

Electrical and Electronic Components for Use in Downhole Completion Equipment

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Contents

	Page
1 Scope.....	1
2 Normative References	2
3 Terms, Definitions, Acronyms, and Abbreviations	2
3.1 Terms and Definitions	3
3.2 Acronyms and Abbreviations	7
4 Functional Specification	8
4.1 Functional Requirements	8
4.2 Product type and configuration	9
4.3 Well Parameters	10
4.4 Operational Parameters.....	10
4.5 Environmental Compatibility	11
4.6 System Architecture	12
4.7 Compatibility with Related Equipment	12
4.8 Installation Considerations.....	12
4.9 Design Validation	13
4.10 Quality Control	13
5 Technical Specification	13
5.1 General	13
5.2 Electrical and Electronic Terms.....	14
5.3 Structure of Electrical/Electronic Equipment.....	14
5.4 General Functions	15
5.5 Telemetry Function	35
5.6 Actuation Function	36
5.7 Sensing Function	40
5.8 Energy Storage Function	44
5.9 Design Changes	50
6 Supplier/Manufacturer Requirements	52
6.1 General	52
6.2 Documentation and Data Control	52
6.3 Product Identification	55
6.4 Quality Requirements	55
6.5 Functional Acceptance Test	61
6.6 Obsolescence Management Plan	62
7 Redress and Repair	62
8 Shipment and Storage	62
Annex A (informative) Actuators	64
Annex B (informative) Reliability.....	69
Annex C (normative) Standalone Sensing Devices Functional Acceptance Testing	80
Annex D (informative) System Integration Testing	83

Contents

	Page
Bibliography.....	85

Figures

1	Example of Well Equipment and Associated Specifications	9
2	Structure of Electrical/Electronic Equipment.....	15
3	Example Pressure Chamber Configurations	17
4	Standalone Electronics Chamber	21
5	Electronics Chamber Connected to Another Assembly (e.g. pressure sensor) via a Pressure Bulkhead ..	21
6	Electronics Chamber Connected to Another Assembly (e.g. actuator) with Pressure Compensation.....	21
7	Example of Pressure and Temperature Cycles.....	23
8	Acceleration Spectral Density Over Frequency Range	27
A.1	General Overview of an Actuation Module	64
A.2	Main Components of an Electromechanical Actuation System	65
A.3	Main Components of an Electrically Powered Solenoid Actuation System	65
A.4	Main Components of an Electrohydraulic Actuation System	65
B.1	Bathtub Curve Derived from Multiple Weibull Curves.....	70
B.2	Impact of Confidence Limits	71

Tables

1	Summary of API Recommended Practice 19E Annexes	13
2	Summary of Testing Requirements and Associated Sections.....	20
3	Example Effect of Temperature on Acceleration Factor.....	30
4	Example of RDT Qualification Times for Various Operating and Test Conditions.....	32
5	Summary of Reliability Statement Default Values.....	32
6	Example of Reliability Statement Based on RDT Derived from 4 DUTs at 160 °C for 26 Weeks	33
7	Summary of Minimum Actuation Cycles Validation Requirements	39
8	Summary of Battery Pack Specific Testing	46
9	Rated Energy Storage Life vs Test Duration.....	48
A.1	Examples of Design Parameters for Actuators	68
B.1	Examples of Acceleration Factor	72
B.2	Symbols Used in Equations.....	72
B.3a	ALT Worked Example Failures	75
B.3b	ALT Worked Example Failures	75
B.4	Reliability Statement for ALT Worked Example	75
B.5	Example Impact of Failure on Test Duration.....	77
B.6	Reliability Statement for RDT Worked Example	78
B.7	Comparison of Worked Examples	78
C.1	Summary of Functional Acceptance Testing for Stand-alone Sensing Devices.....	80

Electrical and Electronic Components for Use in Downhole Completion Equipment

1 Scope

This specification provides the requirements for electrical/electronic components and assemblies used in downhole completion equipment as they are defined herein for use in the petroleum and natural gas industries.

Electrical/electronic components and assemblies related to equipment covered under API specifications such as API 11D1, API 14A, API 19AC, API 19CI, API 19ICV, API 19G1, API 19G2 and API 19V are included. This specification is intended to be complimentary to other API specifications. When other API specifications require that any included electrical/electronic components or assemblies meet the requirements of this specification, the requirements defined in this specification are in addition to any other requirements specified by these other API specifications. Included are the minimum requirements for a functional specification, design verification, design validation of performance ratings, manufacturing quality assurance, functional acceptance testing, shipping, handling, and storage.

This specification covers electrical/electronic downhole completions equipment and assemblies including:

- Sensing devices such as permanent downhole and wireless gauge systems, position sensors.
- Actuation devices intended for use in applications such as safety valves, interval control valves, chemical injection valves, gas lift valves, built-in setting devices.
- In-well control devices used for control of a single device or consolidation of multiple gauge/sensing, or actuation devices.
- Telemetry devices.
- Electrical energy storage devices (including batteries). Any non-electrical storage devices such as springs, gases, hydraulic devices are not in scope of this specification.
- Other downhole equipment containing electrical/electronic components, as applicable, such as wireless couplers (inductive, capacitive), solenoids, motors, relays, transducers.

Testing/equipment not covered by this specification are:

- Electric submersible pumps (ESP).
- Optical downhole gauges where electrical/electronic components are above the tubing hanger.
- Perforating tools.
- Service tools and electrical/electronic systems used during deployment/recovery and logging such as measurement-while-drilling (MWD) systems.
- Through-tubing setting or service tools.
- Well head and other related equipment.
- Subsea control systems.
- Tubing encased conductor (TEC), tubing encased fiber (TEF), associated mechanical splices, mechanical connectors (dry-mates, in-well wet-mates) and clamps.

- Downhole well test tools and related equipment covered by API Specification 19TT.
- Software outside of downhole embedded software, firmware and configuration data.
- Any equipment that does not remain downhole after completion installation and rig demobilization.

This specification does not cover applications, installation, operation, and maintenance. Control systems components which are designated for positions above the tubing hanger are not included.

Requirements for equipment covered under API specifications such as API 11D1, API 14A, API 19AC, API 19CI, API 19ICV, API 19G1, API 19G2 and API 19V, where these components may be used, are outside of the scope of this specification.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Technical Report 5C3, *Calculating Performance Properties of Pipe Used as Casing or Tubing*, 7th Edition

API 20A, *Carbon Steel, Alloy Steel, Stainless Steel, and Nickel Base Alloy Castings for Use in the Petroleum and Natural Gas Industry*

ASME, *Boiler and Pressure Vessel Code (BPVC) — Section VIII: Rules for Construction of Pressure Vessels Division 3 – Alternative Rules for Construction of High Pressure Vessels*

ASME, *Boiler and Pressure Vessel Code (BPVC) — Section IX: Welding and Brazing Qualifications*

ASNT SNT-TC-1A, *Recommended practice for personnel qualification and certification in nondestructive testing*

IPC-A-610, *Acceptability of Electronics Assemblies*

ISO 2859-1, *Sampling procedures for inspection by attributes — Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

ISO 3601-3, *Fluid power systems — O-rings — Part 3: Quality acceptance criteria*

ISO 9001, *Quality Management Systems – Requirements*

ISO 9712, *Non-destructive testing — Qualification and certification of personnel*

ISO/IEC 17025, *Testing and Calibration Laboratories*

ISO/IEC 90003, *Software engineering — Guidelines for the application of ISO 9001 to computer software*

NACE MR0175/ISO 15156, *Petroleum and natural gas industries — Materials for use in H₂S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

ST/SG/AC.10/11, *UN Manual of Tests and Criteria*, 7 Edition (Section 38.3)

3 Terms, Definitions, Acronyms, and Abbreviations

For purposes of this standard, the following terms, definitions, acronyms, and abbreviations apply.

3.1 Terms and Definitions

3.1.1

absolute pressure

Pressure measured with respect to absolute zero.

3.1.2

actuator

A device that converts input electrical power to mechanical force, including the first connected mechanical element to the electrical control unit. See [Annex A](#) for more details.

3.1.3

actuator cycle

The movement of an actuator from its initial position through its required range of motion and, if applicable, back to the initial position. An actuation system may require multiple actuator cycles to complete a single actuation cycle.

3.1.4

actuation system

Electromechanical system comprised of actuator(s) and peripheral device(s) required to perform a specified function.

3.1.5

Actuation Cycle

The movement of an actuation system through its full rated range of motion and, where applicable, return to its initial position.

Example—Moving a sliding sleeve from open to close and return to open position.

3.1.6

ambient temperature

Prevailing temperature of the test site.

3.1.7

assembly

Product comprised of two or more components or subassemblies.

3.1.8

battery

battery pack

A collection of one or more electrochemical cells connected in some combination of parallel and series configurations to form a battery with the desired electrical properties. A battery will also include the physical packaging, circuit protections, and electrical connectors required for a particular application. Battery packs may be constructed using either non-rechargeable electrochemical cells (also known as primary cells) or rechargeable electrochemical cells (also known as secondary cells).

3.1.9

battery powered sub-system

The portion of the electronics system where all the electronic assemblies and associated devices are powered from a single battery pack or multiple battery packs of a single design.

3.1.10

calibration range or calibrated range

The measurement range over which equipment is calibrated and validated to provide the specified sensing accuracy for Quantitative Sensors. The calibrated range of the equipment may be smaller than the rated operating range.

3.1.11**casing**

Pipe extending from the surface and intended to line the walls of a drilled well.

3.1.12**chamber**

An enclosed volume.

NOTE Examples are hydraulic chamber connected to surface, an electrical chamber sealed at atmospheric pressure, or other enclosed volume.

3.1.13**control line (electric or hydraulic)**

Communication, power or hydraulic transmission between the downhole equipment and the surface. Electric conduit is commonly referred to as tubing encapsulated cable.

3.1.14**critical dimension**

Measure of a dimension that if compromised will cause the tool to operate outside of the functional specification

3.1.15**design validation**

Process of proving a design by testing to demonstrate conformity of the product to design requirements.

3.1.16**digital sensor**

A device that produces an output which represents the quantity measured in a digital format, i.e. does not require analog to digital conversion.

3.1.17**dry-mate connector**

Connector designed to be mated in dry or gaseous environments only such as air.

3.1.18**dummy cells**

Inert cells of the same physical size, shape, and weight as real electrochemical cells and are internally shorted.

3.1.19**duty cycle**

The cycle of operation of a machine or other device which operates intermittently rather than continuously. It is usually expressed as ratio or percentage of operational time over the total time.

3.1.20**electrochemical cell**

An individual electrochemical cell capable of storing electrical energy (does not include any form of packaging, electrical protection, or other interconnection). Electrochemical cells may either be non-rechargeable (also known as primary cells) or rechargeable (also known as secondary cells).

3.1.21**energy storage device**

A device which stores energy to power electronic or electromechanical systems. They include the following: non-rechargeable battery pack, a rechargeable battery pack, capacitive storage device.

3.1.22**exposed component**

Flow-wetted component, internally wetted component, or component contacted by well fluid in the annulus.

3.1.23**flow-wetted component**

Component that comes in direct contact with the dynamic movement of well fluids in the flow stream.

3.1.24**functional specification**

Features, characteristics, process conditions, boundaries and exclusions defining the performance and use requirements of the products.

3.1.25**internally wetted component**

Flow-wetted component and any component out of the flow stream, but contacted by well fluids through a port or other passage to the flow-wetted area.

3.1.26**gauge**

An instrument or device for measuring the magnitude, amount, or contents of something, typically with a visual display of such information.

3.1.27**latency**

The time from when a request is sent to when a return message is received.

3.1.28**maximum rated temperature**

The maximum temperature at which equipment is validated to operate.

NOTE Equipment is not validated to operate beyond this temperature. Equipment may be exposed to temperatures exceeding this temperature limit while not operating (see “storage temperature range”).

3.1.29**maximum voltage**

The upper limit of the rated operating voltage range at which an electrical/electronic device is rated to operate.

3.1.30**metrology**

Sensor measurement performance compared with a standardized reference.

3.1.31**minimum power-on temperature**

The minimum temperature at which equipment is rated to both power-on and complete a minimum set of functions.

NOTE This temperature may be below the minimum rated operating temperature.

3.1.32**minimum rated temperature**

The minimum temperature at which equipment is validated to operate.

NOTE Equipment is not validated to operate below this temperature. Equipment may be exposed to temperatures lower than this temperature limit while not operating (see “storage temperature range”).

3.1.33**minimum voltage**

The lower limit of the operating voltage range at which an electrical/electronic device is rated to operate.

3.1.34**multidrop**

System with multiple nodes connected to a common electrical conductor(s) for power or communication.

3.1.35**node**

Equipment connected to an electrical line, or network, in a system with multiple devices.

3.1.36**nominal voltage**

The voltage at which an electrical/electronic device is designed to operate. This voltage is between the minimum and maximum voltage.

3.1.37**polling rate**

The maximum number of request/response cycles, averaged over time, in a bidirectional telemetry system.

3.1.38**power cycle**

The process of turning either the equipment or a portion of the electronic system off by disconnecting all energy sources and then powering it back on again by reconnecting the energy source respecting power cycle sequence (e.g. voltage value and slope).

3.1.39**qualified person**

Individual with documented abilities gained through training or experience or both as measured against established requirements, such as standards or tests that enable the individual to perform a required function effectively.

3.1.40**qualitative sensor**

A sensor which outputs an implied value based on the input, such as trending or ratio metric data.

NOTE Qualitative sensors may be calibrated.

3.1.41**quantitative sensor**

A sensor which outputs a known and repeatable value, within tolerances, given a specific input and require calibration.

3.1.42**rated temperature range**

Temperature range defined by the minimum rated temperature and the maximum rated temperature.

3.1.43**representative fixture**

Fixture designed to transfer specific mechanical or thermal loads from the test equipment to the electronic assembly(s) in the same manner and to a similar level as the final electrical/electronic completions equipment.

3.1.44**single use device**

The device is intended to operate one time.

NOTE The device is not intended to, and it is not possible to be re-activated after activation and remains installed for the life of well. Examples of these devices are packer setting device, fluid loss device (also known as a subsurface completion isolation valve) and circulating valve.

3.1.45**storage temperature range**

Temperature range within which equipment is stored (not powered on) without risk of performance or reliability degradation due to temperature effect.

3.1.46**telemetry**

The communication of data and commands between two or more points.

3.1.47**type 1 component, type 1 weld**

Metallic component or weld that isolates pressure or is loaded in tension as the result of axial loads on the product during run-in, setting, service, or retrieval. It applies only to mechanical components.

3.1.48**type 2 component, type 2 weld**

Metallic component or weld that does not meet the criteria of a type 1 component or weld. It applies only to mechanical components.

3.1.49**update rate**

The frequency, averaged over time, of successful data received in a one-way telemetry system.

3.1.50**wet-mate connector**

Connector designed to be mated while submerged in liquids such as water or wellbore fluids.

3.1.51**wireless couplers**

A device which enables the transfer of power or data wirelessly between two locations.

3.2 Acronyms and Abbreviations

ALT	accelerated life test
CIV	chemical injection valve
COC	certificate of compliance
DUT	device under test
EMC	electromagnetic compatibility
ESP	electric submersible pump
IC	integrated circuit
ICV	interval control valve
MCM	multi-chip module
MTR	material test report
MWD	measurement-while-drilling
PCB	printed circuit board
PCBA	printed circuit board assembly
RCFA	root cause failure analysis
RDT	reliability demonstration test
TEC	tubing encased conductor

TEF tubing encased fiber

4 Functional Specification

4.1 Functional Requirements

The user/purchaser shall prepare a functional specification for the equipment with sufficient detail for the supplier/manufacturer to conduct a complete analysis in accordance with the guidelines in this document.

NOTE The supplier/manufacturer can generate internal requirements for products as the user/purchaser.

The functional specification should include, but not be limited to the requirements outlined in [4.2](#) through [4.10](#).

Electrical/electronic components and assemblies may be part of other API specifications such as API 11D1, API 14A, API 19AC, API 19CI, API 19ICV, API 19G1, API 19G2 and API 19V. [Figure 1](#) shows an example of different equipment in completion and the relevant specifications for each.

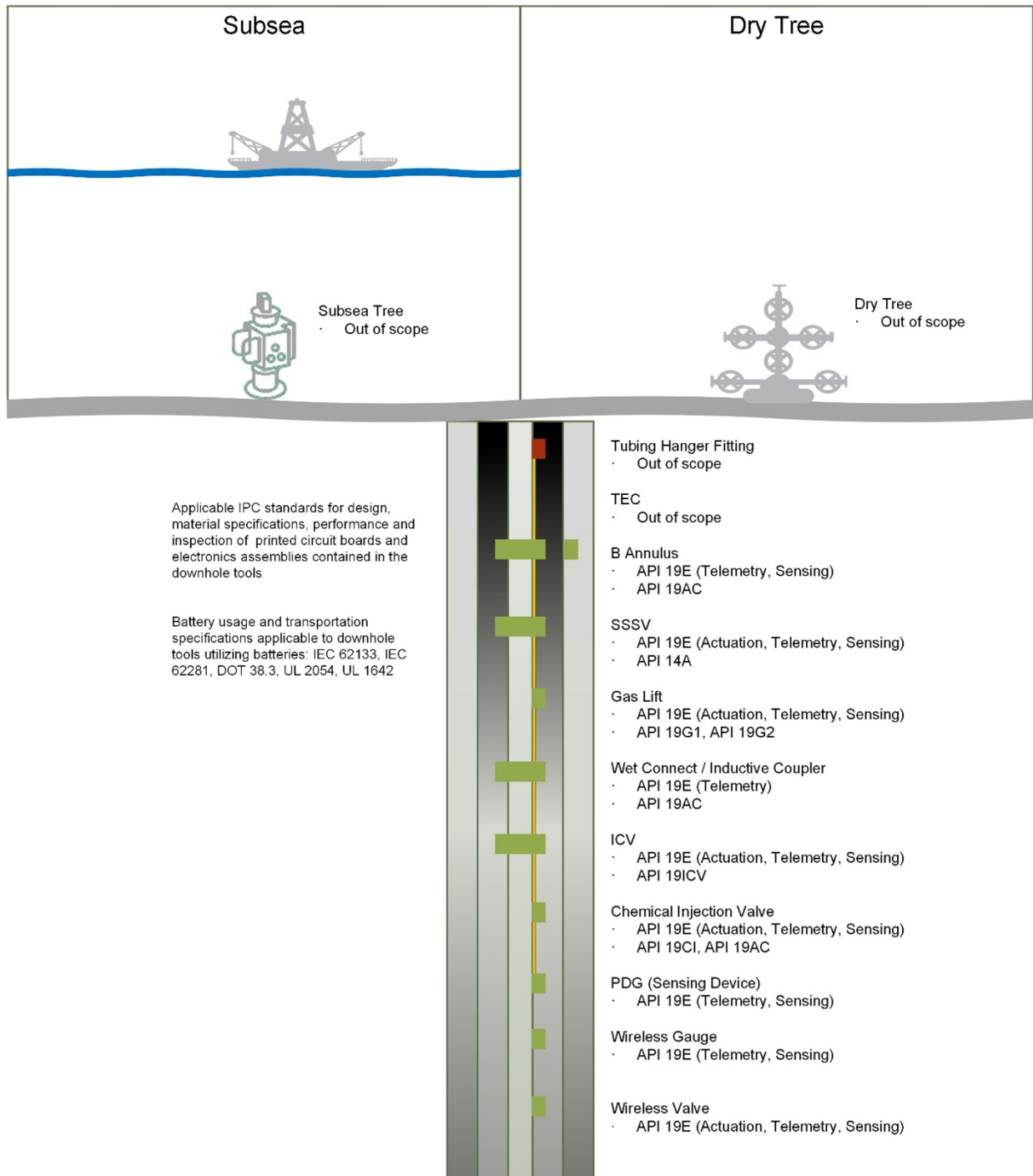


Figure 1—Example of Well Equipment and Associated Specifications

4.2 Product type and configuration

The user/purchaser shall specify the following functional type(s) based on the product's intended function(s) such as:

- Electrical/electronic gauges/sensors devices such as permanent downhole and wireless gauge systems.
- Electrically actuated or controlled downhole equipment such as safety valves, interval control valves, chemical injection valves, gas lift valves, lubricator valves.

- c) Downhole control devices used for control of a single device or consolidation of multiple gauge/sensing, or actuation devices.
- d) In-well telemetry such as wired and wireless communication equipment.
- e) Electrical interface devices such as wet-mates, inductive or capacitive couplings and cable splices.
- f) Stand-alone energy storage devices.
- g) Other downhole equipment containing electronics, as applicable.

4.3 Well Parameters

The user/purchaser shall specify, as applicable, the following well parameters:

- a) Wellhead (dry, wet);
- b) Type of wellhead/tubing hanger system and its number and type of penetrations and feedthrough types;
- c) Surface or subsea tree control system power and hydraulic limitations or range of expected output;
- d) Well type such as producer, injector, gas or water injector, observation, or other type, and number of intervals;
- e) Completion fluids, service fluids and formation fluids with expected time of exposure;
- f) Dimensions, mass, material and grade of the casing and tubing including end connections;
- g) Water depth, setting depth (maximum required for application);
- h) Well construction and overall completion architecture (e.g. open hole, cased hole, sand control method, multi-lateral details, and artificial lift);
- i) Maximum dogleg severity that the completion equipment will pass through, maximum dogleg severity where the completion equipment will be installed;
- j) Restrictions or other internal profiles through which the completion equipment shall pass (e.g. liner tops);
- k) Requirements for bypass of control lines (electrical, hydraulic, fiber optic, ESP);
- l) Expected minimum and maximum values of production/injection pressures, pressure differentials, temperatures, changes in temperatures, and flow rates;
- m) Relationship of the equipment with other well devices/tubing/casing/cables by means of a well schematic drawing;
- n) Any other relevant well parameter(s).

4.4 Operational Parameters

The user/purchaser shall specify, as applicable, any of the following operational parameters:

- a) Operational Pressure Range including:
 - 1) Absolute pressure for tubing or annulus.
 - 2) Maximum differential pressure between tubing and annulus.

- b) Operational temperature range including surface, subsea (mudline) and deck testing;
- c) Lifetime at downhole conditions;
- d) Requirements for cable bypass;
- e) Functional contingencies;
- f) Function or recovery state after unintended shutdown;
- g) Fail position where necessary such as fail closed, fail as-is;
- h) Interface input electrical specifications such as: power range, voltage range, current range, power source reliability;
- i) Regional electrical regulations;
- j) In-well electrical conduit specifications such as length, spacing, TEC configuration, number of wires and gauge;
- k) Electrical equipment protection requirements such as power surge, lightning protection;
- l) Sensing requirements such as accuracy, resolution, stability (drift), sampling rate;
- m) Retrievability considerations;
- n) Presence or use of tubing-conveyed perforating.

4.5 Environmental Compatibility

4.5.1 General

The user/purchaser shall specify material compatibility according to [4.5.3](#).

If the user/purchaser has access to the corrosion property data of the operating environment based on historical data or research, they shall state to the manufacturer which material(s) has the ability to perform as required within the corrosion environment per the requirements of [4.5.4](#) as applicable.

User/purchaser should specify the storage conditions following:

- a) Storage Temperature Range.
- b) Humidity.
- c) Saline environment.
- d) Ultraviolet exposure.

4.5.2 Noise Sources and Compatibility

User/purchaser should specify the presence and type of noise sources that could interfere with the normal operation and functionality of the device, such as:

- a) Radioactive sources generated by tools such as MWD, logging tools.
- b) Sources of acoustic, magnetic or electromagnetic noise such as ESPs, telemetry, energy transfer tools or magnetic wellbore cleanout tools.

- c) Incidental noise or shock sources such as explosives and exposure to pressure surges.

The user/purchaser should also specify sources of electrical noise related to shared power or communications systems, such as:

- d) Grounding and sharing of the same ground by other equipment.
- e) Cathodic protection current and voltage.

4.5.3 Well Environment

The user/purchaser should identify the density, chemical/physical composition, and the condition of the fluid or its components, including solid (examples: sand production and scale), liquid and gas, to which the equipment is exposed during its expected life cycle.

4.5.4 Material Designation

If the user/purchaser chooses to specify materials, requirements for conformance with ANSI/NACE MR0175/ISO 15156 shall be stated.

Material selection should be performed for a group of components using the following designations:

- a) flow-wetted components;
- b) internally wetted components;
- c) exposed components.

4.6 System Architecture

User/purchaser should provide an overview of the overall interfaces interacting with the downhole electrical/electronic equipment. As a minimum the following shall be considered:

- a) Downhole completion schematic including tubing, casing and other completions related equipment.
- b) Electrical and, if applicable, optical system architecture including surface or subsea equipment.
- c) Tubing hanger and well head penetrations, connectivity, splicing requirements.
- d) Available penetrations and bypasses for other completion equipment such as packers and wet-mates.
- e) Number of downhole cables, cable protection and management.

4.7 Compatibility with Related Equipment

User/purchaser should identify where interaction with other equipment is required such as perforating tools, other downhole electrical/electronic equipment, tubing/casing as conduit.

User/purchaser should identify compatibility with workover and intervention equipment.

4.8 Installation Considerations

User/purchaser should provide installation infrastructure considerations such as spools, sheave, rig-up height limitations, splicing, equipment protection (bending, run in hole), landing string configuration, cabins, test equipment such as simulators for functional test at location.

4.9 Design Validation

This specification provides a single validation grade for the electrical/electronic systems and stand-alone sensors. Where the electrical/electronic system is integrated into equipment covered by other API specifications, such as API 14A, API 11D1, API 19ICV, API 19AC, API 19V, API 19G1 and API 19G2, the user/purchaser shall specify the required design validation grade for the equipment.

4.10 Quality Control

This specification provides a single quality level for the electrical/electronic systems and stand-alone sensors. The user/purchaser shall specify the required quality level of the metallic and non-metallic components for the relevant API specifications for the equipment, where applicable to the relevant API specifications for the equipment such as API 14A, API 11D1, API 19ICV, API 19AC, API 19V, API 19G1 and API 19G2. The requirements for metallic and non-metallic components in other API specifications take precedence of the requirements in this specification where the electrical/electronic system is integrated into that equipment.

5 Technical Specification

5.1 General

The purpose of this section is to set requirements for design and validation testing of electrical/electronic downhole equipment. All such equipment shall be designed to perform in accordance with requirements specified in the applicable sections below.

All electrical/electronic assemblies and systems shall be designed and validated per [5.4](#). Additional requirements, considerations and validation testing are given for specific function types as outlined in [5.5](#) through [5.8](#).

Permanent downhole gauges are stand-alone sensing devices and are used to transmit well parameters (pressure, temperature, flow or fluid composition) and shall conform at a minimum in accordance with [5.4](#), [5.5](#), and [5.7](#) as well as [Annex C](#).

Supplementary information is found in the annexes listed in [Table 1](#).

Table 1—Summary of API Recommended Practice 19E Annexes

Annex Identification	Annex Title	General Description of Content	Purpose
A	Actuators	Informative annex. Supplemental information on actuators.	Provides explanation how to determine the minimum actuator assembly to be validated.
B	Reliability	Informative annex. Supplemental information for reliability statements.	Contains examples, considerations and a comparison between ALT and RDT methods of estimating lifetime of electronic assemblies based on testing.
C	Standalone Sensing Devices Functional Acceptance Testing	Normative annex. Functional acceptance testing for standalone sensors (permanent downhole gauges).	Describes minimum activities required for each manufactured standalone sensor (permanent downhole gauge).
D	System Integration Testing	Informative annex. Contains general considerations in performing system integration testing.	Provides framework for system integration testing.

The supplier/manufacture shall prepare and provide to the user/purchaser the technical specification that demonstrates that the equipment meets the requirements of the functional specification. Technical specification

provided under requirement of API 19E shall be added to the technical specification of the equipment covered under other API specifications such as API 11D1, API 14A, API 19AC, API 19CI, API 19ICV, API 19V, API 19G1 and API 19G2 where applicable.

Technical specifications for equipment covered by other API specifications shall take precedence where conflicting with this specification.

Electrical/electronic downhole equipment conforming to this specification shall be manufactured to the same supplier/manufacture requirements and acceptance criteria as those of the configuration that was validated. Any changes made to the manufacturing requirements and acceptance criteria shall be evaluated and documented by a qualified person to determine if any additional validation is required.

5.2 Electrical and Electronic Terms

The terms electric, electrical and electronic are commonly used interchangeably, however there is a difference in the meaning of these terms:

- An electrical component is one that carries or affects the flow of electrical power.
- An electronic component is one that controls, or is controlled by, the flow of electrons; these are generally semiconductor components.

Thus, a resistor is an electrical component but not an electronic component whereas a microprocessor is both an electrical and an electronic component. Any circuit which contains both electrical and electronic components is, by definition, an electronic circuit.

The equipment covered by this specification will, in the main, include electronic components. Consequently, the term electronic will be used within this specification to mean both electrical and electronic. For example, the term electronic component will be used to mean both an electrical component and an electronic component.

Electrical systems which do not have semiconductor devices shall conform to this specification.

The term electrical will continue to be used to describe characteristics of electricity such as: electrical power and electrical energy.

5.3 Structure of Electrical/Electronic Equipment

The different layers of the electrical/electronic components and the electrical/electronic equipment are shown in [Figure 2](#).

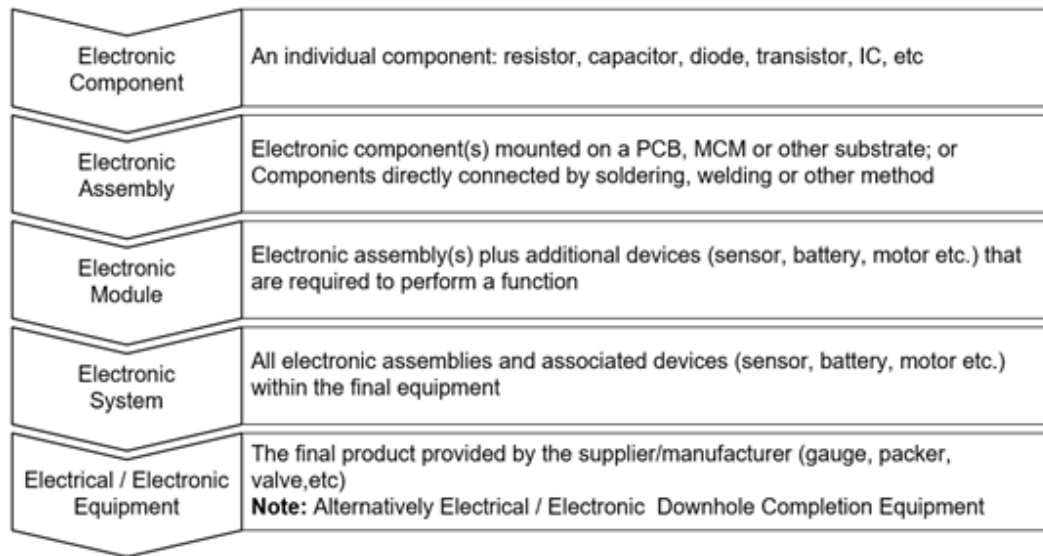


Figure 2—Structure of Electrical/Electronic Equipment

The term electronic module refers to a functional division and not a physical division. A single electronic assembly may be part of two electronic modules (e.g. an actuation module and a telemetry module) or an electronic module may require multiple electronic assemblies (e.g. a drive control assembly and sensor interface assembly).

An electronic system could be a single electronic assembly if the electronic assembly performs all the functions of the equipment, e.g. a downhole gauge with a single printed circuit board assembly (PCBA).

All testing defined in this specification shall be performed at the electronic assembly level or higher, unless otherwise noted.

5.4 General Functions

5.4.1 General

Electronic assemblies and systems may consist of any combination of passive components such as diodes, resistors, capacitors, coils including inductive coupling; and active components such as power converters, signal conditioners, boosters or repeaters.

The supplier/manufacturer shall provide a technical specification of the equipment which conforms to the functional specification, and which identifies any variance(s) from the functional specification.

Design verification shall be performed to ensure that all electronic assemblies and systems meet the supplier/manufacturer's technical specifications. Design verification includes activities such as design reviews, design calculations, physical tests, and comparison with similar designs.

5.4.2 Technical Characteristics

Electrical/electronic equipment shall perform in accordance with functional specification during installation and operation. The supplier/manufacturer shall document any deviations from the functional specification that will occur during the installation phase if the environmental conditions (e.g. temperature) are outside of the normal operating envelope.

Electrical technical characteristics are based on their purpose and the scope of their environment.

5.4.3 Design Requirements

This section covers the general design requirements which apply when designing electronic equipment and assemblies.

5.4.3.1 Safety

Safety considerations with respect to personnel shall be included in designing electrical / electronic equipment against potential hazards while testing or operating.

5.4.3.2 Fluid and Material Compatibility

Supplier/manufacturer shall evaluate fluid and material compatibility for electrical / electronic equipment. Examples of this include electronic assemblies/systems in pressure compensated chambers, electric motors immersed in oil, electronic assemblies/systems sealed in a pressure housing, downhole gauge in well fluids.

5.4.3.3 Power Budget

The supplier/manufacturer shall determine the power budget which includes electrical load variation required from external or internal power sources that is sufficient to provide full functionality of the electrical/electronic equipment.

5.4.3.4 Electromagnetic compatibility (EMC)

Design shall consider other sources of electromagnetic noise in the well. Design shall consider the impact to the EMC qualification of the surface/subsea equipment.

5.4.3.5 Electrostatic Discharge

The supplier/manufacturer shall include design elements or procedures to mitigate damage due to electrostatic discharge.

5.4.3.6 Level of Redundancy

If redundancy is included in the design, then generally the following guidelines are applicable:

- The level of redundancy should prevent or minimize the loss of functionality caused by a single-component failure or common cause failure.
- If redundant components are used, the reliability of the method for switching from the primary to the backup component should be evaluated. Active redundancy, which enables a seamless transfer to a secondary system in the event of a primary system failure, should be implemented, if practical.
- The level of redundancy throughout the system is influenced by its complexity and reliability. An analysis of the expected benefit from redundancy should be performed for all critical parts of the system.

5.4.3.7 Compatibility with Well Interventions

Compatibility and any limitations with well intervention equipment or activities shall be established.

5.4.3.8 Condition Monitoring

Electrical/electronic equipment should allow for health monitoring and diagnostics from the surface where possible.

5.4.3.9 Electronics Chambers and Housings

5.4.3.9.1 General

Electronic assemblies or systems may be housed in a pressure chamber within the equipment, this is commonly referred to as the electronics chamber. The chamber allows the electronic components to be in a known environment and, where applicable, at a pressure independent of the well pressures. The electronics chamber may take many forms but the most common are shown in [Figure 3](#).

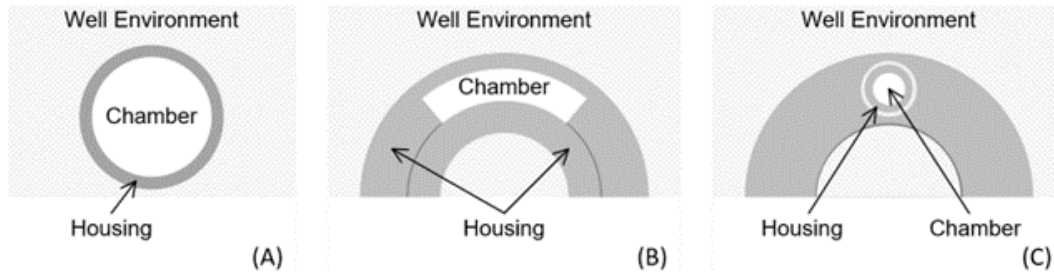


Figure 3—Example Pressure Chamber Configurations

The pressure housing consists of the mechanical part(s) that form the boundary of the electronics chamber. This may include static mechanical parts, electrical feedthroughs, and seals or bellows.

5.4.3.9.2 Design Calculations

5.4.3.9.2.1 General

Completion accessory design calculations may be performed using one of the following methodologies.

5.4.3.9.2.2 Distortion Energy Theory

The distortion energy theory, also known as the von Mises yield criterion, shall be used for the design calculation of pressure-containing components. ASME BPVC Section VIII, Division 3, KD-131(b) provides the equations to calculate the equivalent stress.

The equivalent stress shall be calculated and be limited by the supplier's documented design margin methodology and practice.

Stress concentrations and discontinuities are beyond the scope of this methodology.

5.4.3.9.2.3 Triaxial Yield and Uniform Axial Equations

API Technical Report 5C3, [Annex A](#) (Discussion of Equations for Triaxial Yield of Pipe Body) shall be used to derive the triaxial yield stress of a cylinder.

Tensile (axial) stress calculations shall be performed per the requirements of API Technical Report 5C3, [Annex A](#), Section A.1.2.3 (Uniform Axial Stress).

5.4.3.9.2.4 Finite Element Analysis

Finite element analysis (FEA) is a design verification methodology that analyzes more complex geometries, complex loading or both where conventional verification methodologies are considered incomplete by the design engineer or qualified person. FEA methodology may be used for single or combined loading situations.

FEA analysis inputs and outputs shall be archived in accordance with [6.2.1](#) such that the study can be reevaluated/reproduced.

5.4.3.10 Firmware and Configuration Data

Embedded software and firmware used in downhole completions equipment shall be developed, acquired, supplied, configured, tested, maintained, and supported in conformance with recognized and verifiable standards such as ISO 9001 and ISO/IEC 90003.

Configuration data associated with the software development shall also be maintained and controlled using a documented configuration management system.

Planning of software development and configuration activities, in all phases of the project, should include progress monitoring, and should identify all interdependencies with internal and external interfaces, engineering, production, testing, and delivery of other equipment. Methods to update firmware of already encapsulated electronics and installed equipment should be considered during the design phase.

5.4.3.11 Design Analysis

Analyses shall be performed on the proposed electrical/electronic system for the purpose of validating conformance with equipment requirements (e.g. performance characteristics, performance requirements, electronic component reliability, system availability, system fault tolerance).

Analyses shall include:

- a) electrohydraulic power requirements where applicable;
- b) electrical power distribution analysis;
- c) communication analysis where applicable;
- d) failure mode effects and analysis;
- e) reliability, availability, maintainability and obsolescence analysis;
- f) safety assessment analysis;
- g) mechanical (including structural) where applicable;
- h) thermal analysis.

5.4.4 Testing Requirements

5.4.4.1 General

Unless otherwise specified all electronic assemblies and systems shall be validated per the testing requirements in [5.4.4](#). Specific testing requirements may be required for the following specific functions: telemetry, sensing, actuation, and energy storage. A summary of the testing required for electronic modules based on functionality is shown in [Table 2](#), the tests may be performed in any order.

Considerations for single well/multi-well system integration testing including surface equipment are found in [Annex D](#).

Stand-alone sensing devices primarily intended for measuring reservoir well parameters (such as pressure, temperature, flow) shall be validated at the equipment level.

Testing of permanent downhole gauges may be performed with or without the gauge carrier/mandrel.

The supplier/manufacturer shall document the validation test procedure, acceptance criteria, and results and shall document as applicable:

- electronic component specifications,
- material specifications and certifications,
- electronic assembly documentation of conformance,
- drawings that show all the applicable layout of the electronic system, dimensions, and tolerances of parts contained in the validation-tested product,
- other documentation as applicable for the purpose of correlating validated equipment to manufactured product.

Pre-test and post-test inspection of critical operational parameters or dimensions as determined by the supplier/manufacturer shall be conducted, documented, and maintained by the supplier/manufacturer.

Validation test results shall be approved by a qualified person other than the person performing them, and records of the results shall become a portion of the design documentation. Evaluation and justification for any nonconforming parameters or dimensions that changed from pretest inspection shall be documented as part of the acceptance and become part of the design file.

Unless otherwise stated in the specific validation test, any equipment which is expected to be powered by a battery may be powered during test by either the battery or by an alternative power source. Any alternative power source used for testing shall be configured to provide voltage and the current representative of the power source expected to be used in normal service.

Warning—Due to health and safety risks related to temperature cycling, shock and vibration testing of some chemistries of electrochemical cells, special safety considerations need to be addressed to prevent accidental fire, explosion or release of hazardous chemicals. It is recommended that such testing be performed by specialized entities that are familiar with the risks involved.

Electronic equipment that is impractical to test due to size shall be tested with a smaller scale representative form including interconnects and packaging as justified and documented by a qualified person.

Table 2—Summary of Testing Requirements and Associated Sections

Validation Tests	Function				
	General (Baseline)	Telemetry	Sensing	Actuation	Energy Storage
Functionality	5.4.4.2	5.4.4.2	5.4.4.2	5.4.4.2	5.4.4.2
Operating Pressure Cycling	5.4.4.3	5.4.4.3	5.4.4.3	5.4.4.3	5.4.4.3
Minimum Power-On Temperature Testing	5.4.4.4.3	5.4.4.4.3	5.4.4.4.3	5.4.4.4.3	5.4.4.4.3
Thermal Cycling	5.4.4.4.4	5.4.4.4.4	5.4.4.4.4	5.4.4.4.4	5.4.4.4.4
Vibration Test	5.4.4.4.5	5.4.4.4.5	5.4.4.4.5	5.4.4.4.5	5.4.4.4.5
Mechanical Shock	5.4.4.4.6	5.4.4.4.6	5.4.4.4.6	5.4.4.4.6	5.4.4.4.6
Long-term Reliability	5.4.4.5	5.4.4.5	5.4.4.5	5.4.4.5	N/A
Measurement Verification	N/A	N/A	5.7.4.3 or 5.7.4.2	N/A	N/A
System Integration	5.4.4.6	5.4.4.6	5.4.4.6	5.4.4.6	5.4.4.6
Communication Test	5.5.3.2	5.5.3.2	N/A	N/A	N/A
Actuator Lifetime Usage	N/A	N/A	N/A	5.6.4.2	N/A
Energy Storage System Performance	N/A	N/A	N/A	N/A	5.8.5.2
Functional Acceptance Testing	6.5	6.5	6.5	6.5	6.5
N/A = Not Applicable					

At a minimum, the minimum power-on temperature test ([5.4.4.4.3](#)), thermal cycling ([5.4.4.4.4](#)), vibration ([5.4.4.4.5](#)) and mechanical shock ([5.4.4.4.6](#)) testing shall be completed with the same DUT without re-dress or repair. The sequence in which these tests are performed shall be documented.

5.4.4.2 Functionality Test

5.4.4.2.1 Primary Objective

The objective of the Functionality Test is to demonstrate the operation of the electronic assembly, its intended function and parameters are within the specified range.

5.4.4.2.2 Operational Test Requirements

Operational testing shall be performed at the electronic assembly level or higher.

Supplier/manufacturer shall identify and document the critical operational parameters and functions and their acceptable operational range(s) or variation that are necessary for the equipment to perform its intended function.

The device under test (DUT) shall be placed in a stable controlled environment.

Examples of critical operational parameters:

- Input and output power, input and output current and voltage.
- Sensing—calibrated measurement range, accuracy and repeatability.
- Telemetry—stability of communication.
- Signal quality—amplitude and noise.

- Memory integrity, data quality.
- Electromechanical devices—range of motion vs. applied power.

5.4.4.2.3 Acceptance Criteria

Operational and functional performance shall be within the operational range as defined in the supplier/manufacturer's documented test procedure.

5.4.4.3 Operating Pressure Cycling

5.4.4.3.1 Primary Objective

The purpose of this test is to confirm the functionality of the electronic assembly(s) in a pressure housing when the pressure housing is exposed to external pressure to the rated operating pressure. Refer to [Figure 4](#), [Figure 5](#) and [Figure 6](#).

The operating pressure cycle test can be performed as part of another API specification validation test provided it meets or exceeds the requirements of this section.

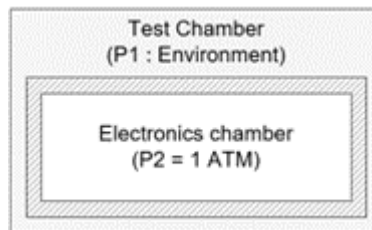


Figure 4—Standalone Electronics Chamber

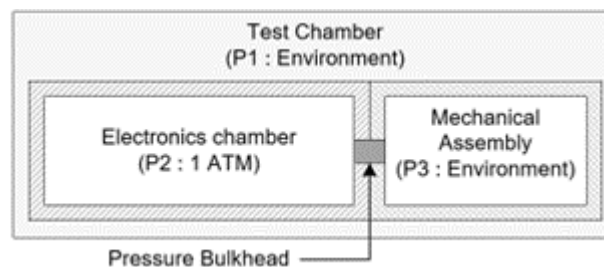


Figure 5—Electronics Chamber Connected to Another Assembly (e.g. pressure sensor) via a Pressure Bulkhead

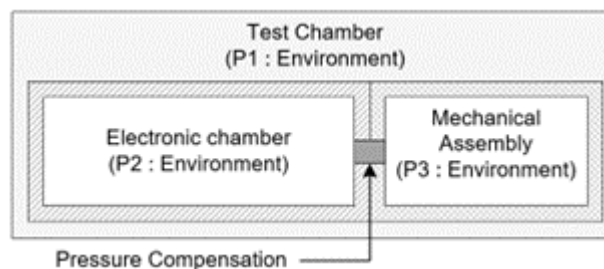


Figure 6—Electronics Chamber Connected to Another Assembly (e.g. actuator) with Pressure Compensation

5.4.4.3.2 Pressure Cycle Test Requirements

5.4.4.3.2.1 The DUT shall consist, as a minimum, of the pressure housing(s) and the electronic assembly(s) normally housed within it to allow for functional monitoring during the test.

5.4.4.3.2.2 For permanent downhole gauges, the DUT shall be the equipment as deployed in the well (including cable head or representative cable head test fixture, any applicable splitters or manifolds, housings, and the electronic system).

5.4.4.3.2.3 Supplier/manufacture shall identify and document any critical dimensions and parameters and their tolerances which will be monitored or measured as part of the test.

5.4.4.3.2.4 The test medium shall be a water-based fluid, hydraulic fluid, or gas. Where fluid other than city water is used the mass density of the test fluid shall be less than 1100 kg/m³ (68.67 lb/ft³) and shall be visibly free from particulate matter or other material that could plug a small leak. Fluids used in the testing shall be defined and documented in the test report.

5.4.4.3.2.5 This test consists of the following steps:

- a) Perform a minimum of five pressure cycles at room temperature. The functionality test per [5.4.4.2](#) shall be performed during the last pressure cycle.
- b) Increase the temperature maximum rated temperature and hold for a minimum of 30 minutes to stabilize.
- c) Perform a minimum of five pressure cycles while at or above the maximum rated temperature. The functionality test per [5.4.4.2](#) shall be performed during the last pressure cycle.
- d) Decrease the temperature to the minimum rated temperature and hold for a minimum of 30 minutes to stabilize.
- e) Perform a minimum of five pressure cycles while at or below the minimum rated temperature. The functionality test per [5.4.4.2](#) shall be performed during the last pressure cycle.

5.4.4.3.2.6 For single-use devices the functionality test shall be performed at the end of the test.

5.4.4.3.2.7 A pressure cycle consists of raising the pressure from atmospheric to or above the maximum rated pressure of the housing, holding the pressure for minimum of 15 minutes after allowing for stabilization, followed by lowering the pressure to atmospheric pressure. Examples of pressure cycles are shown in [Figure 7](#).

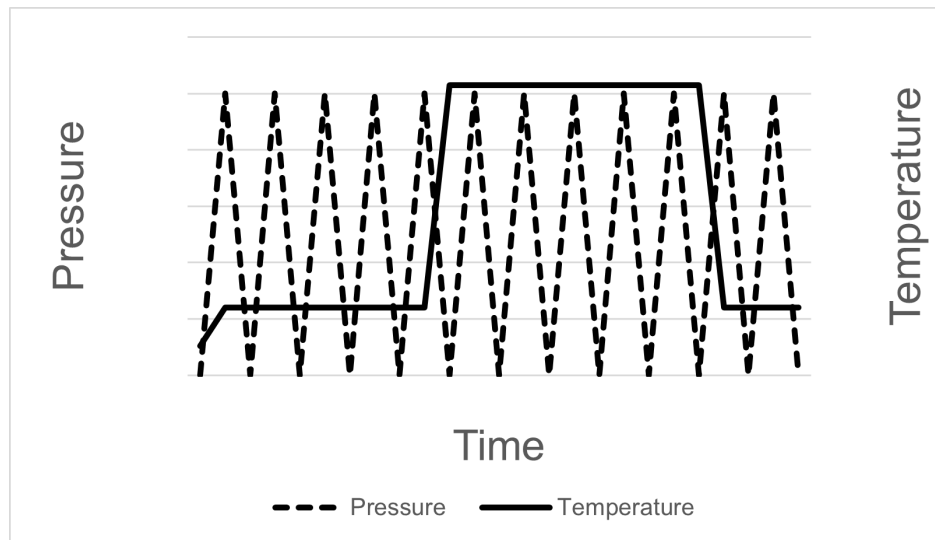


Figure 7—Example of Pressure and Temperature Cycles

5.4.4.3.3 Acceptance Criteria

5.4.4.3.3.1 Electronic assembly(s) shall pass the functionality test(s) as described in 5.4.4.2.

5.4.4.3.3.2 Any visible leakage is considered a failure.

5.4.4.3.3.3 Critical dimensions shall be within supplier/manufacturer's documented specification.

5.4.4.4 Environmental Testing

5.4.4.4.1 Primary Objective

5.4.4.4.1.1 The objective of the environmental testing is to subject the electronic assembly to environmental stresses equal to or greater than the stress the final product shall experience during service.

5.4.4.4.1.2 The environmental testing comprises of the minimum power-on temperature test ([5.4.4.4.3](#)), thermal cycling ([5.4.4.4.4](#)), vibration ([5.4.4.4.5](#)) and mechanical shock ([5.4.4.4.6](#)).

5.4.4.4.1.3 All environmental testing shall be completed with the same DUT without re-dress or repair.

5.4.4.4.1.4 The minimum power-on temperature test ([5.4.4.4.3](#)), thermal cycling ([5.4.4.4.4](#)), vibration ([5.4.4.4.5](#)) and mechanical shock ([5.4.4.4.6](#)) testing shall be completed with the same DUT without re-dress or repair. The sequence in which these tests are performed shall be documented.

5.4.4.4.1.5 At a minimum the functionality test per [5.4.4.2](#) shall be performed at the conclusion of the environmental testing.

5.4.4.4.1.6 A visual inspection and measurement of critical dimensions shall be performed pre and post environmental testing.

5.4.4.4.1.7 Sensing devices shall perform measurement verification testing per [5.7](#) pre- and post-environmental testing except for the measurement drift testing ([5.7.4.4](#)).

5.4.4.4.2 Environmental Testing Acceptance Criteria

At the conclusion of the environmental testing: