ANNEX B

ADDITIONS AND MODIFICATIONS TO API 617

FOREWORD

This Annex is based on API Standard 617, 8th edition, September 2014. It is only written in English.

1 SCOPE

This Annex establishes the minimum conditions required for axial and centrifugal compressors, expander-compressors and their auxiliary equipment or systems, to be supplied in accordance with API Standard 617, 8th edition, September 2014.

2 SUPPLEMENTARY DOCUMENTS

The following documents are referenced in the text and contain valid rules for this Annex.

2.1 Base Standard


3 GENERAL REQUIREMENTS

3.1 The requirements of this Annex are additions to, or modifications of the API Standard 617, 8th edition, which is an integral part of this Annex.

3.2 Except for new clauses, item numbers used in this Annex are the same API Standard 617, 8th edition paragraph ones.

3.3 No additional deviations from Annex D will be accepted. PACKAGER is responsible to relate each deviation from API Standard 617, 7th to 8th had already discussed with PETROBRAS as presented in Annex D. All deviations from new/modified paragraphs from the requirements in this Annex and/or API Standard 617, 8th edition must be clearly identified in the proposal and submitted to PETROBRAS for approval. Any requirement exception or deviation from any of the listed documents not clearly mentioned in tender will be considered by PETROBRAS as full compliance with the material requisition.

3.4 All deviations from the contracted design or scope of supply made by vendor during time of drawings and documents review shall be clearly mentioned in the particular document to be approved.

3.5 Vendor’s compliance with the requirements of these specifications does not exempt him from the responsibility of supplying equipment and accessories suitable for the specified service conditions.

3.6 Compressors and auxiliary equipment shall be in accordance with API Standard 617, 8th edition, plus the following changes, as noted in parenthesis for each clause,
according to the definitions stated below. The information of each clause shall be read as follows, whenever starting with:

**Addition:** Continuation of that particular API Standard 617 paragraph  
**Modification:** Replacement of part of that affected API Standard 617 paragraph  
**Substitution:** Replacement of that API Standard 617 paragraph in its entirety  
**New:** Insertion of a requirement not found in API Standard 617  
**Deletion:** Removal of that particular API Standard 617 paragraph  
**Comment:** Clarification or interpretation on that API Standard 617 paragraph

### 4 PETROBRAS CHANGES TO API STANDARD 617, EIGHTH EDITION

Note - From this point onwards the numbering of the items refer to the corresponding item of the API 617 standard.

**PART 1- GENERAL REQUIREMENTS**

**4.8 DYNAMICS**

**4.8.2 Lateral Analysis**

**4.8.2.3 (Substitution)**

The supplier shall conduct an undamped analysis to identify the undamped critical speeds and determine their mode shapes. The analysis shall identify the first four undamped critical speeds and cover as a minimum the stiffness range from free-free to rigid support rotor modes.

**4.8.2.4 b (Addition)**

The clearance ranges to be used in the analysis shall be: minimum bearing clearance and maximum preload, calculated using maximum pad, minimum bearing and maximum shaft radius; average bearing clearance and preload, calculated using mean pad, bearing and shaft radius; maximum bearing clearance and minimum preload, calculated using minimum pad, maximum bearing and minimum shaft radius; these calculated coefficients for the speed range, shall be presented in the damped unbalance response analysis report. Bearing circumferential temperature profile shall also be included.

**4.8.2.4 c (Addition)**

The pad inertia and thermal effects, convection and pad conduction shall also be considered.

**4.8.2.4 k (New)**

The influence over the operating range of the damper seals stiffness and damping, considering also the tolerance on the component clearance.
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4.8.2.7 (Modification)
Replace first sentence by:
A separate damped unbalance response analysis shall be conducted for each critical speed in the range from ZERO to trip speed, as well as the next mode occurring above the trip speed.

4.8.2.8 (Substitution)
As required by 4.8.3.1, additional analyses shall be made for use with the verification test specified in 4.8.3. The location of the unbalance shall be determined by the supplier. The unbalance shall not be less than 2 times or greater than 8 times the value from Equation (3) or Equation (4) or as specified in 4.8.2.8.1. Any test stand parameters that influence the results of the analysis shall be included, such as actual bearing clearances used during the test and pedestal stiffness. If the chosen location of the unbalance does not excite the critical(s) of concern, the unbalance shall be placed in the plane(s) that would excite the critical most adversely.

4.8.2.9 a (Substitution)
If the AF at a particular critical speed outside the operating speed range is less than 2.5, the response is considered critically damped and no separation margin is required (SMr = 0). However, even though amplification factor calculations for a given rotor may indicate critically damped response and then no separation margin would be required, critical speeds within the operating speed range will only be accepted if the vendor can demonstrate that all efforts to remove the critical speed from the operating speed range have been exhausted.

4.8.2.11 (Modification)
Replace Equation (9) by:
\[ S_{cc} = \frac{A_{vl}}{A_{max}} \]

4.8.2.11.2 (Addition)
For machines with abradable seals, the rotor response amplitudes, corrected in accordance with 4.8.2.11 at any speed from zero to trip speed shall not exceed 100 % of the minimum design diametral running clearances throughout the machine.

4.8.1.4.2 (Substitution)
Unless otherwise specified, the reporting requirements identified as required for independent audit of the results shall be provided.

4.8.1.4.3 (Substitution)
Provisions shall be made to provide the purchaser with access to drawings to develop independent models of the rotor, bearings, and seals. This data shall be made available in electronic format.

Annex C.1.k.ii (Substitution)
Figure C.2 plot of log decrement, δ, vs cross coupled stiffness for minimum and maximum bearing clearances, combined with the two extremes of oil temperature and
pressure (minimum pressure with maximum oil temperature, and minimum temperature with maximum oil pressure);

NOTE The minimum and maximum bearing clearances to be used in the analysis shall be:
   Minimum bearing clearance and maximum preload, calculated using maximum pad, minimum bearing and maximum shaft radius;
   Maximum bearing clearance and minimum preload, calculated using minimum pad, maximum bearing and minimum shaft radius.

4.8.3 Unbalanced Rotor Response Verification Test

4.8.3.1 (Substitution)

An unbalanced rotor response test (URT) shall be performed as part of the mechanical running test (see 6.3.5 of Part 1, 6.3.1 of Parts 2 and 3, and 6.3.3 of Part 4, whichever is applicable), and the results shall be used to verify the analytical model. The actual response of the rotor on the test stand to the same arrangement of unbalance and bearing loads as was used in the analysis specified in 4.8.2.8 shall be used for determining the validity of the damped unbalanced response analysis. To accomplish this, the requirements of 4.8.3.1.1 through 4.8.3.1.6 shall be followed.

NOTE This test may be performed on an on-speed balancing machine if previously approved by PETROBRAS.

4.8.3.1.3 (Substitution)

The machine shall then be brought up to trip speed after being held at maximum continuous speed until bearing temperature and vibration have been stabilized, and the indicated vibration amplitudes and phase shall be recorded during the coastdown using the same procedure as 4.8.3.1.1.

4.8.3.1.4 (Substitution)

The location of critical speeds below the trip speed shall be clearly identified during the test.

NOTE: This may be accomplished on an on-speed balancing machine if previously approved by PETROBRAS.

4.8.3.1.5 (Addition)

If, after vectorial subtraction, the unbalance mass does not change the vibration at critical speed in more than 2.5 μm (0.1 mil), then the unbalance weight shall be increased and the test shall be repeated.

4.8.5 Level I Stability Analysis

4.8.5.8 Level I Screening Criteria (Modification)

Replace item a. ii by:

   ii. \[ \delta_a < 0.2. \]

Replace item b. by:
b. For axial flow rotors:

If $\delta_a < 0.2$, a Level II stability analysis shall be performed. Otherwise, the stability is acceptable and no further analyses are required.

### 4.8.6 Level II Stability Analysis

#### 4.8.6.9 Acceptance Criteria (Substitution)

The Level II stability analysis shall indicate that the machine, as calculated in 4.8.6.1 through 4.8.6.8, shall have a final log decrement, $\delta f$, greater than 0.2.

#### 4.8.6.10 (Substitution)

A stability test, to measure damping ratio (and to determine the corresponding log decrement), shall be performed in accordance with item 6.3.8 if one of the following conditions is satisfied:

a) the machine fails to meet the criteria specified in item 4.8.6.9;

b) the test has been specified in compressor data sheet.

NOTE Some particular applications which have not proven rotordynamic design may require special consideration in determining the actual compressor damping ratio (thus demanding stability test to be performed), such as CO2 injection, high-pressure and high-density gases, etc.

### 4.8.8 Vibration and Balancing

#### 4.8.8.11 (Modification)

Replace the item by:

If the supplier can demonstrate that electrical or mechanical runout is present, a maximum of the level from Equation (13) or 6.35 $\mu$m (0.25 mil), whichever is greater, may be vectorially subtracted from the vibration signal measured during the factory acceptance test.

### 6 - INSPECTION, TESTING, AND PREPARATION FOR SHIPMENT

#### 6.3 Testing

##### 6.3.5.2 Substitution)

Shop test facilities shall include the capability of continuously monitoring, displaying, recording, and printing vibration displacement and phase, vibration spectra, Bode plots, shaft orbits, bearing metal temperatures and oil pressures and temperatures. Shop test facilities shall also include a dedicated station fully available for PETROBRAS use, and capable of handling and analyzing all real time data collected during all tests.

##### 6.3.5.9.3 (Substitution)

Synchronous vibration amplitude and phase angle versus speed during acceleration and deceleration shall be plotted before and after the 4-hour run. Both the synchronous (one per revolution) and overall vibration levels shall be plotted. The speed range covered by these plots shall be from 400 rpm to trip speed and from trip speed to 400 rpm.
6.3.5.9.5 (Substitution)
The following seal flow data shall be taken during the compressor mechanical running test (MRT) and performance test (PT) to assure that the seals are installed and operating properly:

a. For compressors with oil seals, inner oil leakage, pressure and temperature shall be measured at each seal;
b. For single dry gas seals, flow, pressure and temperature in each vent line from each seal shall be measured. If a buffer gas seal is used, injection flow, pressure and temperature for each seal shall also be measured;
c. For tandem dry gas seals, flow, pressure and temperature in the primary and secondary vent line from each seal shall be measured. If a buffer gas for primary and secondary seal is used, injection flow, pressure and temperature for each seal shall also be measured;
d. For double dry gas seals, the pressure, temperature and total flow to each seal shall be measured.

6.3.5.9.5.1 (New)
The guaranteed static seal leakage shall be checked during the assembled compressor gas leakage test.

6.3.5.9.6 (Substitution)
Lube-oil and seal-oil inlet pressures and temperatures shall be varied through the range permitted in the compressor operating manual. The following cases shall be verified during the 4-hour test:

— high lube oil pressure & high lube oil temperature;
— high lube oil pressure & low lube oil temperature;
— low lube oil pressure & high lube oil temperature;
— low lube oil pressure & low lube oil temperature.

Oil conditions change test shall be done during the four-hour mechanical running test, but not before all test parameters and variables are considered to be stable or steady enough to proceed. This test does not constitute a waiver of the other specified test requirements. The oil conditions change shall be held for a minimum of five minutes after temperature stabilization.

6.3.7 Optional Tests (Addition)

6.3.7.9 Spare-parts Test (Substitution)
Spare parts such as rotors, bearings, and seals shall be inspected and tested under the same requirements of main components. Equivalent reports shall be issued as well. Spare rotors need not be performance tested, except when complete spare bundles are purchased. Complete spare bundles shall be performance tested using the same procedure as the main bundle.

6.3.8 (New) Stability Test
The purpose of this entire new item is to provide the minimum requirements for the execution of a Factory Stability Test (FST), in order to measure the actual stability margin of the machine, identifying the sister modes (forward and backward) and their respective log decrements. The log decrement shall be measured, at least, in two different operational conditions, in order to plot the measured actual applied cross-
coupled stiffness vs. Log decrement and the extrapolated produced curve, to the
minimum log decrement at worst design conditions (see item C.1.k Part 1).

The presentation of the results shall include a plot of applied cross-coupled stiffness vs.
Log decrement, showing the measured values and the expected values for similar
conditions.

Equipment shall be tested in accordance with 6.3.8.1 through 6.3.8.6.

6.3.8.1 (New) Methods & Procedures

The manufacturer shall specify in the FST procedure which kind of excitation is
intended to be applied, which measurement devices to be used during the FST and
how the test execution sequence has been planned. The type and direction of the
excitation shall be fully described as well, including whether it would be directional
(horizontal or vertical) or circular (forward or backward). It is purchaser understanding
that there are several methods to apply excitation and to measure the required data, as
below.

6.3.8.1.1 (New) Excitation Methods

Impact exciters such as a hammer, bearing casing exciter or an Active Magnetic
Bearing (AMB) exciter shall be used to excite the rotor. The excitation using an AMB
could also be an impact or a sine sweep (blocking type or conventional).

6.3.8.1.2 (New) Measurement Techniques

The measurement techniques can be applied in the frequency domain or in time
domain. In any of the methods, the approach to estimate the forward and backward
modes and respective log decrements shall be using multiple degrees of freedom
(MDOF). The method employed shall provide acceptable results even in case of the
following difficulties or abnormalities (but not limited to):
   a) rotor system anisotropy;
   b) slightly damped systems (the method must render an acceptable damping ratio
      estimation);
   c) limitations on the number of input and output locations;
   d) noise and/or internal sources of excitations, such as rotor unbalance.

Due to the proximity of modes in the rotating systems, the Single-Degree of Freedom
(SDOF) technique is not acceptable. The methods that lead to the best results are the
PEM (Predicted Error Method) for frequency domain and MOBAR (Multiple Output
Backward Auto Regression) for time domain.

Any other applicable methodology, rendering acceptable results even in case of above
mentioned system characteristics, such methodology shall be fully described (type of
load, application of load, measurement techniques, interpretation of results, definition
of model order, etc.) and demonstrated (list of experience with similar designs, results
and comparison with actual data). Methodologies shall be submitted to purchaser for
review and approval.

6.3.8.2 (New) Definitions

The stability of the machine shall be measured in two different operating conditions as
defined in 6.3.8.2.1 and 6.3.8.2.2.
6.3.8.2.1 (New) Base Stability

The Base Stability is defined as the measured stability with the machine running with zero internal cross-coupling. This can be most closely achieved with the rotor running on High Speed Balancing Machine or running during the Mechanical Running Test, preferably under vacuum, which may be done during HSB at HSBM, or at Test Bed during Mechanical Running Test (MRT) or Performance Test (PT).

The Base stability shall be measured at maximum continuous speed - MCS - and at Performance test speed (if Performance test speed is different than MCS). The procedure for applying the excitation shall be according to item 6.3.8.5.

6.3.8.2.2 (New) Measurement During Pressurized Test

The stability measurement during the Pressurized Test is defined as the measurement of the log decrement of the machine for a specific cross-coupling, calculated taking in account the pressure and speed during the test, for one chosen point. The Pressurized Test may be a performance test according to ASME PTC-10 or a full pressure test (if specified).

For an ASME PTC-10 type II test, the procedure shall consider the following premises:
   a) after determination of the first surge point, the capacity flow rate shall be increased in order to remain in safe region;
   b) there shall be a delay, waiting for system stabilization (pressures, temperatures, flow rates, bearing temperatures and shaft centerline);
   c) the test conditions shall be chosen by manufacturer such that estimated cross-coupling be, at least, 20% of the cross-coupling calculated according to item 4.8.6.8 d. For boundary conditions where such margin cannot be accomplished, the test point shall be the highest feasible;
   d) the excitation shall be started as per item 6.3.8.5.

For an ASME PTC-10 type I test or full pressure test, the procedure shall consider the following premises:
   a) maximum pressure shall be achieved. Purchaser and the manufacturer may agree and define other intermediate points;
   b) there shall be a delay, waiting for system stabilization (pressures, temperatures, flow rates, bearing temperatures and shaft centerline);
   c) the excitation shall be started as per item 6.3.8.5.

6.3.8.3 (New) Preparation for the Test

6.3.8.3.1 (New)

When an active magnetic bearing is used for the excitation, its assembly on the shaft shall not significantly change the rotor response characteristics. The manufacturer shall submit for purchaser approval the proposed device and the expected changes in the rotor response prior to the test.

The equipment measured unfiltered vibration, during the mechanical running and performance tests, with the assembled device, before applying any load, shall not exceed the limits of item 4.8.8.8.

The manufacturer shall send a procedure informing how the AMB will be adjusted/calibrated and how the applied force will be measured. Prior to the tests, the
accuracy of input force measurements shall be verified. The manufacturer shall submit the AMB calibration report for purchaser review.

6.3.8.3.2 (New)

The manufacturer shall present, prior to the test, the calculated log decrement for the forward and backward modes at actual test conditions (Qf), such as bearing clearance, preload and test speed (for ASME PTC-10 type II test, the test speed may be different from maximum continuous speed).

6.3.8.3.3 (New)

The data collect system shall consist as a minimum of an Oscilloscope, a Real Time Analyzer and a Data Recorder (analog or digital) with capability of continuously collecting all probes data and input signals. The sampling rate of the system shall be enough to identify the excitation frequencies and the results.

6.3.8.3.4 (New)

The manufacturer shall present in the lateral vibration report, the expected orbits for both modes (forward and backward) at MCS, from zero to the maximum expected cross-coupling (0 %, 50 %, 100 %) for the average clearance case. The definition of excitation direction shall be based in those orbits.

6.3.8.3.5 (New)

If a sine sweep method is used to identify the actual forward and backward frequencies, the frequency interval of each sine sweep shall be less or equal to 0.25 Hz.

6.3.8.4 (New) Signal Quality

6.3.8.4.1 (New)

In order to have good response when applying the excitation, the Signal to Noise Ratio (SNR) shall be at least two. The amplitude of excitation shall be controlled in order to not exceed an agreed amount of bearing clearances for safety and linearity concerns.

6.3.8.4.2 (New)

If the manufacturer decides to apply filtering to eliminate the synchronous response, the type of filter shall be informed to Purchaser. The design of the filter shall not influence the signal components of interest.

6.3.8.5 (New)

Any measured point (forward and backward) shall be calculated from an average of at least five readings. These five readings shall be in the range of:

$$\delta_m - 0.03 \leq \delta_i \leq \delta_m + 0.03$$

where

$$\delta_m = \frac{\delta_1 + \delta_2 + \delta_3 + \delta_4 + \delta_5}{5}$$

If any value falls outside the above defined range, it shall be discarded and measured again.
The average value ($\bar{m}$) will be used to compare with the predicted values.

6.3.8.6 (New) Acceptance Criteria

6.3.8.6.1 (New) Model Verification

If the measured value is above the predicted one, no correction in the model is necessary.

The vendor shall correct the model if it fails to meet the following criteria:

Any expected log decrement for the forward mode, for both cases (base stability and performance test conditions), calculated according 6.3.8.3.2, shall be inside the range of the measured log decrement ($\bar{m} \pm 0.03$).

6.3.8.6.2 (New) Test Acceptance

The highest difference between the expected value and the measured log decrement ($\delta m$) for each case (base stability and pressurized test conditions) will be the correction factor ($\delta cc$) to be applied to the calculated log decrement ($\delta f$) for the worst condition (see item C.1.k Part 1) at maximum continuous speed and design pressure (see figure below).

The equipment acceptance criteria shall be that the final corrected log decrement ($\delta f'$), at worst condition (see item C.1.k Part 1), is greater than 0.1.

![Figure 1 - Applied Cross-Coupled Stiffness, Q KN/mm (Klbf/in.)](image)

Where:

- $Q_t$: calculated cross-coupled stiffness at test conditions (see 6.3.8.3.2);
- $Q_f$: calculated cross-coupled stiffness at maximum continuous speed, design pressure and worst conditions (see item C.1.k Part 1).

NOTE The example in the curve above is only illustrative; no curve shape correction will be applied.
6.3 Testing

6.3.1 Mechanical Running Test

Replace Figure 4 of API Std 617 Part 2 by the following figure:

Figure 4 - Mechanical Running Test Sequence
6.3.5.2.3 (New)

The shop vibration equipment used during the tests shall be configured in accordance with Annex C of this standard. All cables shall be identified. ADRE system is preferred for data collecting and monitoring. If vendor uses another system, then visualization (or translation into ADRE files) software shall be included as well.

6.3.1.2.10 (New)

During the mechanical running test the measured unfiltered vibration amplitude shall not exceed, at any speed from zero to the minimum operating speed, the limit established in item 2.6.8.8 of Chapter 1 or the amplitude at probe locations in which the calculated major-axis, peak-to-peak, unbalanced rotor response amplitude reaches 50% of the minimum design diametral running clearance at any point throughout the machine, whichever is greater.

6.3.3.1 Factory Performance Test

6.3.3.1.10 (New)

During the performance test, the bearing temperatures limits used as acceptance criteria for mechanical running test shall also be applied. During the performance test, the following vibration limits shall apply for all points in the compressor operating range:

a. The measured unfiltered vibration shall not exceed the limits of 2.6.8.8 of Chapter 1.

b. The amplitude of any discrete, supersynchronous vibration shall not exceed 20% of the allowable vibration as defined in 2.6.8.8 of Chapter 1.

c. The amplitude of any discrete, subsynchronous vibration shall not exceed 0.1 micron or the following value, whichever is greater:

\[
SSV_{lim} = 0.2 \times A \times \frac{\rho_t}{\rho_d}
\]

where

- \( A \) = amplitude of unfiltered vibration, as defined in item 2.6.8.8 of Chapter 1.
- \( \rho_t \) = gas density at the compressor suction in test conditions.
- \( \rho_d \) = gas density at the compressor suction in design conditions.

Note: Any point located in the area defined by the minimum compressor running speed, the maximum continuous running speed, the anti-surge control line and the compressor capacity limit (Stonewall limit) is considered to be within the compressor operating range.