

September 2006

Hydro Plant Risk Assessment Guide

Appendix E6: Turbine Condition Assessment

E6.1 GENERAL

The hydraulic turbine is a critical component of a hydroelectric powerplant but it may not be apparent that degradation of the condition of the turbine has occurred. Weld repairs, operation in a “rough zone,” and operation on Automatic Generation Control (AGC) all take their toll on the overall condition of the turbine. Efficiency losses are usually gradual and are not noticeable unless efficiency tests are performed. New turbine runners are often not considered unless a considerable uprate is possible or the existing runner is physically failing. Assessing the overall condition of the turbine may show that a replacement runner with a state-of-the-art hydraulic design, fabricated from modern materials and refurbishing other components, may provide economic benefits when compared to the current costs of repair and the efficiency of the existing runner.

Determining the present condition of a turbine is an essential step in analyzing the risk of failure. This appendix provides a process for arriving at a Turbine Condition Index which may be used to develop a business case addressing risk of failure, economic consequences, and other factors.

E6.2 SCOPE / APPLICATION

The turbine assessment methodology outlined in this appendix applies to Francis, Kaplan, and propeller (reaction type) hydraulic turbines. The entire turbine is considered in this assessment tool, with the turbine runner as a major component. At the Facility Manager’s discretion, the assessments can be performed on individual turbines or a family of identical or near-identical turbines. This appendix is not intended to define turbine maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

E6.3 CONDITION AND DATA QUALITY INDICATORS, AND TURBINE CONDITION INDEX

This appendix describes the condition indicators generally regarded by hydro plant engineers as providing the basis for assessing turbine condition. The following four indicators are used in the initial, or Tier 1, assessment:

- Age
- Runner Physical Condition
- Operational Conditions/Restrains

- Maintenance

The Tier 1 condition indicators are based on the known turbine runner condition and/or inspections conducted by utility staff or contractors over the course of time and as part of routine maintenance activities. Numerical scores are assigned to each turbine condition indicator, which are then weighted and summed to determine the Turbine Condition Index.

An additional stand-alone indicator is used to reflect the quality of the information available for scoring the turbine condition indicators. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the accuracy of the associated condition indicator scores as well as the validity of the overall Condition Index. Given the potential impact of poor or missing data, the Turbine Data Quality Indicator is used as a means of evaluating and recording confidence in the final Turbine Condition Index.

Additional information regarding turbine condition may be necessary to improve the accuracy and reliability of the Turbine Condition Index. Therefore, in addition to the Tier 1 condition indicators, this appendix describes a “toolbox” of Tier 2 inspections, tests, and measurements that may be applied to adjust the Turbine Condition Index, depending on the specific issue or problem being addressed. Tier 2 tests are considered non-routine. However, if Tier 2 data is readily available, it may be used to supplement the Tier 1 assessment. Alternatively, Tier 2 tests may be deliberately performed to address Tier 1 findings. Results of the Tier 2 analysis may either increase or decrease the score of the Turbine Condition Index. The Data Quality Indicator score may also be revised during the Tier 2 assessment to reflect the availability of additional information or test data.

The Turbine Condition Index may be used as the sole justification for replacing or rehabilitating a turbine. The Turbine Condition Index may also be used as an input to a computer model that assesses risk and performs economic analyses.

Note: A severely negative result of ANY inspection, test, or measurement may be adequate in itself to require immediate corrective action, regardless of the Turbine Condition Index score.

E6.4 INSPECTIONS, TESTS, AND MEASUREMENTS

Inspections, tests, and measurements should be conducted and analyzed by staff suitably trained and experienced in turbine diagnostics. The more basic tests may be conducted by qualified staff that are competent in these routine procedures. More complex inspections and measurements may require a turbine diagnostics expert.

Inspections, tests, and measurements should be conducted on a frequency that provides accurate and current information needed by the assessment.

Turbine condition assessment may cause concerns that justify more frequent monitoring. Utilities should consider the possibility of taking more frequent measurements or installing on-line monitoring systems that will continuously track critical parameters. This will provide

additional data for condition assessment and establish a certain amount of reassurance as turbine alternatives are being explored.

E6.5 SCORING

Condition indicator scoring is somewhat subjective, relying on the experience and opinions of plant staff and turbine experts. Relative terms such as “Results Normal” and “Deterioration” refer to results that are compared to industry-accepted levels; or to baseline or previous (acceptable) levels on this equipment; or to turbines of similar design, construction, or age operating in a similar environment.

E6.6 WEIGHTING FACTORS

Weighting factors used in the condition assessment methodology recognize that some Condition Indicators affect the Turbine Condition Index to a greater or lesser degree than other indicators. These weighting factors were arrived at by consensus among turbine design and maintenance personnel with extensive experience.

E6.7 MITIGATING FACTORS

Every turbine is unique and, therefore, the methodology described in this appendix cannot quantify all factors that affect individual turbine condition. Mitigating factors not included in this Guide may determine the final Turbine Condition Index and the final decision on turbine replacement or rehabilitation. If the Turbine Condition Index triggers significant follow-up actions (e.g., major repairs or a Tier 2 assessment), it may be prudent to first have the index reviewed by turbine experts. Mitigating factors specific to the utility may affect the final Turbine Condition Index and the final decision on turbine replacement or rehabilitation.

E6.8 DOCUMENTATION

Substantiating documentation is essential to support findings of the assessment, particularly where a Tier 1 condition indicator score is less than 3 (i.e., less than normal) or where a Tier 2 test results in subtractions to the Turbine Condition Index. Test reports, photographs, O & M records, and other documentation should accompany the Turbine Condition Assessment Summary form.

E6.9 CONDITION ASSESSMENT METHODOLOGY

The condition assessment methodology consists of analyzing each condition indicator individually to arrive at a condition indicator score. The score is then summed with scores from other condition indicators. The sum is the Turbine Condition Index. Apply the Turbine Condition Index to Table 17 – Turbine Condition-Based Alternatives to determine the recommended course of action. Each step is described below.

E6.10 TIER 1 – INSPECTIONS, TESTS, AND MEASUREMENTS

Tier 1 tests include those inspections, tests, and measurements that are routinely accomplished as part of normal operation and maintenance, or are readily discernible by examination of existing data. Tier 1 test results are quantified below as condition indicators that are weighted and summed to arrive at a Condition Index. Tier 1 tests may indicate abnormal conditions that can be resolved with standard corrective maintenance solutions. To the extent that Tier 1 tests result in immediate corrective maintenance actions being taken by plant staff, then adjustments to the condition indicators should be reflected and the new results used when computing the overall Tier 1 Condition Index. Tier 1 test results may also indicate the need for additional investigation, categorized as Tier 2 tests.

E6.11 TURBINE CONDITION INDICATORS

Turbine Condition Indicator 1 – Age

Age is an important factor to consider when identifying candidates for turbine runner replacement or refurbishment. As a turbine ages, it becomes affected by fatigue and becomes susceptible to cracks. The effect of weld repairs over the years can be cumulative, increasing the likelihood of failure. Also, an older turbine has greater potential to be improved by state-of-the-art design and materials. Contours changed by weld repairs will change the hydraulics of the runner, reducing its efficiency. In addition, it has been found by a large number of field performance tests that turbine efficiency and capacity declines with age. Most decisions to commence rehabilitation are driven by economics, and efficiency and capacity gains have historically yielded most of the net benefits. Therefore, while age is not relevant when predicting a failure, it is relevant to rehabilitation decision-making. The in-service date will be used to determine turbine age. When looking at a family of turbines that were installed over a period of time at a specific facility, the average age should be used.

The turbine runner age should be determined and applied to Table 1 to arrive at an appropriate Condition Indicator score.

Age (New/Full Rehabilitation)	Age (Partial Rehabilitation)	Condition Indicator Score
< 25 years	< 15 years	3
≥ 25 and < 35 years	≥ 15 and < 25 years	2
≥ 35 and < 45 years	≥ 25 and < 35 years	1
≥ 45 years	≥ 35 years	0

A partial rehabilitation is defined as a new runner with the majority of remaining critical turbine components not restored, or an existing turbine repaired and the majority of remaining critical components restored. The remaining critical turbine components include:

- Facing plates and gate end seals
- Discharge ring
- Gate mechanism (motors, shift ring, wicket gate locking mechanisms, bushings)
- Main shaft bearing
- Wicket gates

The intent of the age criterion for the turbine condition assessment is to indicate performance degradation.

Turbine Condition Indicator 2 – Physical Condition

The surface condition of the waterway is important, especially since it affects the efficiency and capacity of the machine. Areas in the waterway that see the highest velocities will have the largest effects on efficiency. The surface condition of metal components may deteriorate over time due to erosion, corrosion, operating in cavitation zones, and cavitation and cracking damage and repairs. The following can be evaluated through inspection of the turbine and its components: the runner, wicket gates, stay vanes, and discharge ring. The photographs in Annex A are intended to assist in evaluating the surface condition of the runner.

Results of the physical inspection are analyzed and applied to Table 2 to arrive at condition indicator scores.

Table 2 – Physical Condition Scoring	
Cracks	
Results*	Condition Indicator Score
No Cracking	2
Inactive Cracks	1
Active Cracks	0
Cavitation and Surface Damage	
Results	Condition Indicator Score
Good Surface/Minimal Cavitation Damage	2
Fair Surface/ Moderate Cavitation Damage	1
Poor Surface/Severe Cavitation Damage	0
Total	
	Physical Condition Score
Sum of Cracks plus Cavitation and Surface Damage Condition Indicator Scores	

* Active cracks are those cracks, which when measured, are growing over time. Inactive cracks are cracks that appear and when re-measured at a later date, have not grown.

Turbine Condition Indicator 3 – Operations

Operational limitations play a role in determining the serviceability of equipment: the greater the limitations, the greater the impact to the power system leading to lost generation and sometimes spilling. Minimal operating restraints include operations to avoid minor rough zones. Moderate operating restraints would include last-on/first-off, hot bearings, large rough zones, high vibration, etc. Severe limitations include situations which make the turbine undesirable to operate such as a blade falling off, or the use of the head gate to stop the unit due to wicket gate leakage. This rating does not include environmental restrictions, such as minimum flows, up ramp, or maximum flow limitations.

Operational limitations of the turbine are analyzed and applied to Table 3 to arrive at a Turbine Operational Limitations score.

Table 3 – Operational Limitations Scoring	
Form of Operation	Condition Indicator Score
No operating restraints	1.5
Minimal operating restraints	1.0
Moderate operating restraints	0.5
Severe limitations, inoperable	0

Turbine Condition Indicator 4 – Maintenance

The amount of corrective maintenance that either has been or must be performed is an indication of condition. No corrective maintenance is an indication that the turbine is in good shape. Small amounts of corrective maintenance would be repairs that could be completed during a unit preventative maintenance outage that is scheduled on a periodic basis. Moderate corrective maintenance is maintenance that extends the normal scheduled outage time to perform. Severe corrective maintenance is maintenance that requires scheduled or forced outages to perform.

Results of turbine maintenance history are analyzed and applied to Table 4 to arrive at an appropriate Turbine Condition Indicator score.

Table 4 –Maintenance Scoring	
Corrective Maintenance	Condition Indicator Score
No corrective maintenance	1.5
Small amounts of corrective maintenance (e.g., less than 3 staff days per unit per year)	1.0
Moderate corrective maintenance that causes extensions of unit preventative maintenance outages	0.5
Severe corrective maintenance or forced outages	0

E6.12 TIER 1 – TURBINE CONDITION INDEX CALCULATIONS

Enter the turbine condition indicator scores from Tables 1 through 4 above into the Turbine Condition Assessment Summary form (at the end of this document). Multiply each indicator score by its respective Weighting Factor, and sum the total scores to arrive at the Tier 1 Turbine Condition Index. This index may be adjusted by the Tier 2 turbine inspections, tests, and measurements described later in this document.

The Turbine Condition Index is suitable for use in risk-based economic analysis models. As in all decision-making related to life expectancy of existing equipment, there is a certain amount of uncertainty. Current condition is not a definitive indicator of remaining life; however, it is an important consideration and may be used to modify typical life expectancy curves and to arrive at a reasonable and defensible probability of continued life.

E6.13 TIER 1 – TURBINE DATA QUALITY INDICATOR

The Turbine Data Quality Indicator reflects the quality of the inspection, test, and measurement results used to evaluate the turbine condition under Tier 1. The more current and complete the inspections, tests, and measurements, the higher the rating for this indicator. The normal testing frequency is defined as the organization's recommended frequency for performing the specific test or inspection.

Qualified personnel should make a subjective determination of scoring that encompasses as many factors as possible under this indicator. Results are analyzed and applied to Table 5 to arrive at an appropriate Turbine Data Quality Indicator Score.

Table 5 – Turbine Data Quality Scoring	
Results	Data Quality Indicator Score
All Tier 1 inspections, tests and measurements were completed within the normal frequency.	10
One or more of the Tier 1 inspections, tests and measurements were completed ≥ 6 and < 24 months past the normal frequency.	7
One or more of the Tier 1 inspections, tests and measurements were completed ≥ 24 and < 36 months past the normal frequency, or some of the results are not available.	4
One or more of the Tier 1 inspections, tests and measurements were completed ≥ 36 months past the normal frequency, or no results are available.	0

Enter the Turbine Data Quality Indicator Score from Table 5 into the Turbine Condition Assessment Summary form at the end of this document.

E6.14 TIER 2 – TURBINE INSPECTIONS, TESTS, AND MEASUREMENTS

Tier 2 inspections, tests, and measurements require specialized personnel to inspect the turbine, interview plant O & M staff and, if necessary, perform a simplified field performance test. The work will require an outage to perform. A Tier 2 assessment is not considered routine. Tier 2 inspections may affect the Turbine Condition Index established using Tier 1. An adjustment to the Data Quality Indicator score may be appropriate if additional information or test results were obtained during the Tier 2 assessment.

Hydraulic turbines, unlike generators and transformers, rarely fail catastrophically and do not really have a physical lifetime. They do have an economic lifetime, however. Because the performance of existing turbines degrades with time, and the value of energy and power and the performance of replacement units increase with time, there comes a point when it becomes more economical to rehabilitate or replace them than to continue to operate and maintain them. Families of identical or near-identical turbines at a plant should be evaluated as a group as opposed to individual units.

A team consisting of the Plant O & M Representative(s) and Technical Support Staff should perform Tier 2 assessments. The tasks that need to be performed for Tier 2 are summarized as follows:

1. Technical support staff will be responsible to:
 - Visit the plant to perform a physical inspection of a turbine and interview O & M staff.
 - Determine current performance and perform a simplified field test, if necessary.
 - Review and, if necessary, adjust the Tier 1 Condition Index based upon the inspection and comparison with the condition of other similar families of units.
2. Plant O & M Representative will be responsible to:
 - Provide necessary assistance and information to Technical Support staff.
 - Assist in the assessment process.

For each Tier 2 test performed, add or subtract the appropriate amount to/from the Turbine Condition Index. Many of the following Tier 2 tests are used to detect or confirm a similar defect or state of deterioration. In the event that more than one Tier 2 tests are performed to assess the same problem or concern, then the test with the largest adjustment shall be used to recalculate the Turbine Condition Index. It is important to avoid adjusting the Condition Index downward twice or more simply because multiple tests are completed for the same suspected problem. Since the Tier 2 tests are being performed by and/or coordinated with knowledgeable technical staff, the decision as to which test is more significant and how different tests overlap is left to the experts.

Test T2.1: Efficiency Test

The efficiency of the turbine is probably the most important factor in determining if a turbine runner should be replaced. The efficiency test may show that the condition of the turbine has degraded to a point that its efficiency has been reduced significantly. Even if efficiency has not degraded, newer turbine designs are usually more efficient than those 30 years or older. In addition, many turbines were designed for best efficiency head in the mid-range of the reservoir elevation swing, but operational philosophy has changed. An efficiency increase and decreased cavitation can be gained from installing a replacement runner that is designed around a head range established from historical operations rather than original design data.

Turbine efficiency test results are analyzed and applied to Table 6 to arrive at a Turbine Condition Index score adjustment.

Table 6 – Efficiency Test Scoring	
Measured Efficiency Test Results	Adjustment to Condition Index Score
Measured efficiency is $\geq 93\%$ or $< 2\%$ less than original efficiency.	Add 0.5
Measured efficiency is ≥ 91 and $< 93\%$ or ≥ 2 and $< 3\%$ less than original efficiency or efficiency not measured.	No Change
Measured efficiency is $< 91\%$ or $\geq 3\%$ less than original efficiency.	Subtract 1.0

Test T2.2: Capacity Test

The capacity of the turbine is another important factor in determining if a turbine runner should be replaced. As efficiency degrades over time, so does the maximum capacity of the machine. Tests may show that the condition of the turbine has degraded to a point that its capacity has been reduced significantly, sometimes more than 4 percent. Installing a new runner will restore maximum capacity to original output level. In some cases, a new runner may provide an opportunity to increase the capacity above the original design.

Capacity test results are analyzed and applied to Table 7 to arrive at a Turbine Condition Index score adjustment.

Table 7 – Capacity Test Scoring	
Measured Capacity Range	Adjustment to Condition Index Score
Lost $< 2\%$ of original capacity.	Add 0.5
Lost ≥ 2 and $< 4\%$ of original capacity or capacity not measured.	No Change
Lost $\geq 4\%$ of original capacity.	Subtract 0.5

Test T2.3: Off-Design Conditions Test

Consideration of present conditions must be given. If there is a significant change in the flow rate or head from the original design condition, this can greatly impact the machine performance and lead to recurring maintenance issues.

Test results from design conditions are analyzed and applied to Table 8 to arrive at a Turbine Condition Index score adjustment.

Table 8 – Off-Design Conditions Test Scoring	
Changes in Design Conditions	Adjustment to Condition Index Score
No significant changes in flow rate or head from original design condition.	No Change
Significant changes in flow rate or head since original design condition.	Subtract 0.5

Test T2.4: Paint Film Quality Test

A visual inspection should be made of the ferrous portions of the spiral case and extension, stay vanes, wicket gates, runner, discharge ring, head cover, and draft tube. The paint film quality will be scored and compared to that of other units.

Paint Film Quality test results are analyzed and applied to Table 9 to arrive at a Turbine Condition Index score adjustment.

Table 9 – Paint Film Quality of Ferrous Wetted Surfaces Test Score	
Paint Film Quality Test	Adjustment to Condition Index Score
Paint film is mostly intact ($\geq 90\%$ of the surface is intact).	Add 0.5
The paint film is mostly absent but the steel surfaces have not yet suffered serious corrosion or erosion damage.	No Change
Ferrous surfaces exhibiting extensive erosion or corrosion are observed (or need to be periodically repaired) in critical areas (stay vanes, wicket gates, around (or in) man-door or in spiral case or penstock).	Subtract 0.5

Test T2.5: Surface Roughness of Runner and Discharge Ring Test

During the physical inspection, surface quality comparison gages or measurement tools will be used to determine the surface roughness. Although roughness can be caused from cavitation attack, erosion, corrosion or any combination of the three, this indicator is focused only on roughness caused by erosion and corrosion. Test T2.7 focuses on damage caused by cavitation.

Surface quality comparison test results are analyzed and applied to Table 10 to arrive at a Turbine Condition Index score adjustment.

Table 10 – Surface Roughness of Runner and Discharge Ring Test Scoring	
Surface Quality	Adjustment to Condition Index Score
Good	Add 0.5
Moderate	No Change
Severe	Subtract 0.5

Test T2.6: Cracking of Runner and Discharge Ring Test

O & M personnel will be interviewed to determine and document the cracking repair history. If a cracking problem has been permanently solved (i.e., no cracks have occurred in the last 10 years), it will be scored as “minimal.” If cracking occurs, but in non-critical areas, it will be scored as “moderate.” See the sketches in Annex B. Critical areas are those labeled I and II. All other areas are considered non-critical.

The cracking repair test results are analyzed and applied to Table 11 to arrive at a Turbine Condition Index score adjustment.

Table 11 – Cracking of Runner and Discharge Ring Test Scoring	
Cracking During Last 10 Years	Adjustment to Condition Index Score
Minimal (i.e., none, or not active in non-critical areas and < 1” long)	Add 1.0
Moderate (i.e., active but in non-critical areas and ≥ 1” and < 2” long)	No Change
Severe (i.e., active in critical areas or ≥ 2” long)	Subtract 1.0

Test T2.7: Cavitation of Runner and Discharge Ring Test

Both the average depth of the worst pitting and size of area of damage should be considered. Photographic evidence could be utilized in the event a physical inspection is not possible.

The following areas will be inspected: Suction side of the vanes/blades near the band; pressure side of the vanes/blades near the leading edge; discharge ring, 18 inches below the runner; and runner hub adjacent to blades.

The cavitation damage test results will be analyzed and applied to Table 12 to arrive at a Turbine Condition Index score adjustment.

Table 12 – Cavitation Damage of Runner and Discharge Ring Test Scoring		
Cavitation Damage		Adjustment to Condition Index Score
Minimal: Stainless – frosting only (in small areas) Carbon – frosting only (in small areas)		No Change
Moderate:	Depth Area Stainless < 1/8” < 5% Carbon < 3/8” < 5%	Subtract 0.3
Severe:	Depth Area Stainless ≥ 1/8” ≥ 5% Carbon ≥ 3/8” ≥ 5%	Subtract 0.6

Test T2.8: Condition of Remaining Parts and Systems Test

In addition to the turbine runner, there are many other parts and systems which need to function to enable the turbine to operate satisfactorily. Each one by itself would not necessarily change the condition assessment score of the unit. However, taken together, an overall assessment can be made. The following is a list of other components and considerations:

- Gate mechanism (servo motors, shift ring, wicket gate locking mechanisms, bushings)
- Guide bearings
- Seals
- Oil-head (if Kaplan)
- Blade adjusting mechanism (if Kaplan)
- Alignment/verticality
- Concrete growth
- Run-out
- Vibration
- Noise
- Greasing system
- Oil circulating pumps
- Headcover drains or pumps
- Vacuum breakers

Test results from the condition of all remaining parts and systems are analyzed and applied to Table 13 to arrive at a Turbine Condition Index score adjustment.

Table 13 – Condition of Remaining Parts and Systems Test Scoring	
Equipment Condition	Adjustment to Condition Index Score
All sub-systems are normal and there are no major issues in any of the listed areas. In general, very little maintenance is required.	Add 0.2
Some sub-systems require frequent maintenance or do not operate well. Frequent minor maintenance is needed to keep the unit running well.	No Change
The unit runs but takes significant or frequent maintenance. Some more important components are damaged or broken.	Subtract 0.7

Test T2.9: Environmental Improvement Test

The primary environmental issues relative to turbines are losing oil or grease into the waterway, poor survival of fish passing through them, and low Dissolved Oxygen (DO) content of released water during portions of the year. Facilities without environmental issues score “No Change.”

Environmental improvement test results are analyzed and applied to Table 14 to arrive at a Turbine Condition Index score adjustment.

Table 14 – Environmental Improvement Test Scoring	
Environmental Conditions	Adjustment to Condition Index Score
There are no perceived environmental issues and rehabilitation of the turbine would have minimal positive effect on the environment. Little or no oil or grease is released into the environment and no DO improvements can be gained by a turbine replacement.	No Change
There is some history of negative impacts (occasional minor oil releases, some mortality of fish which transit the turbine, and most years, the desired dissolved oxygen content of released water is met or exceeded during all months).	Subtract 0.3
There are known negative impacts which regularly occur which can be mitigated by a turbine rehabilitation. Significant amounts of oil or grease are occasionally released into the environment. Or, DO improvements or fish passage survival improvements can be gained by a turbine replacement.	Subtract 0.6

Test T2.10: Operating Conditions Test

Operating conditions are a good indicator of potential wear on a machine. Conditions such as the loading (base loaded or peaking), Automatic Generation Control (AGC), condensing, and the number of start/stops may lead to accelerated damage to units.

Test results from the operating conditions are analyzed and applied to Table 15 to arrive at a Turbine Condition Index score adjustment.

Table 15 – Operating Conditions Test Scoring	
Form of Operation (Annually)	Adjustment to Condition Index Score
Base loaded.	Add 0.2
Peaking operation, AGC or < 100 start/stops or condensing cycles.	No Change
≥ 100 start/stops or condensing cycles.	Subtract 0.5

Test T2.11: Maintenance Test

O & M staff should work with Engineering personnel to evaluate the past 5 to 10 years of maintenance records to determine the level of maintenance that has been required to keep the unit operational. Significant maintenance activities known to be needed in the near future shall also be considered. Given the individual nature of the equipment in each operating facility and variations in how it is operated and maintained, the specific factors considered in this evaluation may be somewhat different for each facility.

The evaluation of past and upcoming maintenance is analyzed and applied to Table 16 to arrive at a Turbine Condition Index score adjustment.

Table 16 – Maintenance Test Scoring	
Maintenance Performed	Adjustment to Condition Index Score
Normal maintenance.	Add 0.2
Additional maintenance during normal outages.	No Change
Additional outages or extended outages needed to perform maintenance task or maintenance work deferred due to lack of time.	Subtract 0.5

Test T2.12: Other Specialized Diagnostic Tests

Additional tests may be applied to evaluate specific turbine problems. Some of these diagnostic tests may be considered to be of an investigative research nature. When conclusive results from other diagnostic tests are available, they may be used to make an appropriate adjustment to the Turbine Condition Index.

E6.15 TIER 2 – TURBINE CONDITION INDEX CALCULATIONS

Enter the Tier 2 adjustments from the tables above into the Tier 2 Turbine Condition Assessment Summary form at the end of this guide. Subtract the sum of these adjustments from the Tier 1 Turbine Condition Index to arrive at the Net Turbine Condition Index. Attach supporting

documentation. An adjustment to the Data Quality Indicator score may be appropriate if additional information or test results were obtained during the Tier 2 assessment.

E6.16 TURBINE CONDITION-BASED ALTERNATIVES

The Turbine Condition Index – either modified by Tier 2 tests or not – may be sufficient for decision-making regarding turbine alternatives. The Index is also suitable for use in a risk-and-economic analysis model. Where it is desired to consider alternatives based solely on turbine condition, the Turbine Condition Index may be directly applied to Table 17 – Turbine Condition-Based Alternatives below.

Table 17 – Turbine Condition-Based Alternatives	
Turbine Condition Index	Suggested Course of Action
≥ 7.0 and ≤ 10 (Good)	Continue O & M without restriction. Repeat or update Tier 1 assessment during next scheduled maintenance outage.
≥ 3.0 and < 7 (Fair)	Continue O & M without restriction. Schedule a Tier 2 assessment in 4 years or less.
≥ 0 and < 3.0 (Poor)	Schedule a Tier 2 assessment in 1 year.

TURBINE TIER 1 CONDITION ASSESSMENT SUMMARY

Date: _____ Location: _____

Turbine Identifier: _____ Manufacturer: _____ Yr. Mfd.: _____

Tier 1 Turbine Condition Summary <i>(For instructions on indicator scoring, please refer to condition assessment guide)</i>				
No.	Condition Indicator	Score	x	Weighting Factor = Total Score
1	Age <i>(Score must be 0, 1, 2, or 3)</i>			0.667
2	Physical Condition <i>(Score must be 0, 1, 2, 3, or 4)</i>			1.250
3	Operations <i>(Score must be 0, 0.5, 1, or 1.5)</i>			1.000
4	Maintenance <i>(Score must be 0, 0.5, 1, or 1.5)</i>			1.000
Tier 1 Turbine Condition Index (Sum of individual Total Scores) <i>(Condition Index should be between 0 and 10)</i>				

Tier 1 Turbine Data Quality Indicator <i>(Value must be 0, 4, 7, or 10)</i>	
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Evaluator: _____ Technical Review: _____

Management Review: _____ Copies to: _____

(Attach supporting documentation.)

Turbine Condition-Based Alternatives	
Condition Index	Suggested Course of Action
≥ 7.0 and ≤ 10 (Good)	Continue O & M without restriction. Repeat or update Tier 1 condition assessment during next scheduled maintenance outage.
≥ 3.0 and < 7 (Fair)	Continue O & M without restriction. Schedule a Tier 2 assessment in 4 years or less.
≥ 0 and < 3.0 (Poor)	Schedule a Tier 2 assessment in 1 year.

TURBINE TIER 2 CONDITION ASSESSMENT SUMMARY

Date: _____ Location: _____

Turbine Identifier: _____ Manufacturer: _____ Yr. Mfd.: _____

Tier 2 Turbine Condition Summary		
No.	Tier 2 Test	Individual Adjustments to Tier 1 Condition Index
T2.1	Efficiency	
T2.2	Capacity	
T2.3	Off-Design	
T2.4	Paint Film Quality	
T2.5	Surface Roughness	
T2.6	Cracking	
T2.7	Cavitation	
T2.8	Condition of Remaining Parts	
T2.9	Environmental	
T2.10	Operating Conditions	
T2.11	Maintenance	
T2.12	Other Specialized Diagnostic Tests	
Tier 2 Adjustments to Turbine Condition Index (Sum of Individual Adjustments)		(≥ 0 and ≤ 10)

Tier 2 Data Quality Indicator (Value must be 0, 4, 7, or 10)	
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To calculate the Net Turbine Condition Index (*Value should be between 0 and 10*), subtract the Tier 2 Adjustments from the Tier 1 Turbine Condition Index:

$$\begin{array}{rcl} \textbf{Tier 1 Turbine Condition Index} & \underline{\hspace{2cm}} & \\ \text{minus Tier 2 Turbine Adjustments} & \underline{\hspace{2cm}} & = \underline{\hspace{2cm}} \\ & & \textbf{Net Turbine Condition Index} \end{array}$$

Evaluator: _____ Technical Review: _____

Management Review: _____ Copies to: _____

(Attach supporting documentation.)

Annex A: Steel Conditions



Figure A-1: Stainless Steel – Fair Condition.



Figure A-2: Stainless Steel – Poor Condition.



Figure A-3: Carbon Steel – Fair Condition (pitting).



Figure A-4: Carbon Steel – Poor Condition.



Figure A-5: Carbon Steel – Poor Condition.



Moderate

Light

Figure A-6: Carbon Steel.



Figure A-7: Carbon Steel – Poor Condition.

Annex B: Critical Areas

(As Referenced for Test T2.S6)

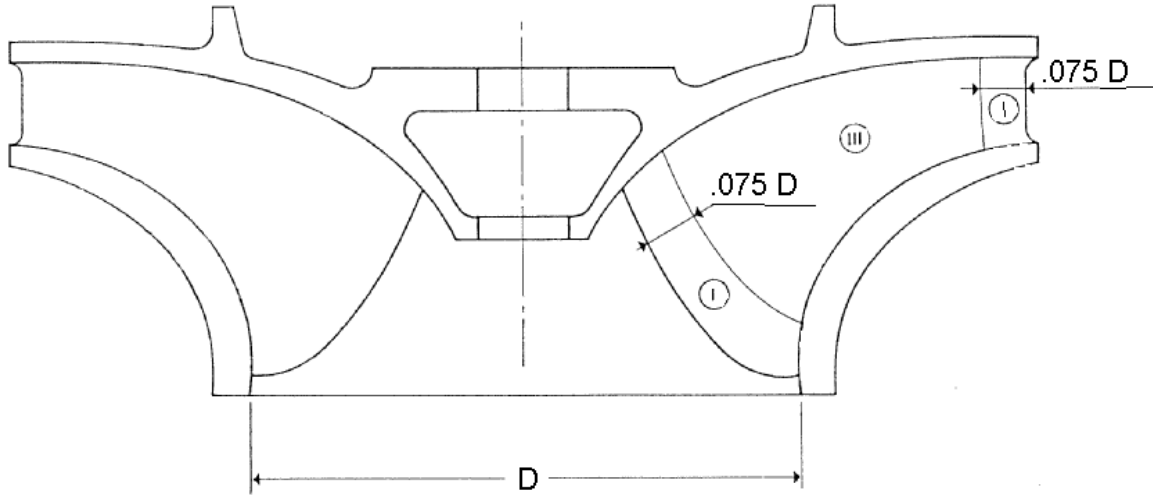


Figure B-1: Francis Runner Critical Areas.

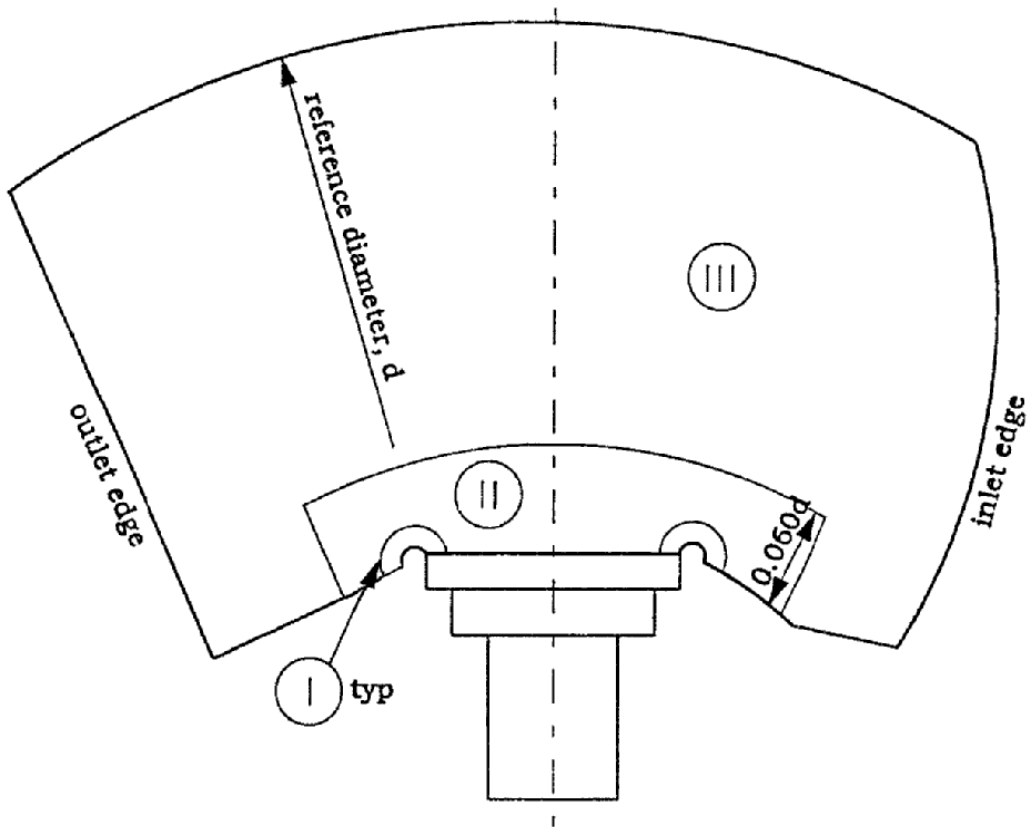


Figure B-2: Kaplan Blade Critical Areas.

I – Most Critical, II – Less Critical, III – Least Critical