $\eta_t = f(P_t)$ 
  - Hill chart, see Figure 19
  - Generator losses, see Annex D
  - Electrical connection sheet, see Annex D

#### 4.2.5 Interpretation of losses

The parties shall agree on interpretation of losses due to the following mechanical and electrical equipment:

- a) turbine bearings and additional equipment;

- b) mechanical power transmission devices such as gears and belts;
- c) generator including bearings, excitation system, mechanically driven or electrically connected auxiliaries;
- d) mechanically or electrically driven auxiliaries;
- e) transformer.

The following subsystems and devices are excluded from consideration:

- f) devices which are needed for dewatering (mud pumps);
- g) temporary heating and / or cooling systems;
- h) any lights.

### **4.3 Scope of tests**

#### **4.3.1 Safety tests**

If testing reveals that operation of the unit is not safe, then no further operation of the plant may be continued, until such deficiency is located, evaluated and repaired.

#### **4.3.2 Trial run and reliability tests**

When all the safety tests are completed, and within the allowable limits, the time limited trial run can be started. The duration of the trial run is normally at least 72 h.

#### **4.3.3 Performance test**

##### **4.3.3.1 General test condition**

- a) Method of measurement: the methods to be used for the measurement or computation of discharge, power, head, efficiency, speed, and losses shall be stated in the general procedure (see Clauses 7, 8, and 9).
- b) Number of points, runs and readings: a performance curve such as the ones shown in Figure 15 (class A), Figure 16 (class B), and Figure 18 (class C) requires a minimum of six and preferably eight or ten points. Each point will be obtained from one or more runs (see Figure 25 and Table H.4). The number of measurements taken during a run depends upon the methods of measurement used. To eliminate outliers, at least three runs are to be taken over an agreed time or over the duration of any time-based measurement.
- c) The interval of time used for instrument recording shall generally be the same for each variable.
- d) Small hydro turbines are often built from standard components. Care shall be taken to avoid operating the turbine above its maximum power (see Figure 15).

##### **4.3.3.2 Test condition to be fulfilled**

- a) Fluctuations and variations during a run (see Figure 22, Figure 23, and Figure 24). Fluctuations are defined as high frequency changes, of more than 1 Hz, in the values of head, power output, discharge and rotational speed about average values. They are often caused by head and pressure variation in the peripheral areas such as the river, canal, reservoir, penstock, and outlet channel. Variations are longer period changes or trends.
- b) The extreme variation of power shall not exceed  $\pm 1,5$  % of the average value of power.
- c) The extreme variation of head (pressure) shall not exceed  $\pm 0,5$  % of the average of value of head (pressure).
- d) The extreme variation of rotational speed shall not exceed  $\pm 0,5$  % of the average of value of rotational speed.

#### 4.3.3.3 General check after the tests

The preliminary computation of the test results shall be made at site. If the plant appears to fail its guarantee, steps shall be taken to identify the cause before disconnecting the instrumentation.

- a) Check the data for errors, and recalculate the results if any errors are found.
- b) Check all the instrumentation for correct connection, calibration, absence of air in the measuring pipes, and for irregular fluctuations.
- c) Check for random errors and outliers.
- d) Check for any hydraulic failure within the waterway such as the inflow conditions.
- e) Check for suspended particles within the turbine such as grass, algae, or industrial fibre, etc. (stop the turbine, and clean the turbine and the water passages).
- f) Check of the reference levels.
- g) Check of the unit for any abnormal hydraulic and/or electrical behaviour.
- h) Check for possible air release at the draft tube outlet.
- i) Investigate unexpected vibrations and/or noise level.
- j) Verify the equipment set-up and the flow passage geometry:
  - turbine opening in closed and full opened position, check for any signal offset;
  - cam correlation (double regulated turbines);
  - deflector correlation to needle opening;
  - runner geometry.

After this investigation, the chief of tests shall make a short report to indicate the possible reason for failure. The manufacturer shall have the right to inspect the dewatered turbine and the upstream and downstream water passages at this time.

#### 4.4 Aptitude

All parties shall have confidence in the test team with respect to responsibility and competence when testing the unit under critical conditions. Commissioning engineers shall normally carry out class A tests. Specialists may be required to carry out class B and C tests.

#### 4.5 Warranty

An example of a procedure for installation, acceptance and warranty of a hydroelectric installation is shown in Figure 2.

**Contract**

- production
- delivery

**Installation**

- commissioning
- start up
- debugging

**Commissioning test (trial run)**

- safe and commercial operation
- punch list is handed over

**Acceptance tests**

- performance
- vibration
- noise

**Chief of test**

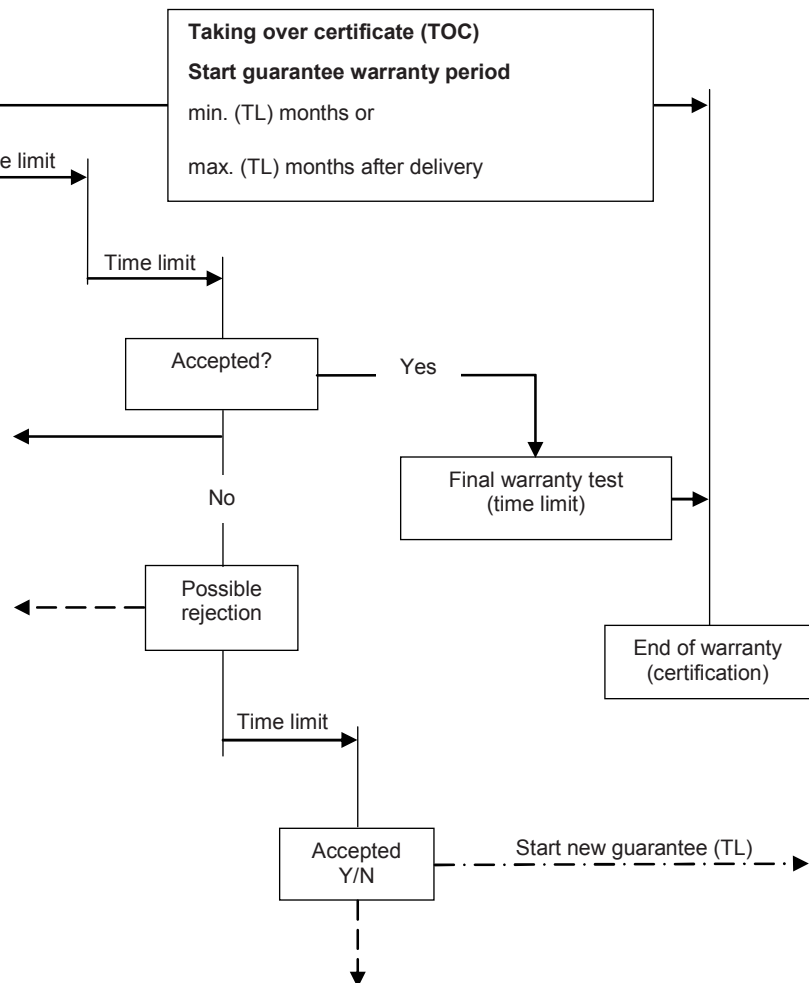
- before disconnecting the instrumentation → countercheck
- inspection
- report

**Manufacturer : have the right**

- inspect the turbine and waterway
- make internal tests on the unit

**Improvement/proposal****Repair**

- start tests

**New guarantee**

NOTE TL is the mutually agreed Time Limit (normally 6 months).

**Figure 2 – Warranty period**

## 5 Safety tests (commissioning)

### 5.1 Pre-start tests

Small hydro installations vary considerably as to their complexity. Some general guidance as to the nature of commissioning is given in Annex G.

### 5.2 Closing devices

#### 5.2.1 General

Ensuring that the water supply can be turned off safely under all circumstances is a matter of safety. The following control devices should be carefully checked.

### 5.2.2 Intake gate or valve

This device is normally designed to close in any condition including leakage or rupture of the penstock. The closing time shall be set to prevent dangerous surges or water waves in the channel or in the upper bay.

### 5.2.3 Turbine inlet valve

This valve should be normally designed to close against maximum discharge, and when the turbine is at runaway conditions. Closing characteristics and closing time are generally selected so that surges and water hammer effects are less than the effects caused by the turbine.

### 5.2.4 Guide vanes (Francis and Kaplan turbines)

This component is the main regulating device and shall be able to close against full discharge both in normal and emergency conditions. Operation of the guide vanes should be tested under all known operating conditions. The friction forces and hydraulic forces should be compared with relevant design values for dry and wet opening and closing pressures, and load ramps from no load to full load and back, see Figure 3 and Figure 4).

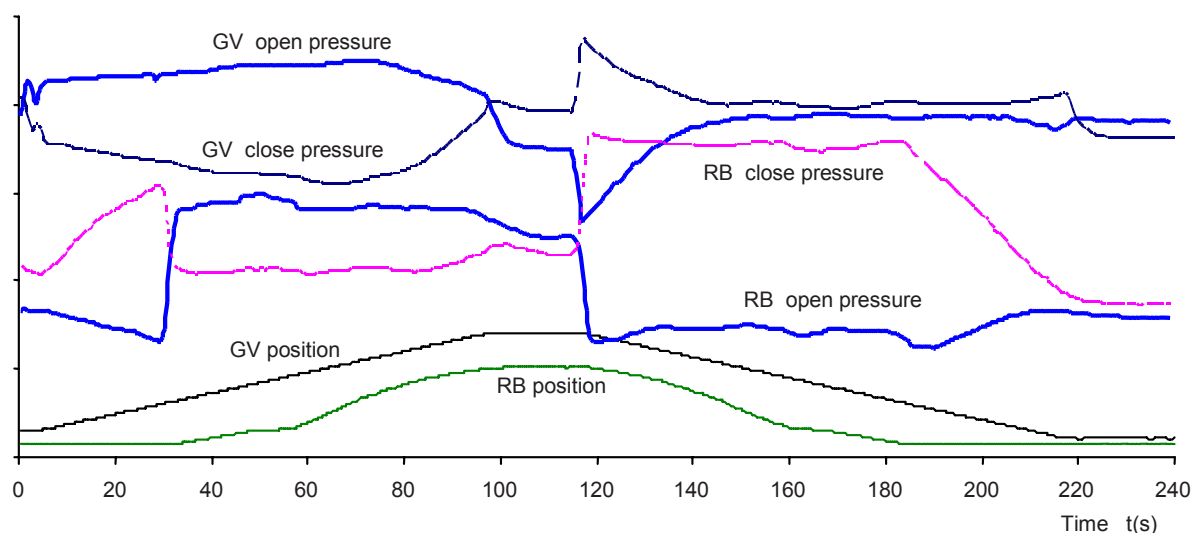
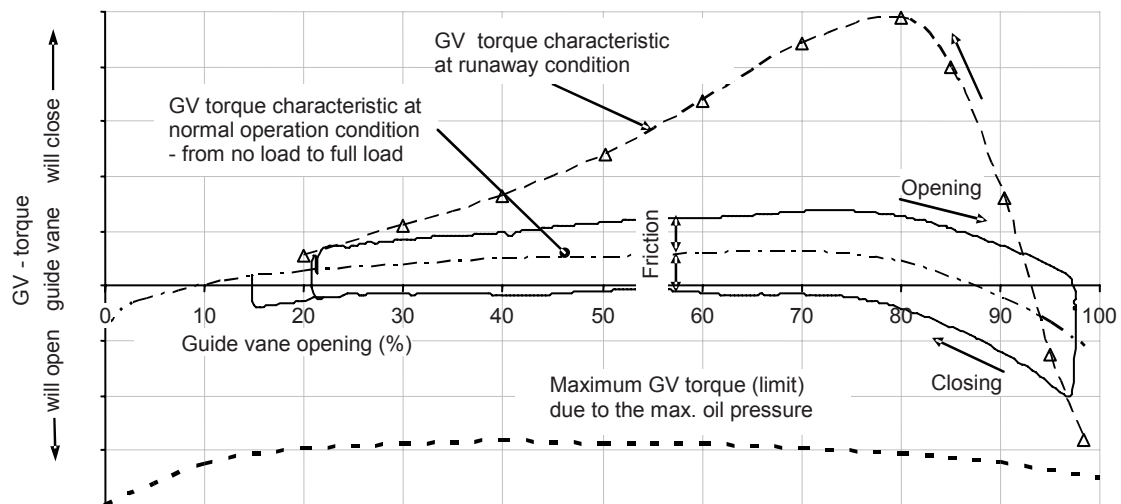


**Figure 3 – Vanes and blades servomotors force measurements (Kaplan on line)**

The guide vane closing characteristic and closing time are generally defined in order to optimize the opposing effects on overpressure (water hammer) and overspeed. Generally, the most severe conditions occur during emergency shutdown or during load rejection.

In double regulated Kaplan or bulb turbines the overspeed under normal operation may be controlled by the opening of the runner blades (see Figure 3). In these cases, opening and closing pressures of the runner blade servomotors shall also be recorded, in order to calculate friction and hydraulic forces and to compare those with design values.



NOTE The characteristics of the guide vane (GV) torque represents a typical design. However, the individual characteristics of the curve, in terms of opening and closing, depend on the individual GV shape and profile.

**Figure 4 – Evaluation of the guide vane (GV) closing characteristic**

### 5.2.5 Needle valve and deflector (Pelton and Turgo turbines)

The needle is the main regulating device and shall be able to close in presence of full flow both in normal and emergency conditions. The deflector (if fitted) shall also be designed to intercept the full flow and is used as the regulating device in some systems. The friction forces and hydraulic forces should be compared with relevant design values for dry and wet opening and closing pressures, and load ramps from no load to full load and back (see Figure 5).

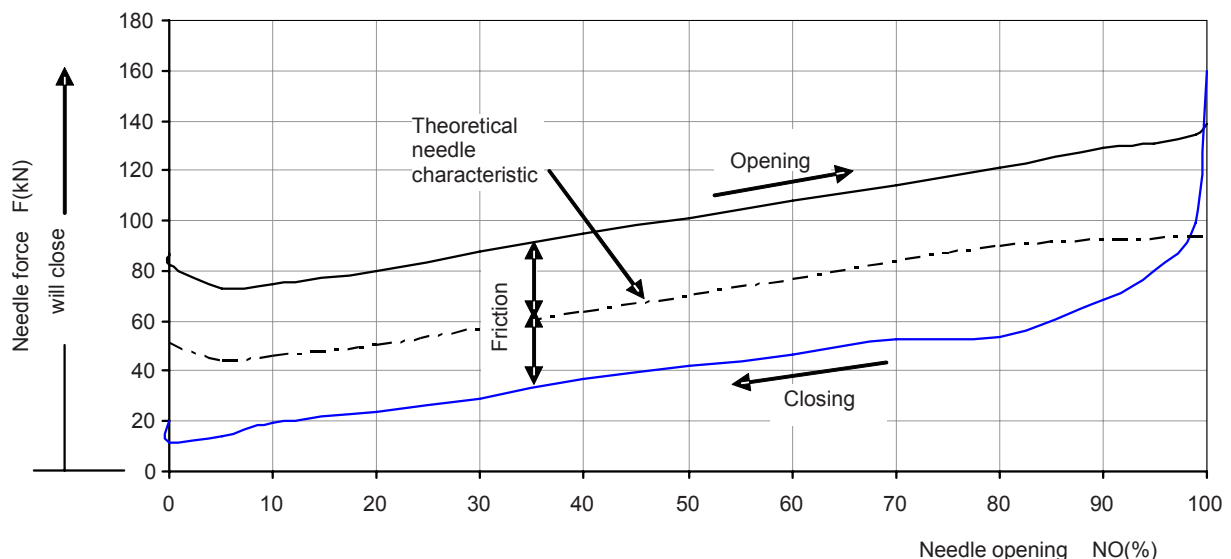


**Figure 5 – Needle servomotor force**

The needle closing characteristic and the closing time is generally defined in order to control overpressure (water hammer) while the deflector is used in order to control overspeed (see 5.5, and 5.7).

If a cam is fitted to control the relationship between needle and deflector, this relationship shall be verified in order to obtain safe overspeed values without any interference between jet and deflector on all needles.

NOTE It is important to individually check each cam for correct needle stroke/governor stroke/deflector position relationship.

### 5.3 First run operation and control

The commissioning engineer will decide if the unit can be started. If, during this or any of the following tests, any abnormal behaviour is observed, the unit shall be shut down immediately. Particular care shall be taken to detect any anomalous noise, scraping etc., see Figure 6.

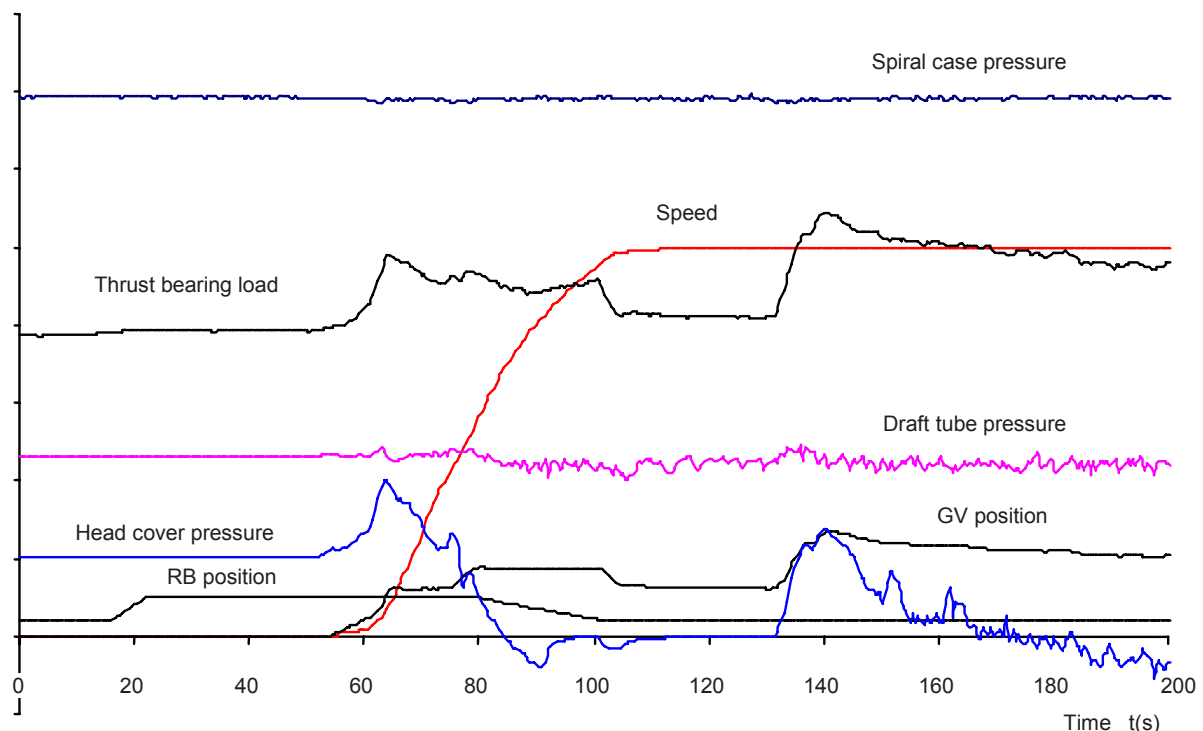


**Figure 6 – Automatic start – Synchronization – No load test (Kaplan turbine)**

### 5.4 Bearing run at rated speed

The speed shall be increased in steps to the rated value. The number of required steps and the time spent at each step should be decided in advance between the parties. Note that hydrodynamic bearings can be damaged if run at slow speeds, and the minimum speed should be specified by the manufacturer.

The criteria for accepting the turbine at each speed step will be decided between the manufacturer's representative and the commissioning engineer. This could be either the time for all bearing temperatures to stabilize sufficiently to determine the final temperature value, or just to determine whether there is any internal rubbing.

If a bearing temperature increases rapidly, or is excessive, the unit shall be shut down and the causes of the phenomenon investigated and corrected. The condition of the lubrication system should be monitored, and if water is noticed in oil or oil foaming is observed, the cause shall be located and eliminated. Other control devices may be tested during the bearing run. The correct behaviour of the governing system may be checked at this time and, when the governor is operating correctly, it may be used for running the unit.

Unless specifically required by the manufacturers, the above mentioned checks do not require specific instrumentation, only those normally installed in the plant or available during the erection (i.e. micrometer-comparators to check the shaft run-out). Vibration measurements need only be conducted if contractually required.

### 5.5 Emergency shutdown (no load)

The turbine will be tripped when running at rated speed and no electrical load. The closing time of the guide vanes (or needle valves), and the hydraulic pressure or electric current to operate them shall be measured. These values should be compared with the design values.

The pressures in the water passages and the run down time of the turbine shall also be measured. Correct operation of the brake (if fitted) should be verified, see Figure 7.

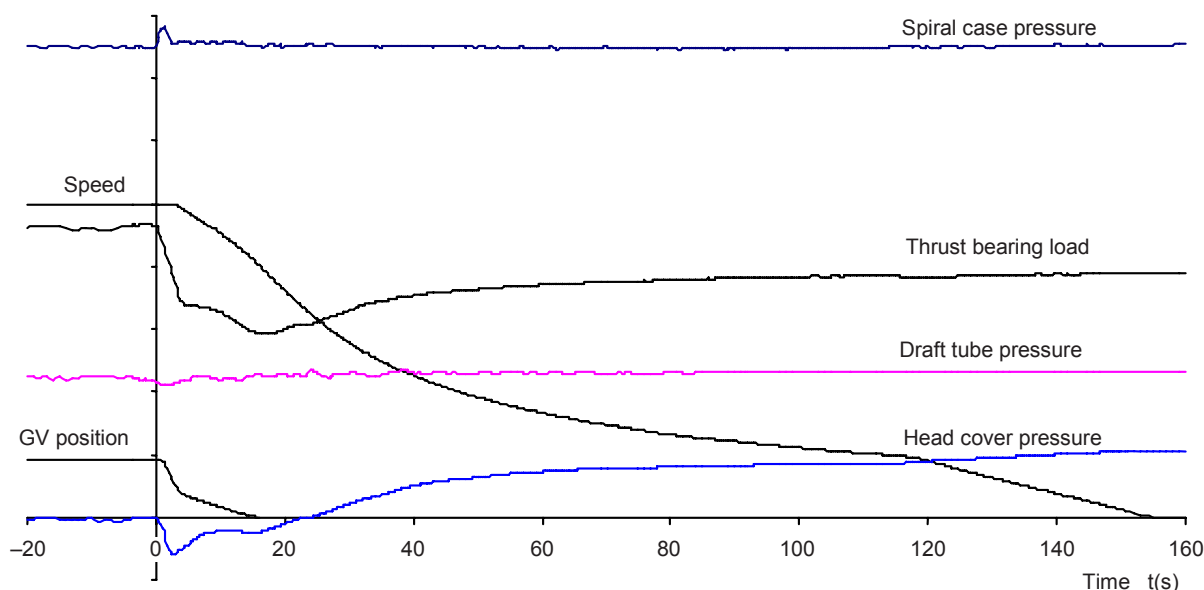


Figure 7 – Emergency shutdown from no load test (Kaplan turbine)

### 5.6 Electrical protection

When a small hydroelectric generator is connected to a grid, there is a need for electrical protection to ensure that the generator is safely disconnected from the grid in the event of a fault. The electrical fault can occur either on the generator or on the grid. The protection should guarantee that the generator is disconnected when repairs are being made to the grid.

The common elements of the protection system are relays that detect under- and over-voltage, under- and over-frequency, and rate of change of frequency. The operators of the local grid should specify the protection relays required and the nature of the acceptance tests.

After the mechanical tests have given satisfactory results, the testing of the electrical protection shall be undertaken according to the contractual conditions. During the tests, the manufacturer's requirements shall be strictly observed.

NOTE The electrical protection tests have normally to be completed before any electric connection to the grid is made and any power is exported.

The acceptance tests normally include the sequence and time to open circuit breakers, once the fault has been detected (simulated during the test). The results of the electrical protection tests shall be recorded.

## 5.7 Overspeed test

The turbine speed is carefully increased under manual control, and any speed set points are checked. The operation of the runner blade servomotor of a double regulated Kaplan or bulb turbine shall be checked at this time.

## 5.8 Runaway test

A total runaway speed test may also be performed especially in the case of turbines with guaranteed steady state runaway. The steady state runaway tests shall only be carried out if expressly laid down in the contract. The real need of performing this test shall be deeply evaluated by all parties taking into account all possible risks.

All runaway tests shall be time limited. The runaway test concerns the worst case for each type of turbine when all closing regulation is locked in the full open position. As an example, the maximum expected runaway speeds are shown in Table 2 below. If the vibration level rises after a runaway test, the cause should be investigated and remedied.

**Table 2 – Maximum runaway speeds ( $n_{run}$ ) expressed as a percentage of rated speed**

| Turbine type            | $n_{run}\%$ |
|-------------------------|-------------|
| Francis turbine         | 160 to 210  |
| Pelton and Turgo        | 200         |
| Crossflow               | 190 to 230  |
| Kaplan propeller type   | 200         |
| Double regulated Kaplan | 300 to 360  |
| Bulb turbine            | 300 to 360  |

NOTE For double regulated turbines this speed is expected when the wicket gate is locked in the full open position and the runner is closing out of cam correlation.

A runaway test shall be executed as shown in Figure 8. The time at stabilized runaway speed shall be limited to an agreed value. Generally, the runaway guarantee refers to the maximum guaranteed head, but the actual runaway test shall be carried out at the head available when the test is performed.

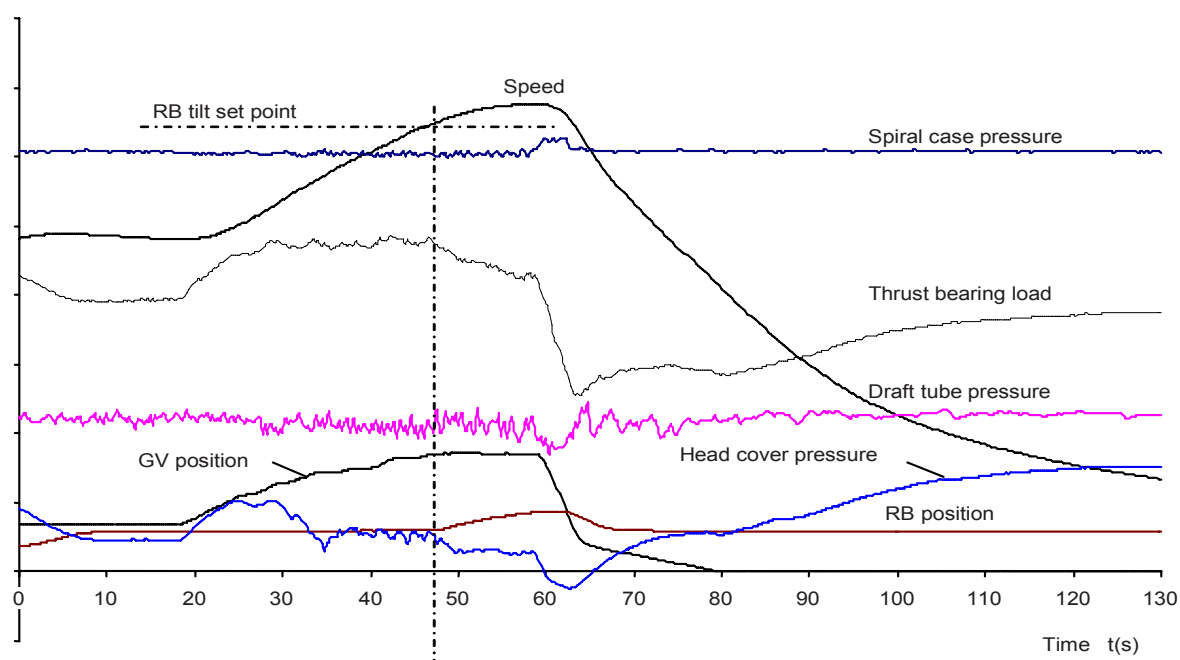


**Figure 8 – Runaway test (Kaplan turbine)**

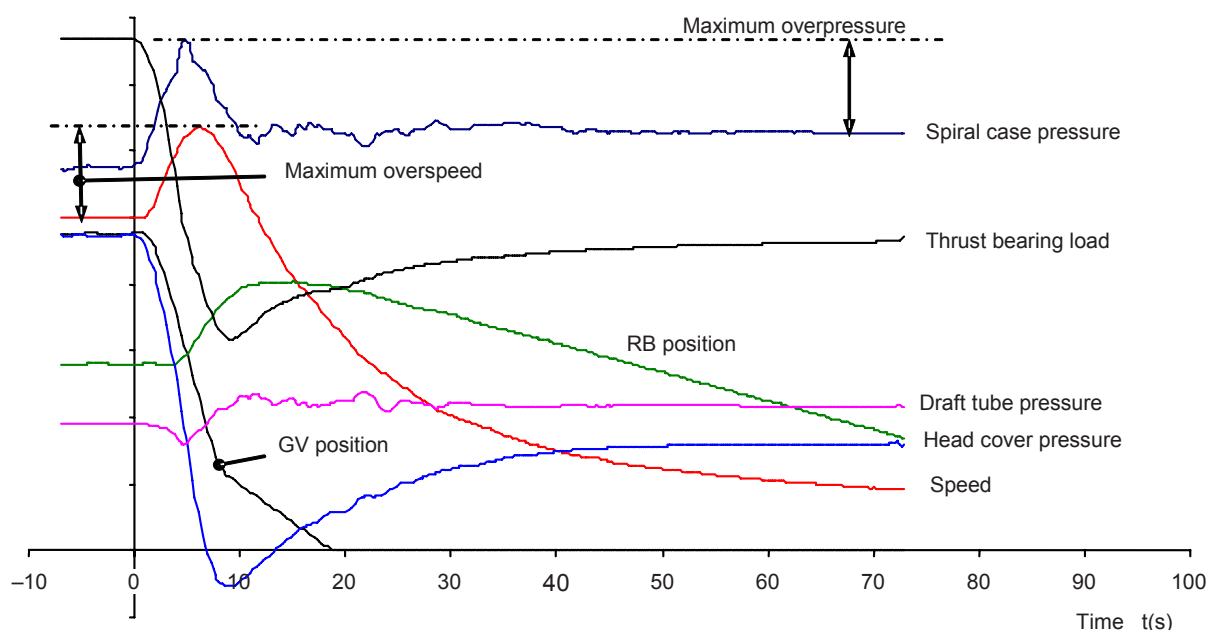
## 5.9 Overpressure, emergency trip and load rejection tests

### 5.9.1 General conditions

The load shall be increased in steps to the maximum value. At each step, observations and measurements in steady state condition shall be repeated and the operating stability of the turbine shall be verified. In so far as the load conditions so permit, the hydroelectric unit shall be subjected to load rejection tests at each stage (generally 1/4, 1/2, 3/4 and 4/4 of rated load). If the governor parameters are readjusted, then all the tests affected by these readjustments shall be repeated.

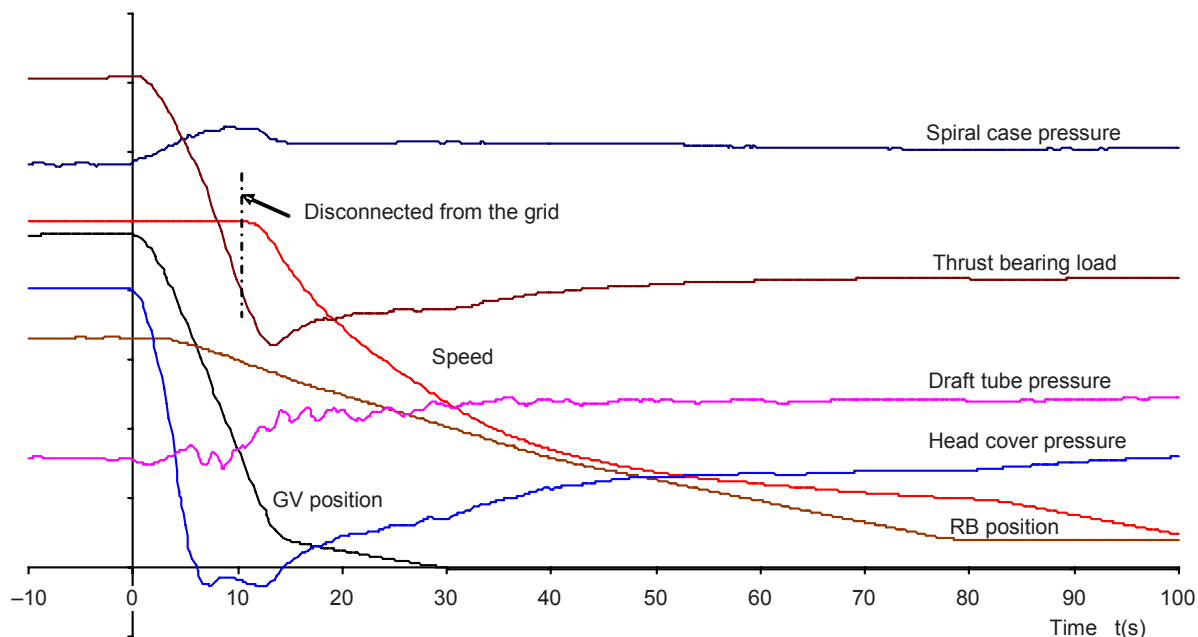
The unit can be subjected to different types of load rejection including emergency shutdown (due to electrical or mechanical failure), normal stopping sequences and normal shutdown with or without return to no-load operation. For safety reasons the emergency shutdown tests shall be performed first.

The test sequence shall include the most unfavourable conditions within the guaranteed operating range. This may correspond to load rejections from full opening, partial opening (with pressure relief valve) or low loading. If the plant includes several units with common intake, the most unfavourable condition may correspond to the simultaneous closure of the shut-off components of all the units, rather than the simultaneous load rejection. Some typical examples of emergency shutdowns are shown in Figures 9, 10, 11, and 12.



NOTE The turbine is closing and disconnecting from the grid immediately. The closing is controlled by the governor (Kaplan turbine).

**Figure 9 – Emergency shutdown due to an electrical fault**



NOTE The turbine is closing and disconnecting from the grid at no load. The closing is controlled by the governor.

**Figure 10 – Emergency shutdown due to a mechanical fault**

### 5.9.2 Testing the guide vanes or needle valves

The closing time of the guide vanes (or needle valves), and the hydraulic pressure or electric current to operate them shall be measured. These values should be compared with the design values.

### 5.9.3 Testing the turbine inlet valve

If the turbine inlet valve is the only method for isolating the turbine from the waterway, the operation of the valve shall be tested when the turbine is at full discharge.

NOTE This is a potentially dangerous test, and it should be carried out in stages at  $\frac{1}{4}$ ,  $\frac{1}{2}$ ,  $\frac{3}{4}$  of full discharge first.

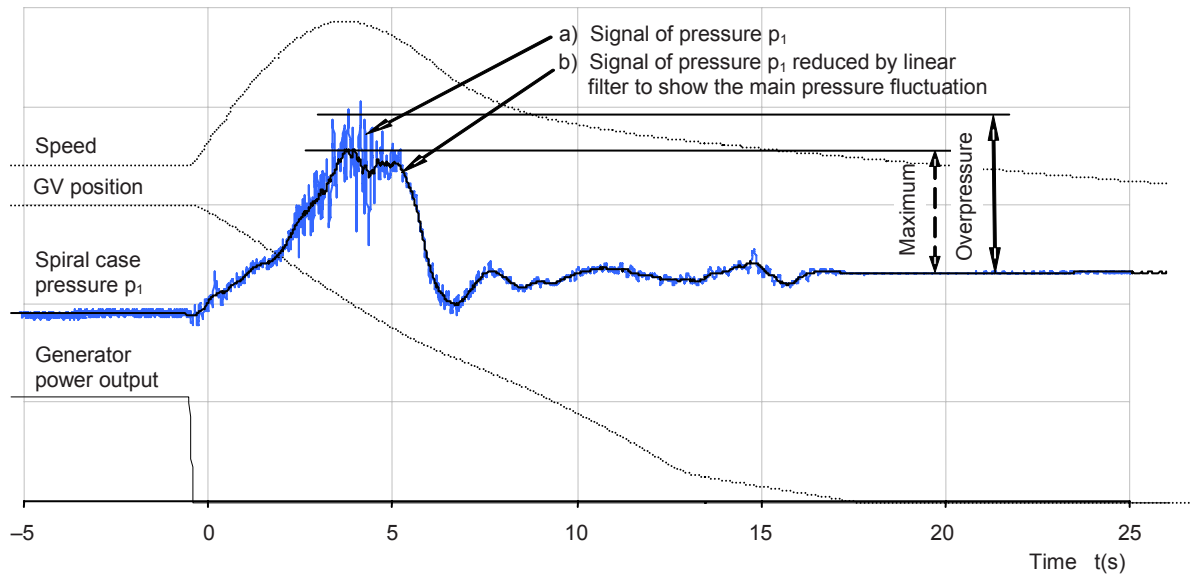
### 5.9.4 Testing the pressure relief valve

If a pressure relief valve is fitted, operational tests should be made to show that the turbine can be shut down in a safe manner under all circumstances, even when the valve fails to open.

### 5.9.5 Pressure rise

The curves given in Figure 11 show the pressure rises caused by closing the guide vanes, and are from actual site test results. The superimposed fluctuation is due to runner rotation and other dynamic phenomena such as cavitation or hydraulic resonance. Normally, for small installations, the mean pressure should be used for comparison with the guarantees.

However, when the fluctuation is large, the procedure outlined in Figure 11 and Figure 12 may be applied to find the maximum pressure due to the hydraulic transients. In order to avoid ambiguity, the method of plotting the high frequency signal envelope should be agreed upon with the purchaser, and clearly explained in the test report. This example uses a low pass filter with a high cut-off with half of the noise band deducted before calculating the maximum pressure.



NOTE The turbine is closing and disconnecting from the grid immediately. The closing time and characteristics are controlled by orifices. Example for pressure fluctuation (Francis turbine).

**Figure 11 – Emergency shutdown due to the governor failure**

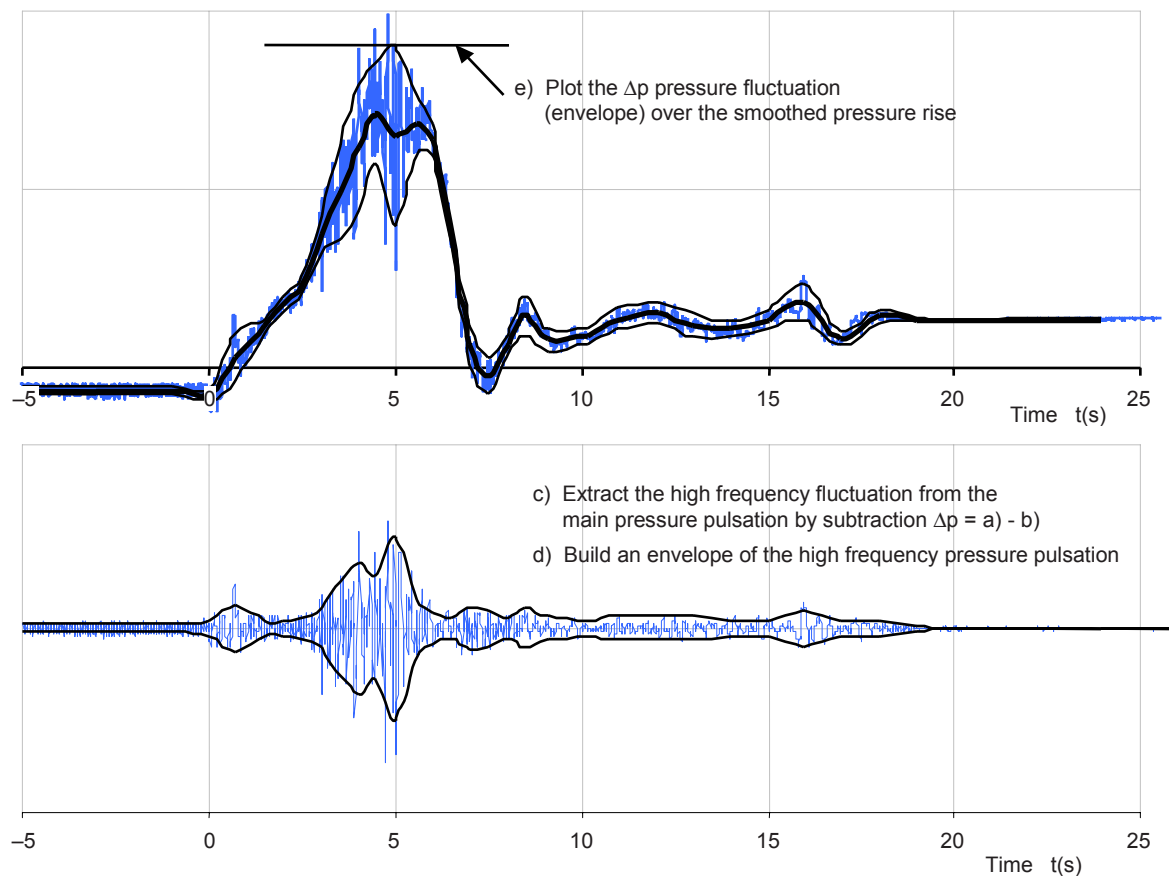


**Figure 12 – Evaluation of the maximum overpressure**

## **5.10 Measured quantities**

### **5.10.1 Pressure**

Pressures shall be measured using taps located at the inlet and at the outlet of the turbine as close as possible to the upstream and downstream pressure reference section (see Annex B).

If the maximum pressure in the upstream waterways is of importance, four pressure taps should be used placed 90° apart round the same cross section upstream of the inlet valve. The pressure taps should be connected by steel pipes to a ring manifold and with the pressure transducer directly connected to the manifold. Dimension of the pressure taps, ring manifold etc. should be as given in B.4.1.

The use of pressure transducers is recommended so that the transient over pressure and under pressure can be acquired and preferably recorded. The equipment used shall have a response time compatible with the frequency of the pressure fluctuations being studied. For this purpose the transducers shall be placed in the immediate proximity to the pressure taps.

### **5.10.2 Speed**

Rotational speed shall be measured using a tachometer or by using the governor signal.

### **5.10.3 Control components**

The movement of control components (guide vanes, blades, or needle and deflector) shall be recorded by using governor signals or displacement transducers.

## **6 Trial operating and reliability tests (commissioning)**

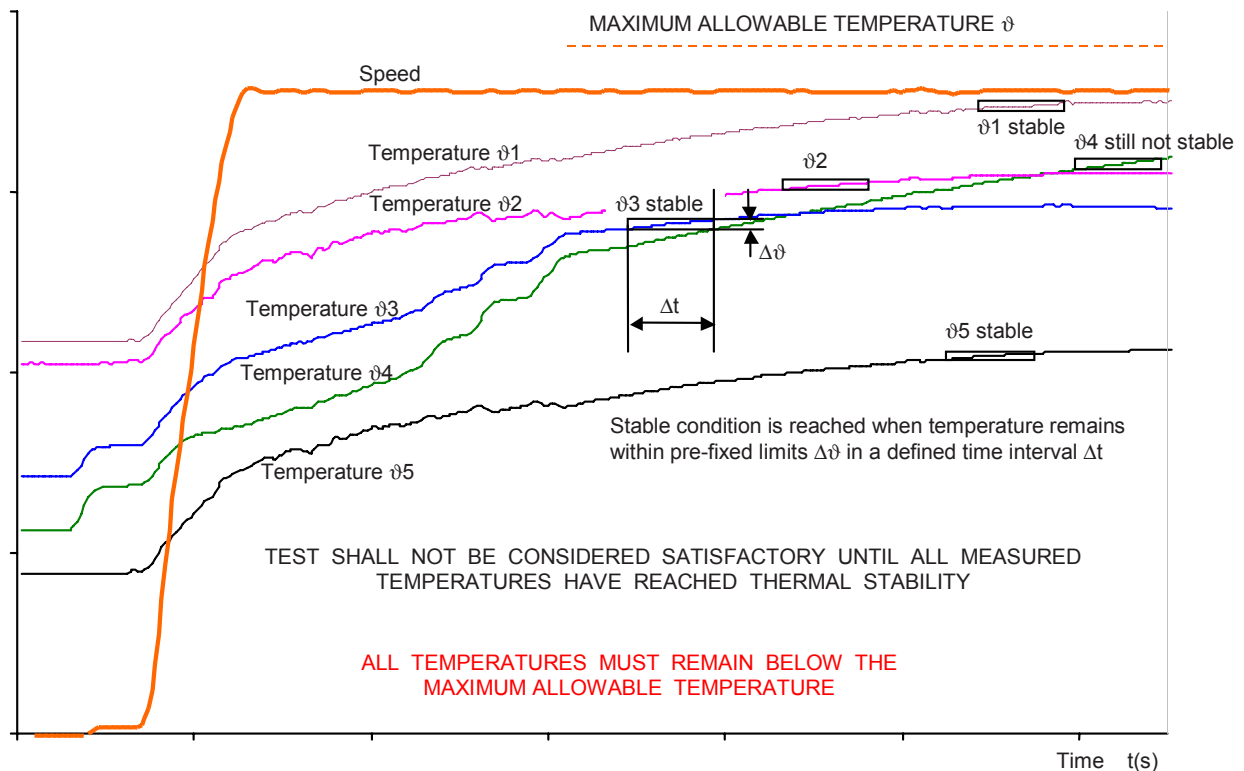
### **6.1 General**

During these tests, the hydroelectric unit shall be on “trial run” to enable any necessary adjustments to be made while operating over the full load range. The duration of “trial run” of the complete equipment shall be for a specified period agreed between purchaser and manufacturer. The “trial run” shall be accepted if each item has operated successfully.

### **6.2 Temperature stability of rotating parts**

#### **6.2.1 General**

The unit shall be run under the most arduous conditions to check that the bearing and generator temperatures achieve stability. The behaviour of radial bearings, thrust bearings and core temperature of the generator and all other circuits or mechanical components likely to suffer a temperature increase shall be verified.



NOTE During this test, the ambient air and cooling water temperature should not be higher than the values indicated in the contract. If this occurs, all parties should decide on how to rectify the situation. Higher maximum temperature limits can be proposed provided all parties agree that the safety margins are still reasonable.

**Figure 13 – Temperature stability, recording at no load up to stable conditions**

## 6.2.2 Temperature guarantees

The temperature rises and absolute temperature values shall be compared with the maximum admissible values stated in the contract or agreed between parties. A typical recording showing the stabilisation of various temperatures is given in Figure 13.

## 6.3 Speed controller system

### 6.3.1 General

There may be various combinations of the following types of control.

- No active regulation because the speed is set by the grid frequency.
- A speed governor.
- A voltage governor adjusting the excitation of the alternator.
- A head level controller maintaining the water level at inlet or outlet.
- A load management controller maintaining a set power output.
- An electric load governor absorbing the excess generator output.

### 6.3.2 Unit operating without regulation

Asynchronous generators can be connected to a grid when the speed is 1 % to 2 % above synchronous speed. The control system should cope with the inrush of current when connection is made to the grid. Small synchronous generators can be connected to a stiff grid without using a speed governor provided frequency and voltage are maintained within the grid limits whilst synchronizing.

### 6.3.3 Unit operating with a speed governor

#### 6.3.3.1 General

The nature of the tests varies according to the role of the governor and the precision required. If the governor is expected to provide stable operation, the acceptable frequency variation should be stated in the contract. The speed governor should be set up for stable operation by a speed variation test with no external load. The test should demonstrate that when the control device is opened or closed rapidly, the speed returns to the set point within one cycle of speed variation. An example of a satisfactory response is given in Figure 14.

For a more complete study of the speed governor, reference is made to the publications IEC 61362 for specification and IEC 60308 for testing.

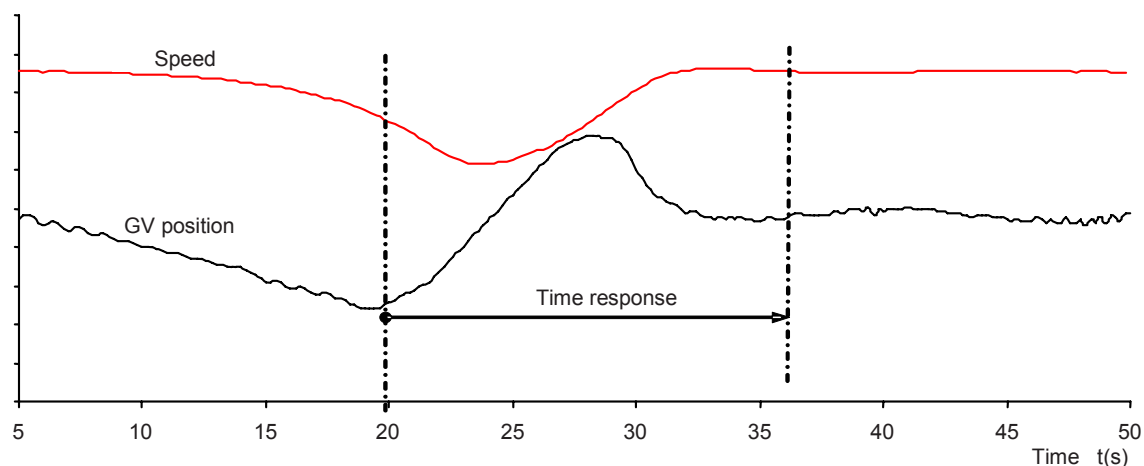


Figure 14 – Speed governor check at no load

A small hydroelectric turbine may be fitted with a speed governor for one or more of the reasons described below.

#### 6.3.3.2 Synchronizing only

This mode is used when a small turbine is required to connect to a large grid. The speed governor may then be used to load the turbine, using speed droop, or may switch to another management system such as level control.

Once synchronized, the governor should automatically switch to the appropriate operational mode. The timing of the changeover is important if delay could cause a conflict between the grid frequency control and the turbine governor.

#### 6.3.3.3 Frequency control on an isolated system

A small turbine may have difficulty in accepting the load changes on an isolated grid without large frequency fluctuations. The contract should state what size and type of load is expected and the frequency tolerance that is to be achieved. A grid supplied by a single hydroelectric unit shall be configured so that the plant can be started. The load should be segmented so that load increments are applied as agreed in the contract.

#### 6.3.3.4 Frequency stability in conjunction with diesel generators

A small local grid may contain a mixture of turbines and other prime movers, such as diesel generators. The contract should state what role the small hydroelectric turbine is expected to provide. The ability of the turbine to provide frequency stability depends on its relative size compared to the other generators, and its speed of response. The governor shall be tested to

verify that it can cope with the expected load changes within the frequency tolerance stated in the contract.

#### **6.3.4 Unit operating with a voltage governor**

A voltage governor is used when the generator takes part in controlling the reactive energy on the grid. The excitation of a synchronous generator is adjusted to maintain the voltage or power factor within prescribed limits. The voltage or power factor variation should be measured using a data logger during the load tests and load rejection tests. The ability of the voltage governor to maintain the voltage depends on the other generators feeding the grid. The acceptable limits shall be specified in the contract.

An asynchronous generator may have a controller to adjust the power factor of the unit. This is usually in the form of extra capacitors across the load.

#### **6.3.5 Unit operating with a controller**

##### **6.3.5.1 Head level controller**

The discharge through the turbine is controlled to maintain the head or tail water level. The discharge should be varied throughout its operational range to identify whether the controller can operate in a stable manner. If there are two or more hydroelectric units, or single units with multiple jets, connected to the same supply, there should be an overall water management system to start up or shut down the turbines in order to maintain the head level.

If operational guarantees have been specified in the contract, then measurements of the variation of head level should be made.

##### **6.3.5.2 Unit operating with a load management controller**

The load management controller maintains power output from the generator at the present level. The controller should operate in a stable manner throughout the permissible operating range. Variations of voltage and head that affect the control and the allowable limits of variation of power shall be agreed contractually.

If operational guarantees have been specified in the contract, the measurement of the load deviation from the set point should be made.

##### **6.3.5.3 Unit operating with an electric load governor**

The electric load governor is used on an isolated system so that the generator produces a constant power output. Excess power is switched to and from a resistor to match the load changes on the system. The resistance has to dissipate the excess power as heat and shall be able to operate within the temperature limits defined by the manufacturer. The operational temperature of the governor should therefore be monitored during load tests and load rejection tests.

The load governor can cause electrical emissions of radio frequency interference when switching loads. The level of emissions should be measured if operation guarantees have been specified in the contract.

#### **6.3.6 Measurements when testing the control system**

The stability of the hydroelectric unit shall be tested throughout the operational range. If instability in frequency, voltage or power is observed then the following measurements should be taken:

- position of all control servomotors;
- grid frequency or the speed of the turbine;

- voltage at the generator terminals;
- active and reactive power or current supplied;
- headwater or tailwater levels;
- pressures in the inlet and/or outlet turbine sections.

If there are operational guarantees specified in the contract, they should specify the allowable variation and the allowable grid frequency or voltage variation that may occur at the same time.

#### 6.4 Control of cam correlation

Cams are used to provide a relationship between the controls of a turbine for the following reasons:

- to achieve optimum efficiency on double regulated turbines such as Kaplan and bulb turbines. See also 7.3.5;
- to correlate the movement of needle and deflector on Pelton or Turgo turbines.

The relationship should be tested throughout the entire operational range of the turbine.

### 7 Performance guarantees and tests

#### 7.1 General

The aim of performance tests is to verify contractual guarantees as listed in the main performance guarantee in 4.2. These guarantees shall be verified under contractually defined site conditions. The turbine and hydroelectric unit performance (efficiency) is evaluated from the parameters shown in Table 3.

**Table 3 – Performance test parameters**

| Class                                                                                                                                                                                                                                             |                                                | Measured parameters                                                                                                                                               |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A,B,C                                                                                                                                                                                                                                             | H                                              | Net head related to the turbine guarantee domain between the high pressure section 1 and the low pressure section 2, measured and evaluated as an absolute value. |
| A,B,C                                                                                                                                                                                                                                             | $P_{\text{gen}}$ ( $P_t$ )<br>$P_{\text{out}}$ | Generator power output (transformer input) measured directly as an absolute value.<br>Transformer power output measured directly as an absolute value.            |
| B,C                                                                                                                                                                                                                                               | $Q_{ix}$                                       | Discharge passing the sections 1 or 2. The discharge is measured as a relative value by an index.                                                                 |
| C                                                                                                                                                                                                                                                 | $Q$ , $\eta$                                   | Discharge or efficiency, which is measured as an absolute quantity by a primary method.                                                                           |
| NOTE A preliminary test of class A category is highly recommended. If, after the analysis of test results, there are justifiable doubts about the performances of the turbine, additional tests could be made with more accurate instrumentation. |                                                |                                                                                                                                                                   |

Before testing, the hydroelectric unit shall be in a state of commercial operation. The following data are required according to the test being made:

- Hill chart, with operation and cavitation limit, and with a list of rated data for different heads.
- Maximum power output  $P_t$ ,  $P_{\text{gen}}$ ,  $P_{\text{out}}$  as a function of the net head, see Figure 15.
- Physical, geometrical and geodetic data, see 8.1.2 and Table 5.
- Head losses in water passages as a function of discharge or power output.
- Losses in the generator, transformer, and auxiliaries (mechanical /electrical).

- f) A diagram showing discharge  $Q$  as function of turbine opening (guide vanes or needle) and static head to calculate the velocity head, see Figure B.18.

## 7.2 Maximum generator (transformer) power output as a function of net head

### 7.2.1 Guarantee

The guaranteed maximum generator (transformer) power output shall be equal to or greater than the measured and evaluated output taking into account systematic and random errors. The reference head for this guarantee is the net head between the turbine guarantee domain sections 1 and 2.

### 7.2.2 Instrumentation

The panel equipment can be used; the accuracy class shall be known and shall be in accordance to the agreed systematic uncertainties. Care shall be taken of the position for head measuring sections, refer to Annex B. Precision instrumentation with calibration certification should be used if the contract provides for a penalty (or a premium).

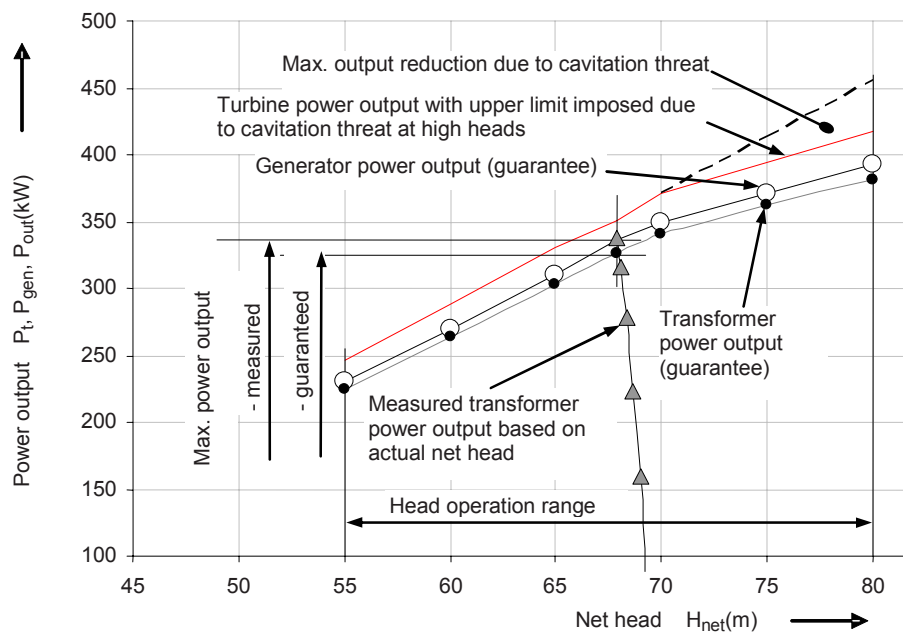


**Figure 15 – Maximum power output: procedure to compare measured power output at actual net head to the guarantee**

## 7.3 Index test

### 7.3.1 General

An index test may be used for any of the following purposes:

- to determine the shape of the performance characteristics and the relative efficiency of the turbine (shape control) alone, or the plant overall;
- to assess the change of performance when upgrading turbines. When using an index test for this purpose it shall be noted that modification may affect flow patterns in the measurement sections;
- to assess the change in performance due to cavitation resulting from a change in the tail water level and/or net head;
- to optimize the maximum annual energy of single or multiple units;
- to calibrate the discharge for monitoring over the operation range of discharges and net heads based on the guaranteed hill chart;

- f) to determine the optimum cam correlation between the runner blade and guide vane opening for most efficient plant operation of double-regulated turbines;
- g) an index test may be used as part of a performance test to complement the primary method of discharge measurement, for any of the following purposes:
  - 1) to provide additional test data during a field acceptance test, to interpolate and extrapolate the range of data produced by the primary method;
  - 2) to make a cross check of the index discharge to any primary method;
  - 3) to obtain calibration data for permanent powerhouse flow measuring instruments by measuring an absolute value of turbine efficiency at some operation points.

### 7.3.2 Index discharge measurement

An index test is based on a relative measurement of discharge, and one of the following methods given in Table 4 may be used. The discharge may be assumed to be nearly proportional to the square root of the differential pressure.

**Table 4 – Index discharge measurement methods**

| Device                                     | Usual differential pressure ( $\Delta p$ ) at maximum load<br>kPa |
|--------------------------------------------|-------------------------------------------------------------------|
| Differential pressure methods              |                                                                   |
| Full spiral case (Winter-Kennedy)          | 10 to 40                                                          |
| Tubular turbine (bulb, pit turbine)        | 10 to 30                                                          |
| Convergent pipe (conical pipe)             | 10 to 40                                                          |
| Stagnation probe                           | 15 to 60                                                          |
| Flow indicators                            |                                                                   |
| Simplified flow measuring methods          |                                                                   |
| Needle stroke on Pelton and Turgo turbines |                                                                   |

### 7.3.3 Shape control

Figure 16 shows how the shape of turbine performance characteristics can vary within the allowable deviation range (systematic errors). The deviation can be weighted as a function of the turbine power output or discharge.

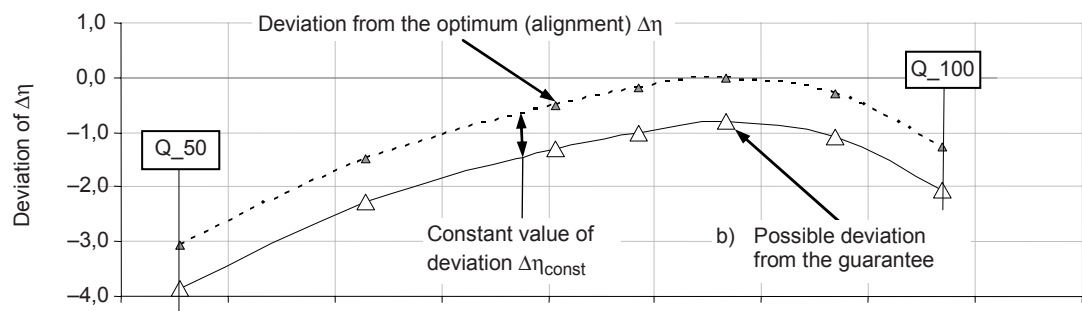


Figure 16a – Deviation of the turbine characteristic from the guarantee

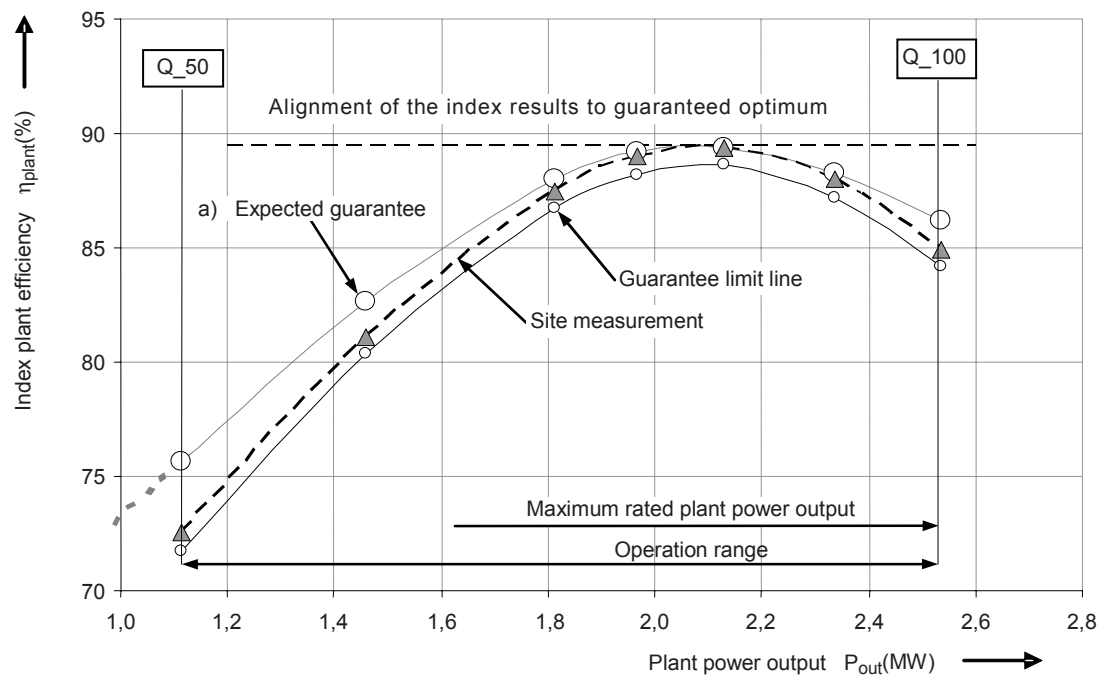


Figure 16b – Alignment of the turbine characteristic to the guarantee

NOTE Q\_100 refers to the full discharge at maximum power output, and Q\_50 is half the full discharge.

Figure 16 – Comparison of the shape of the turbine characteristic to the guarantee

#### 7.3.4 Index plant efficiency

This test determines the relative efficiency of the turbine or overall plant. These results give information about the plant efficiency curve at actual plant conditions. They can be used to optimize the joint control of all the units in order to attain the maximum annual energy production. Figure 17 shows the switch band for starting or stopping the second unit optimized to attain the maximum annual energy production.