

## WITNESS TESTING OF API 610 CENTRIFUGAL PUMPS AND API 611 STEAM TURBINES

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### ABSTRACT

The tutorial outlines the basic concepts and offers some tips on witness testing of API 610 centrifugal pumps and API 611 steam turbines. The section on API 610 pump testing discusses performance, NPSH and mechanical run tests of API 610 centrifugal pumps that are often specified with witness testing. Various parameters that are measured during testing and the related instrumentation are introduced. This section references related paragraphs and tables from ANSI/API Standard 610 (2010). The section on API 611 steam turbine testing covers the mechanical run test and cites the related paragraphs of API Standard 611 (2008). The same section also recommends a few additional tests that could be performed on general purpose steam turbines, if feasible and applicable.

### INTRODUCTION

Many companies affiliated with the petroleum, petrochemical and natural gas industries require at least some machinery testing to be witnessed by quality inspectors and/or engineers at the equipment vendor's shop prior to release for shipment. This ensures that the testing is being performed in accordance with the contract requirements, applicable standards and/or test procedures that have been reviewed and accepted in advance of the test. Successful witnessing of these tests requires prior understanding of the test setup, test conditions and measured parameters.

### THE RATIONALE OF WITNESS TESTING

The prime intent of witness testing is rarely just to see the equipment operate when the start button is pushed. Witness testing provides the opportunity for an engineer or quality inspector witnessing the test (hereinafter, called the "witness") to ensure that the equipment vendor carries out the factory acceptance tests in accordance with the specifications and other contract requirements. Many a time, the size and complexity of the equipment may not be palpable through drawings and documentation. Witness testing also provides the opportunity to experience the "look and feel" of the actual equipment. Furthermore, it provides the opportunity to identify and address issues with non-conformance or misinterpretation of the specifications with respect to equipment construction or testing. The following is just an abridged list of such items:

- Location/orientation of connections, equipment, instrumentation and accessories
- Instrumentation, controls and their tagging
- Nameplates and equipment tagging
- Scope of supply of equipment, instrumentation and accessories
- Documentation
- Painting and coating requirements

The cost of correcting equipment non-conformance significantly increases for both, the vendor and the purchaser, once the equipment is shipped to the field. Hence, it is in the best interests of both these parties to identify non-conformances in the vendor's factory and ensure compliance with the contract requirements before shipment.

It is important to note that factory acceptance testing is generally performed prior to the final painting, assembly and packaging of equipment. Hence, certain items that are listed above may still not be evident during testing. However, if the

purchaser has multiple equipment orders with the same vendor, then the witness can request to see the other equipment that has already passed testing and is being assembled and packaged for final shipment. In the same manner, the witness can request to look at the other items on order that are being manufactured at that time. During the same trip for test witnessing, the witness can request the vendor to give them a tour of the manufacturing facility.

Witness testing is generally also specified if the purchaser is uncertain about the vendors' abilities, experience and performance. Moreover, for new equipment designs and for prototype qualification testing, witness testing provides the opportunity to ensure that the agreed test procedures are unequivocally followed. Finally, witness testing may also be required to ensure satisfactory operation with certain critical constraints such as insufficient NPSH margin, high energy density or high operating temperature.

When possible, the test to be witnessed should not be the first one seen by the witness at that facility. It is recommended that an apprentice type system be used – experienced engineers should recommend to management that they take along a new engineer for each new type of test or facility.

Having stated the above, one cannot negate the fact that the requirement of witness testing adds the burden of cost, time and resources to the project. Hence, the decision to require witness tests for certain equipment should be made prior to sending requests for quotation with careful consideration to the size, criticality and complexity of the equipment, in addition to the purchaser's past experience with the vendor(s). The purchaser should be mindful of the fact that once an order is placed, it usually becomes hard to justify the addition of witness testing at a later stage of the project.

### Virtual Witnessing

Virtual witnessing is a fairly recent development that allows an engineer or inspector to witness equipment testing from the comfort of their work location. Measured parameters and collected data can be displayed on the witness' computer in real time during the testing. Generally, test performance curves can also be constantly seen by the virtual witness on their computer screen as the test progresses. In addition, multiple cameras are often installed at the test site, thus enabling the virtual witness to remotely monitor the actions and events at the test site from their computer screen.

To enable such witnessing, the vendor provides the witness with access to a secure internet location that has a dedicated username and password. From there, the witness can launch a secure application that is configured to enable such witnessing.

Although the significant benefits of virtual witnessing with respect to cost, time and resources are obvious, it generally limits the extent of witness' involvement in the testing. Moreover, the witness' potential to uncover other problems with equipment non-conformance is also fairly reduced. Virtual witnessing typically limits itself in scope to the contract performance tolerances and vibration limits for specific sub-systems (e.g. hydraulics, bearing housing, shaft). On the other hand, the witness' physical presence can ensure satisfactory operation of the equipment as a complete unit, wherein problems not explicitly spelt out in the test acceptance criteria may also be uncovered. Hence, when possible, physical

witnessing of tests should be generally preferred to virtual witnessing.

## TIPS ON WITNESS TESTING

### Before the Test

The witness should review the test procedure with regard to the contract specifications in advance for acceptability and become completely familiar with the testing methodology before traveling to the vendor's factory. Furthermore, the witness should become familiar with and carry copies of necessary supporting documents to the test. Examples of such helpful documents are given below:

- Contract specifications and technical datasheets
- Applicable industry standards
- Test procedure(s)
- Piping and Instrumentation Diagrams (P&IDs)
- Equipment General Arrangement (GA) drawing(s)
- Applicable detail drawings
- Contact information of key project decision-makers and subject matter experts

After careful review of the contract documents, the witness should develop a checklist based on project specifications and referenced test standards (Jones et al., 2008). This checklist should have a list of items to be observed before, during and after the test, besides having provisions for recording readings from the test instrumentation in a tabular format. Table 1 of this tutorial is an excerpt of such a checklist.

PERFORMANCE TEST										
Pump tag #		Shop order #		Serial #						
Data sheet #				Rev #						
<b>8.3.3 PERFORMANCE TEST</b>										
API 610 requirement	Concept	Parameters to be noted by Witness				Results (Accept/Reject)				
		Reading		Time						
	Rated Speed (according to Data Sheet)									
8.3.3.3 c)	Actual speed in shop test - within +/- 3% of rated speed									
8.3.3.2 i)	Test water temperature - less than 55°C (130°F)									
8.3.3.2 c)	Seal leakage  When the pump is on the test stand and water is used as the test liquid, liquid seals suitable for testing on water shall exhibit no visible signs of leakage. ISO 21049:2004, A.1.3, should be reviewed to confirm that a zero-visible-leakage criterion is appropriate for the seals being tested. Notably, pressurized dual seals with high barrier-fluid pressures [greater than 4000 kPa (40 bar; 600 psi)] should be reviewed.									
8.3.3.3 a)	Test data (five points) (TOLERANCES PER TABLE 16)									
Test flow	Data sheet flow	Test flow reading	Head reading	Power reading	Rpm reading	NPSH reading*				
Shutoff										
MCSF										
Be'n 95% & 99% of rated										
Be'n rated & 105% of rated										
BEP (if not covered above)										
Maximum										
* Note: NPSHr if NPSH test has been requested (for performance test in a closed loop with suppression tank - usual). There may also be a requirement to limit the NPSHr at each test point on the project specifications, even if no specific NPSHr test has been requested.										
6.9.3.6 Pumps furnished with proximity probes shall meet both bearing housing and shaft vibration limits.										
Bearing Housing Vibration (Velocity) measurement (LIMITS PER 6.9.3.6)										
Test flow	Drive End				Non-Drive End					
	Horizontal		Vertical		Axial		Horizontal		Vertical	
	Overall	Max. Filt.	Overall	Max. Filt.	Overall	Max. Filt.	Overall	Max. Filt.	Overall	Max. Filt.
Shutoff (optional)										
Be'n 95% & 99% of rated										
Be'n rated & 105% of rated										
BEP										
Maximum										

Table 1. Excerpt of a Sample Test Checklist

The contract requirements for certain critical and unique equipment may require an engineer, in addition to the quality

inspector, to witness the tests. When a "witness" test is specified on the datasheet or contract specifications, it corresponds to a "hold" point on the Inspection and Test Plan to allow the purchaser to witness the test. On the other hand, an "observed" test corresponds to a "witness" point on the Inspection and Test Plan, wherein the vendor is only required to notify the purchaser of an impending test. In this case, the purchaser's attendance is not mandatory for the test to go ahead as scheduled. This can cause confusion at times due to the ambiguous usage of the term "witness" in two altogether different contexts. To preclude any ambiguity, the engineer should set up the test notification protocol for the witness test in advance with the vendor and the quality inspector; otherwise, there is a possibility of the notification not reaching the appropriate engineer in good time ahead of the test.

Once the witness test notification is received from the vendor, the witness should communicate with the vendor, enquiring whether a preliminary test was performed on the equipment and whether it passed. Certain expectations with respect to the testing methods and measured parameters can also be aligned at this time.

The witness should remember to carry certain items such as safety shoes, safety glasses and hard hat (if needed) to the vendor's factory. The witness should enquire with the vendor if they can bring their own camera to the test. A personal camera would enable them to take pictures of the test setup, equipment and dismantled components for reporting and reference purposes. If possible, the witness should carry a portable vibration meter and a portable pyrometer to the test that can be used for performing a qualitative comparison with the vendor's test instrumentation and for taking measurements at equipment locations that are not instrumented for the test.

Some vendors may require that outside attendees show their passports before being allowed into the factory premises. The witness should enquire with the vendor in advance regarding any such requirements and carry the necessary documents to the test.

If possible, the witness should travel to the test facility on the day preceding the test. This way they can also check the location of the test facility in advance to ensure that they do not cause inadvertent travel delays on the day of the test.

#### *At the Test*

At the vendor's factory, the witness should pay attention to and comply with all safety instructions provided by the vendor. They should not move around in the shop area without the vendor to escort them. They should not climb onto the test skid to reach or see a remote location.

Before the test begins, it is helpful to reinforce the test procedure and acceptance criteria with vendor's test engineer to ensure that there is a clear understanding among all parties concerned. The witness should become familiar with the test layout, instrumentation and computer displays prior to the start of test. This becomes vital if the test duration will be very short. The witness should ensure that the test setup is in accordance with the accepted test procedure. For example, if the test procedures and the contract documents so far did not call out for a gearbox in the drive train, then the witness should question the vendor if they see one in the test setup now.

The witness should review the calibration logs and

certificates for all test instruments and gauges prior to the test. They should also check for zero points and readings on instruments before the test is started (Jones et al., 2008). It is important to ensure that the accuracy of the test instrumentation is acceptable in light of the test acceptance tolerances.

The witness should stand several feet away from the equipment and all electrical junction boxes and terminals while the equipment is being started up. This would ensure safety against unwarranted projectiles and electrical shocks. The witness should be aware that the vendor's standards with respect to safety may well be below their own. The shop area typically has a lot of movement of materials, cranes, forklifts, etc. that requires the witness to be vigilant at all times.

The witness should note down the time and date of starting the test, besides the serial number of the equipment being tested on their checklist.

The witness should keep their "eyes" and "ears" wide open during the test. This means that with proper attention, it is easy to spot operational abnormalities (overheating, no oil flow, excessive vibration, etc.). The witness should listen for any unexpected noise during the test. Sometimes, this is difficult due to the ambient noise in the manufacturing facility. Alternatively, the witness can use a mechanic's stethoscope to listen for any unusual or excessive casing noises (Jones et al., 2008). Excessive noise from the equipment can point to problems such as cavitation, excessive vibration, component looseness, etc. The witness should ask the vendor to record the sound level prior to starting the test and also during the test for reference purposes. Any leaks, whether on the equipment being tested or on the test setup, should be documented.

During the mechanical run test, in particular, the witness should plot the bearing temperature rise versus time, and also the asymptote to determine when temperature stabilization occurs. This can be easily done on a laptop computer during the test. This would become even easier if the witness were to go to the test with a spreadsheet template ready for plotting the various bearing temperatures.

While the test is being conducted, the witness should constantly verify that all instruments actually do work and their measurements make sense. If an instrument fails during the test and if all parties agree that the test can be continued with the failed instrument, the witness should ensure that the failed instrument and its identification number are noted by the vendor on the test log. If the test cannot go ahead with the failed instrument, the time of stopping the test should be noted.

Finally, if the test is deemed as failed for any reason, the witness should not volunteer answers or direct the vendor with solutions to the test problems. This can lead to a rather complicated situation if the solution fails. It is advisable to discuss the situation with the vendor and other key project personnel to jointly arrive at the solution and agree on further course of action.

#### *After the Test*

The witness should note down the time of stopping the test and the test duration once the test is completed. If possible, a few hand-calculations should be performed to verify the numbers for a few test points. This would provide assurance that no retesting is immediately required.

If required, the witness should sign copies of the test logs

and obtain photocopies of the test data. It is important for everyone to realize that by signing the test logs, the witness is only agreeing that the test was witnessed and completed per the agreed test procedures. Even though there is almost always pressure to get the equipment shipped, signing of the test logs must not constitute the witness' acceptance of the test results. This is important because the raw test data typically need to be further corrected for certain factors (viz. viscosity, specific gravity, speed, impeller diameter) before the vendor can generate the final test report for acceptance.

When the contract specifications require post-test teardown for hydrodynamic bearing inspection, the witness should carefully look for signs of any undue wear or local overheating on the bearing surfaces. The bearing edges may be sharp and cause injuries; hence, proper care should be taken when handling the bearings. Pictures of the disassembled bearings should be taken for records and future analysis. If bearing inspection has been specified after only a short performance test and no mechanical run test was specified or conducted, not much bearing wear or overheating may be discernable.

Overly-tight wear ring clearances may improve pump performance in the short term, but once the clearances open up after continued operation, the pump performance drops. Depending on the difference in hardness of the wear ring materials, close clearances may also be subject to galling. Paragraph 6.7.4 and table 6 of ANSI/API Standard 610 (2010) specify the limits for the running clearances. Thus, when inspecting pump impellers, the witness should watch out for overly-tight wear ring clearances, besides other performance-enhancing items such as excessive polishing or too much underfiling that may have been put in place solely to meet the "as sold" performance.

At time of departure, the witness should provide the vendor with a written summary of any test issues including a brief list of the action items for the vendor to follow up. The summary should list any deviations to the test procedure, contract specifications or acceptance criteria. It is also advisable that the witness generates a trip report soon after the test, while the test is still fresh in the memory. A detailed trip report ensures that other project personnel (and the client, if applicable) are kept abreast of the test events, the witness' impressions of the test, in addition to any results and conclusions from the test.

## TESTING OF API 610 CENTRIFUGAL PUMPS

This section primarily discusses pump performance, NPSH and mechanical run tests. Casing hydrostatic tests that ensure the integrity of the pump pressure-containing components and joints are considered fairly straightforward, and hence, not covered in this section. The complete unit test is rarely requested even for larger pumps and its acceptance criteria are based on vendor-purchaser agreement; hence, not covered here. The bearing-housing resonance test is often used for failure diagnosis and troubleshooting, rather than for quality assurance. The use of sound level tests for pump acceptance are taken exception to by several major pump vendors since it is normally not feasible to suppress ambient noise in the factory. Still, the witness should request the vendor to take sound level measurements for reference purposes during the pump performance test.

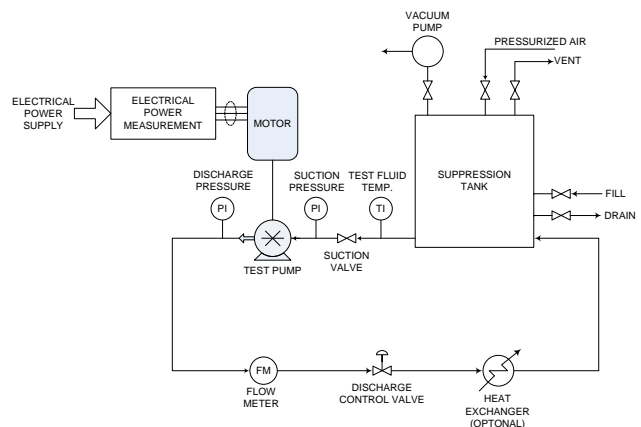


Figure 1. Basic Pump Performance Test Loop

ANSI/API Standard 610 (2010) requires that, unless the purchaser specifically chooses not to, each pump must undergo a test to prove its performance prior to shipment. Figure 1 shows a basic pump performance test loop. The performance test is generally conducted using cold tap water as the test fluid. ANSI/API Standard 610 (2010), paragraph 8.3.3.2 i), requires that the test water temperature must be limited to 130 °F (55 °C) maximum.

Unless performance testing with the job motor or a complete unit test is specifically required in the contract, the vendor will generally use a calibrated lab motor as the test driver. ANSI/API Standard 610 (2010), paragraph 8.3.3.3 c), requires the test speed to be within 3 percent of the pump rated speed. If a lab motor with the required speed and power combination is not available, then the vendor may use a calibrated gear drive besides a lab motor to match the pump rated speed. However, if such an arrangement is necessary, then prior purchaser approval should have been obtained by the vendor.

Usually, adequate NPSHA is maintained at the pump suction during the performance test. However, in order to better evaluate the pump performance with the specified NPSHA at the pump suction, some purchasers may specify that the test stand NPSHA be limited to 110 percent of that specified on the data sheet (see ANSI/API Standard 610 (2010), paragraph 8.3.3.6). In such cases, the witness should ensure that the vendor limits the suction pressure at each test point such that the NPSHA is limited as specified.

### Test Instrumentation

The flowrate through the test loop is generally measured using either a calibrated venturi meter and a differential pressure instrument (gauge, transducer or mercury manometer) or a magnetic flow meter. The differential head across the pump is determined from the differential pressure calculated from the suction and discharge pressure readings and accounting for the velocity heads and gauge elevations (see ANSI/HI 1.6 (2000)). The power consumption is measured using a digital or polyphase wattmeter, with current and potential transformers or with a torque meter. Speed is generally measured with a photo tachometer. The readings of hand-held tachometers are generally not precise and hence, they should not be used during the test. Temperatures of the test water, bearing metal surfaces and lubricating oil are measured

using resistance temperature detectors (RTDs) or thermocouples. Hand-held infrared temperature sensors should not be used to determine the oil temperature inside the bearing housing. Since these sensors measure the skin temperature of the bearing housing, they may not provide an accurate indication of the oil temperature inside. Hence, where fluid temperature measurement is necessary, a well-supported RTD or thermocouple should be installed inside the fluid prior to performing the test as shown in figure 2 of this tutorial. Thermowells with suitable intermediate conducting materials could be used if needed.



Figure 2. RTD for Bearing Oil Sump Temp. Measurement

Depending on the bearing configuration of the pumps being tested, there are two classes of vibration instrumentation that can be used: those that measure bearing housing vibration, and those that measure shaft vibration. The measurement locations for vibration instrumentation during the testing of different types of pumps are shown in figures 31 through 33 of ANSI/API Standard 610 (2010). Note that paragraph 9.2.7.3 of the standard requires that all purchased vibration instrumentation must be used during testing.

Bearing housing vibration is measured with accelerometers or velocity transducers. These are simply called "vibration transducers" in common parlance. Vibration transducers generally provide housing vibration readings in the velocity units of in/s (mm/s). These transducers are magnetically attached or threaded on to the bearing housing (see figure 3 of this tutorial) to measure vibration radially (in two planes) and axially. Tables 8 and 9 of ANSI/API Standard 610 (2010) provide the limits for bearing housing vibration for use as acceptance criteria during pump testing. Figure 34 of ANSI/API Standard 610 (2010) should be consulted for determining the vibration limits for horizontal pumps that operate above 3600 rpm or absorb more than 400 hp (300 kW) power per stage.



Figure 3. Bearing Housing Vibration Measurement

Shaft Vibration is measured using non-contact proximity probes. These are simply called "vibration probes" in common parlance. Vibration probes measure shaft vibration in the displacement units of mils ( $\mu\text{m}$ ). These probes are typically mounted at the hydrodynamic bearing locations to read the shaft movement as seen in figure 4 of this tutorial. Again, tables 8 and 9 of ANSI/API Standard 610 (2010) provide limits for shaft vibration in the two radial planes. Paragraph 6.9.3.6 of the standard requires pumps furnished with vibration probes to meet both bearing housing and shaft vibration limits. For pumps with vibration probes, paragraph 6.6.13 of ANSI/API Standard 610 (2010) requires the vendor to record the electrical and mechanical runout for the full 360° at each probe location on the test report.

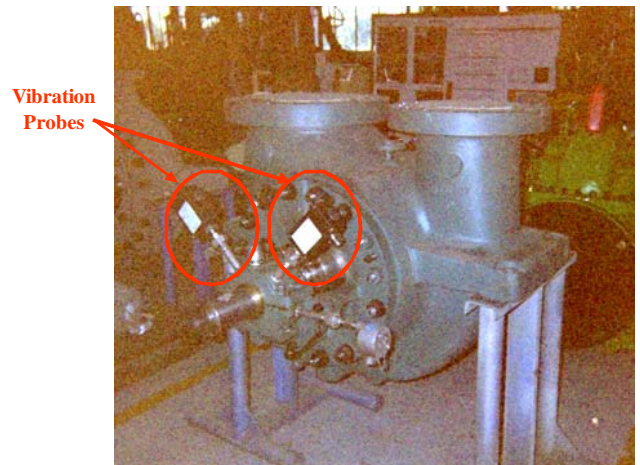


Figure 4. Probes for Shaft Vibration Measurement

Axial position probes are mounted on the hydrodynamic thrust bearing housing of the pump. These probes sense either the axial movement of shaft or an integral axial surface. Note that ANSI/API Standard 610 (2010) does not provide acceptance criteria for axial shaft vibration. Still, where axial position probes are provided, their measurements should be recorded for reference during testing. These readings are important for high suction pressure applications, where the pump shaft has the potential of displacing appreciably in the axial direction at startup. Prior to test startup, the witness should request the vendor to measure the electrical gap to

confirm the axial clearances in the thrust bearing.

An API 610 pump's preferred operating region is generally 70 to 120 percent of the best efficiency flowrate, as specified in paragraph 6.1.12 of ANSI/API Standard 610 (2010). Tables 8 and 9 of the standard allow an increase in vibration of up to 30 percent for flows outside the preferred operating region, but within the pump's allowable operating region.

Although placed outside the section on testing, bearing oil temperature limitations are provided in paragraph 6.10.2.4 of ANSI/API Standard 610 (2010) and should be used as acceptance criteria during the tests. Key aspects of this paragraph are stated below:

- For pressurized oil lubrication systems, the standard limits the oil outlet temperature to 160 °F (70 °C) and its differential temperature increase, from inlet to outlet, to 50 °F (28 °C).
- For ring-oiled or splash lubrication systems, the standard limits the maximum oil-sump temperature to 180 °F (82 °C) and its temperature rise to 70 °F (40 °C) above the ambient temperature. Note that the standard requires the ambient temperature in the test lab to be measured at the time of each reading that could be cumbersome.
- If bearing temperature sensors are provided, then the standard limits the bearing metal or outer ring temperatures to 200 °F (93 °C) maximum.

For pumps with pressure-lubricated bearings, paragraph 9.2.7.2 of ANSI/API Standard 610 (2010) requires the oil flowrate to each bearing housing to be measured and recorded.

After the performance test is completed, the vendor should correct the raw data taken during the test to account for the pump rated speed, besides the viscosity and specific gravity of the actual process fluid. If post-test impeller diameter modifications are required to meet the rated performance, they are only permitted for less than 5 percent changes in diameter per paragraph 8.3.3.7 a) of ANSI/API Standard 610 (2010). The performance tolerances specified in table 16 of the standard are applicable to these final corrected curves. Contrary to ANSI/HI 1.6 (2000), note that ANSI/API Standard 610 (2010) does not base pump acceptance on efficiency, but on rated power.

#### *NPSH Test*

If an NPSH test has been specified, it will generally be conducted simultaneously with the performance test. This test is conducted by gradually reducing the pump suction pressure by drawing vacuum on the suppression tank or by throttling the suction valve until the differential head developed (first-stage head in a multistage pump) drops by 3 percent at every flowrate (except shutoff).

The vacuum suppression method employs reduction of the suction pressure by creating a partial vacuum in the suppression tank with the use of a vacuum pump. On the other hand, the valve throttling method utilizes reduction of the suction pressure by throttling the suction valve. The vacuum suppression method is more common since the throttling action on the suction valve may cause disturbance in the flow, thus affecting the accuracy of the results.

It should be noted that ANSI/API Standard 610 (2010) denotes NPSHR for 3 percent head drop as "NPSH3". The

NPSH3 curve is developed using the NPSH3 values developed from the suction pressure (and vapor pressure) for each flowrate. Note that if the pump needs to be disassembled to correct NPSH problems, then ANSI/API Standard 610 (2010) paragraph 8.3.4.3.4 requires a retest for performance.

#### *Pump Mechanical Run Test*

For critical and/or unsparred pumps, the contract may require the pump to undergo a mechanical run test prior to acceptance. The mechanical run test proves acceptable mechanical operation over an extended period of time with respect to vibration, bearing and oil temperatures and leakage through mechanical seals, gaskets and oil lines. The mechanical run test is often called the "endurance test".

Unless otherwise specified or agreed, the mechanical run test is performed at the rated flow. Readings of vibration, bearing temperatures and oil temperatures are taken at pre-determined periodic intervals. These readings must also meet the same acceptance criteria for vibration and temperatures as outlined earlier for the performance tests. The witness should monitor the flowrate during the mechanical run test and request the vendor to adjust it during the test if it deviates greater than 5 percent of the rated flow. This becomes necessary if some play in test discharge valve lets the flowrate drift over time.

ANSI/API Standard 610 (2010) provides options for three types of mechanical run tests that are fairly self-explanatory:

- Mechanical run test until bearing oil temperature stabilization
- Four-hour mechanical run test
- Four-hour mechanical run test after bearing oil temperature stabilization

## **TESTING OF API 611 STEAM TURBINES**

General purpose steam turbines that are used as pump drivers at times are commonly purchased per the API Standard 611. Similar to the previous section, casing hydrostatic tests, although mandatory per API Standard 611 (2008), are not covered here. For the most part, this section discusses the mechanical run test of these turbines. Moreover, this section also does not discuss the performance test, complete-unit test, gear test, sound-level test and auxiliary equipment test since these are not conducted very often for general purpose steam turbine acceptance. API Standard 611 (2008) does not provide the acceptance criteria for these tests and their use for acceptance is subject to prior agreement between the vendor and purchaser. This section, however, does recommend some optional testing for the trip and throttle valve integrity, governor valve integrity and trip response time determination that, if feasible and applicable, could be specified in the contract.

#### *Steam Turbine Mechanical Run Test*

Mechanical run tests are mandatory for API 611 steam turbines. API Standard 611 (2008), paragraph 8.3.3.1 a) requires job shaft seals and bearings to be used for the mechanical run test. The steam conditions during the test should be as close to design as practical. The following subsections outline the procedures for mechanical run test of the steam turbine.

### Oil System Cleanliness Test

For turbines with pressure-lubricated bearings, API Standard 611 (2008) requires the test stand to meet the oil filtration cleanliness requirements of ANSI/API Standard 614 before the mechanical run test is started. This ensures that any existing debris within the bearing oil lines does not damage the bearings.

In order to perform the cleanliness test, the upper-half of the bearings are removed or screens are placed in the supply lines for inaccessible bearings. Oil is then circulated for about two hours at the design flowrate without any screens at the bearing housing inlet ports. Then, 100 mesh screens are placed at all bearing housing inlet ports and the oil is circulated for 1 hour at the design flowrate before checking the screens. Piping, coolers and valves of the oil system are hammered frequently during test.

The total particle count on the screens must be within the limits specified in table D.6 of ANSI/API Standard 614 (2008). This table specifies the maximum number of particles for different pipe sizes and schedules. A rule of thumb approximation of 6 particles per square inch of the pipe inner cross-sectional area can be used in lieu of the table. These particles must be randomly distributed on the screen, and should be soft in nature. The largest particle dimension must not exceed 0.010 in (0.25 mm).

Even if the oil cleanliness test is non-witnessed, the witness should still ask to check the screens before the mechanical run test starts, besides visually inspecting the system for cleanliness.

### Steam Turbine Startup and Overspeed

The mechanical run test starts with increasing the turbine speed in 10 percent increments from the minimum allowable speed, specified by the vendor, to the maximum continuous speed. Paragraph 3.14 of API Standard 611 (2008) defines "maximum continuous speed" as "the speed at least equal to 105 % of the highest speed required by any of the specified operating conditions".

The test is run at the maximum continuous speed until the bearing temperatures, lube oil temperatures and shaft vibrations stabilize. Vibration readings are taken after stabilization at the maximum continuous speed. Subsequently, the turbine speed is increased to 110 percent of the maximum continuous speed (about 1 percent below the trip speed) and run for 15 minutes at this increased speed. Vibration readings are again taken at this speed.

### Overspeed Trip Speed Test

The overspeed trip test is covered under the same section on mechanical run test in API Standard 611 (2008), (see paragraph 8.3.3.2 c)). This test checks the operation of the overspeed trip device. The trip speed setting can vary with the class of governor, but is typically set at 110 percent of the maximum continuous speed.

The overspeed trip speed test is particularly dangerous in the sense that the maximum turbine speed reached is dependent upon the operation of the trip device. If the trip device fails to operate, then the turbine can potentially overrun its safe speed, causing the turbine rotor or other

components to fail and cause physical injuries. In order to minimize the inherent dangers of this test, safety precautions such as remote readings, safety barriers, redundant pickups and limited steam supply may all need to be utilized.

In order to perform this test, the speed of the turbine is increased further after completion of the fifteen-minute run at increased speed (see previous sub-section). The speed at which the turbine instantaneously trips is recorded. The trip speed setting on the device is adjusted until three consecutive trip speed readings do not show a specific increasing or decreasing trend. These three readings must also be within 2 percent of the nominal trip speed setting.

### Governor Control Test

The governor is then tested for smooth performance over the operating speed range of the steam turbine. Its no-load stability and response to the control signal are checked. Governor sensitivity, linearity of relationship between speed and control signal, and actual travel of the governor actuator are recorded for electronic governors. On the other hand, the response speed range is recorded for adjustable governors. Vibration readings are recorded at the minimum specified governor speed.

### One-hour Mechanical Run

The turbine is then run at the maximum continuous speed for 1 hour. The witness should request the vendor to record the sound pressure level at this speed for reference purposes.

For turbines with pressure-lubricated bearings, the purchaser should specify the measurement and recording of oil flowrates from each bearing housing during the test. This is an optional requirement in paragraph 8.3.3.1 b) of the standard and should be built into the contract. This can be used to ascertain if sufficient oil supply is available for the driven equipment and for performing control functions on the turbine if a common lube-oil and control-oil system has been provided.

### Vibration Limits

Paragraph 6.9.4.6 of API Standard 611 (2008) specifies the shaft vibration limits that are shown in table 2 of this tutorial. These limits are intended to be used as acceptance criteria for the test.

Turbine Speed "N"	Max. Unfiltered Shaft Vibration per API 611
$N \leq$ max. continuous speed	Lower value of: $(12000 / N)^{0.5}$ mils p-p OR 2 mils p-p (50 $\mu$ m p-p)
$N >$ max. continuous speed	Greater value of: 150 percent of OR 0.5 mil over the max. value recorded at max. continuous speed

Table 2. Shaft Vibration Limits per API Standard 611 (2008)  
(Reproduced courtesy of the American Petroleum Institute)

Paragraph 6.9.4.9 of API Standard 611 (2008) specifies that if vibration probes are not provided and if shop probes cannot be used during testing, then the bearing housing vibration should be measured using vibration transducers and acceptance should be based on the vibration limits summarized in table 3 of this tutorial.

All Turbine Speeds "N"	Max. Bearing Housing Vibration per API 611
Unfiltered Vibration	0.12 in/s RMS (3 mm/s RMS)
Filtered Vibration (at running speed frequency)	0.08 in/s RMS (2 mm/s RMS)

**Note:** Although not specifically mentioned in API 611, "RMS" values are assumed for the vibration velocity limits stated therein.

Table 3. Bearing Housing Vibration Limits per API Standard 611 (2008)  
(Reproduced courtesy of the American Petroleum Institute)

#### After the Turbine Run Test

After the mechanical run test, paragraph 8.3.3.3 a) of API Standard 611 (2008) requires the hydrodynamic bearings to be removed, inspected, and reassembled. Figure 5 of this tutorial shows the bearings removed for inspection. Paragraph 8.3.3.3 b) of the standard affirms that any post-test correction to the bearings or seals requires the steam turbine to be retested. If spare rotors have been purchased, then each spare rotor must also undergo a mechanical run test, preferably in the same turbine casing.



Figure 5. Post-Test Inspection of Hydrodynamic Bearings

#### Additional Recommended Tests

The following additional tests are not specified in API Standard 611 (2008). However, where feasible and applicable, it is recommended that these be built into the contract specifications to be conducted with the mechanical run test.

#### Trip and Throttle Valve Integrity Test

The trip and throttle valve is located at the main steam inlet of the turbine as shown in figure 6 of this tutorial. It functions to quickly shut off the steam supply when an emergency operating condition occurs. It is also used during turbine startup to warm up the high temperature steam turbine components, to bring the unit up to the minimum speed of the governor and to confirm proper operation of the control system.

When the trip and throttle valve is completely closed, the steam turbine should shutdown. In order to test this function, the trip and throttle valve is completely closed.

At the same time, the governor valve is completely opened and kept open mechanically. The time taken for the turbine to come to a complete stop is recorded. Since the turbine is unloaded during the factory testing, it should take about ten to fifteen minutes for a complete shutdown. On the other hand, if the turbine never stops and keeps rolling, then the trip and throttle valve is possibly leaking steam into the turbine, and needs correction.



Figure 6. Location of the Trip and Throttle Valve

#### Governor Valve Integrity Test

When the governor valve is completely closed, the steam turbine should shutdown. In order to test this function, the governor valve is completely closed. Concurrently, the trip and throttle valve is completely opened. The time taken for the turbine to come to a complete stop is recorded. Since the turbine is unloaded during the factory testing, it should take about ten to fifteen minutes for a complete shutdown. If the turbine never stops and keeps rolling, then the governor valve is possibly leaking steam into the turbine, and needs correction.

It is, however, important to keep in mind that the governor valve may not have a tight shutoff design. Hence, the implications and expected results of this test should be discussed with the vendor in advance.

#### Overspeed Trip Response Measurement

When the critical speed of the steam turbine is calculated to be only slightly higher than the trip speed setting, it is recommended that the electronic trip system response time (from the instance the trip speed is encountered) be determined. The turbine may run into the critical speed if this response time is excessive. It should be recognized that such time response measurement requires special setup and configuration to duplicate the actual setup or else the measurement holds little value. The test should measure and record the turbine speed (to enable waveform analysis) and the trip system response time. If the trip response time is deemed to be excessive, then alternative solutions for tripping, signal transmission or critical speed alteration could be looked into.

## CONCLUSIONS

With prior knowledge and proper understanding of the test setup, test procedure and expected results, the witness can ensure that the equipment testing is carried out in accordance



with the contract requirements. Witness testing also provides the opportunity to uncover potential problems with the equipment that may otherwise go undetected prior to shipment. By using proper knowledge and experience, the test witness can make their test visit very productive.

## **NOMENCLATURE**

ANSI = American National Standards Institute  
API = American Petroleum Institute  
GA = General arrangement (drawing)  
HI = Hydraulic Institute  
N = Speed, rpm  
NPSH = Net positive suction head, ft (m)  
NPSH3 = Net positive suction head that results in a 3 percent loss of head (first-stage head in a multistage pump), ft (m)  
NPSHA = Net positive suction head available, ft (m)  
NPSHR = Net positive suction head required, ft (m)  
p-p = Peak-to-peak  
P&ID = Piping and instrumentation diagram  
RMS = Root-mean-squared (value)  
RTD = Resistance temperature detector

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