# Condition Assessment Manual

## *Appendix 1.14 – Guide for Lubrication System Condition Assessment*

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## 1.0 General

Unforeseen failure of the lubrication system can have a substantial impact on power generation and revenues due to an extended forced outage. Therefore, it is important to maintain an updated condition assessment of the lubrication system and plan accordingly. A lubrication system condition assessment is essential to estimate the economic lifespan and potential risk of failure, and to evaluate the benefits and cost of lubrication system upgrading.

For any type of lubrication system, the following three-step analyses are necessary to arrive at a lubrication system condition indicator:

1) What parts should be included for a lubrication system condition assessment and which parts are more important than others (parts and their weighting factors)?

2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?

3) How to assign numerical scores to the lubrication system parts (rating criteria)?

This Appendix provides guides to answer the above questions, which can be applied to all lubrication systems. The condition assessment is performed on individual lubrication systems in a plant, because even the originally identical lubrication systems may have experienced different Operation & Maintenance (O&M) histories and would arrive at different values of condition indicators. Due to the uniqueness of each individual lubrication system, the guides provided in this Appendix cannot quantify all factors that affect individual lubrication system condition. Mitigating factors not included in this guide may trigger testing and further evaluation to determine the final score of the lubrication system condition and to make the decision of lubrication system replacement or rehabilitation.

This Appendix is not intended to define lubrication system maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

## 2.0 Constituent Parts Analysis

The reliability related components of lubrication systems include the lubricant/oil, filter sub-system, cooling sub-system, oil pumps, vessel and piping, and instrumentation/alarm. If any part (e.g., instrumentation/alarm) does not exist in a particular lubrication system, this part will be excluded from scoring mechanism by inputting “NA” into the Table. The effect of one part exclusion is usually insignificant to justify any adjustment for the weighting factors of other lubrication system parts.

## 3.0 Metrics for Lubrication System Condition Assessment

As listed in Table 1, the following five condition parameters are considered for condition assessment of lubrication system parts:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on the previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports if conducted, interviews with plant staff and some limited inspections. It is noticed that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmarking condition assessment without specific testing and measurements conducted on site, these five parameters are regarded as providing the basis for assessing the condition of lubrication system parts.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of available information and the confidence on the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the information and data availability, integrity and accuracy and the confidence on the given condition ratings (MWH 2010).

## 4.0 Weighting Factors

There are two categories of weighting factors in Table 1. It is recognized that some condition parameters affect the lubrication system condition to a greater or lesser degree than other parameters; also some parts are more or less important than other parts to an entire lubrication system. These weighting factors should be pre-determined by consensus among experienced hydropower mechanical engineers and plant O&M experts. Once they are determined for each type of lubrication system, they should be largely fixed from plant to plant for the same type of lubrication system, except for special designs found in a lubrication system where the weighting factors have to be adjusted. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors won't affect the Condition Indicator of a lubrication system, which is the weighted summation of all scores that assigned to the lubrication system parts and five condition parameters.

**Table 1: Typical Lubrication System Condition Assessment & Scoring - XXX Hydropower Plant (Unit #)**

| Lubrication System for Unit ____ | Taxonomy ID | Physical Condition Score | Age Score | Installed Technology Score | Operating Restrictions Score | Maintenance Requirement Score | Data Quality Score | Weighting Factors for Parts |
|---|---|---|---|---|---|---|---|---|
| Lubricant/Oil | 4.2.5.1 | | | | | | | 2.5 |
| Filter Sub-System | 4.2.5.2 | | | | | | | 1.5 |
| Cooling Sub-System | 4.2.5.3 | | | | | | | 1.5 |
| Oil Pumps | 4.2.5.4 | | | | | | | 1.5 |
| Vessel and Piping | 4.2.5.5 | | | | | | | 1.0 |
| Instrumentation/Alarms | 4.2.5.6 | | | | | | | 1.0 |
| Weighting Factors for Condition Parameters | | 2.0 | 1.0 | 1.0 | 1.0 | 1.5 | Data Quality --> | *0.00* |
| | | | | | | | **Condition Indicator -->** | ***0.00*** |

## 5.0 Rating Criteria

Physical Condition - Rating Criteria for Lubrication system Parts

Physical Condition of lubrication system parts refers to those features that are observable or detected through measurement and testing, including some observed performance. It includes the observation of pump vibration and noise, oil loss, looseness of pins and linkages, and sticking of valves, as well as the analysis result from lubricant/oil condition assessment testing. The Best Practices of Lubrication System Condition Assessment can assist in evaluating the lubrication system condition.

For HAP site assessment, it is important to conduct interviews and discussions with plant personnel in order to score the physical condition of lubrication system parts. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores of lubrication system parts.

| Chart 1 Lubrication System Physical Condition Rating Criteria | | |
|---|---|---|
| **Physical Condition Rating Scale** | | **Physical Condition Score** |
| **Excellent** | No noticeable defects. Some aging or wear may be noticeable. No evidence of pump vibration and noise, oil loss, looseness of pins and linkages, or sticking of valves. Oil cleanliness levels meet the requirements of ISO 4406. | **9 – 10** |
| **Very good** | Only minor deterioration or defects are evident, and function is full. Minor evidence of pump vibration and noise, oil loss, looseness of pins and linkages, or sticking of valves. Oil cleanliness levels largely meet the requirements of ISO 4406. | **7 – 8** |
| **Good** | Some deterioration or defects are evident, but function is not significantly affected. Observable evidence of pump vibration and noise, oil loss, looseness of pins and linkages, and sticking of valves. Oil cleanliness levels meet the requirements of ISO 4406 at most parts, and plan for cleaning process is needed. | **5 – 6** |
| **Fair** | Moderate deterioration, function is still adequate, but the unit efficiency may be affected. Wide evidence of pump vibration and noise, oil loss, looseness of pins and linkages, and sticking of valves. Oil cleanliness levels meet the requirements of ISO 4406 at some parts, and cleaning process is needed immediately. | **3 – 4** |
| **Poor** | Serious deterioration in at least some portions, function is inadequate, unit efficiency or availability significantly affected. | **2** |
| **Very poor** | Extensive deterioration. Barely functional. | **1** |
| **Failed** | No longer functions, may cause failure of a major component. | **0** |

Age - Rating Criteria for Lubrication system Parts

Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allows the age score be automatically generated in the HAP Database by the actual years of the installed part.

**Chart 2 Age Rating Criteria for Lubrication System Parts**

| Ages of the Lubrication System Major Parts/Items | Age Score |
|---|---|
| <2 years | 10 |
| 2-5 years | 9 |
| 5-7 years | 8 |
| 7-10 years | 7 |
| 10-12 years | 6 |
| 12-17 years | 5 |
| 17-20 years | 4 |
| 20-22 years | 3 |
| 22-25 years | 2 |
| 25-30 years | 1 |
| >30 years | 0 |

<u>Installed Technology Level – Rating Criteria for Lubrication System Parts</u>

The Installed Technology Level indicates advancement levels of designing, machining, installation and materials, which may effect on the unit and plant performance. The outdated technology may bring difficulties for spare parts supply and come a prolonged outage when it fails.

Scoring the Installed Technology Level requires historic knowledge of lubrication system technology advancement and familiarity with the current lubrication system manufacturing industry. Early designs for oil lubricating systems, for vertical hydro turbine-generator bearings, consisted of pumps driven by gears or belts from the main shaft or by simple viscosity pumps which move oil by hydrodynamic action. Horizontal hydro turbine-generator bearings were often lubricated by oil rings riding on top of the shaft. Modern designs have evolved into systems which move the oil by electric motor driven pumps. This has many advantages such as providing electrical controls, backup pumps (AC and DC), and flexible capacities such as flow rates and pressures.

As state of the art technology, stainless steel reservoir, vessels and piping are used to ensure minimum oil flushing time, optimum unit component life and unit reliability. The use of centrifugal pumps eliminates the need for relief and backpressure (bypass) control valves and thus reduces the oil system induced unit trips. Single stage centrifugal pumps can be used whenever the ambient temperature along with the use of thermostatically controlled reservoir heaters maintain an oil viscosity that allows the use of a centrifugal pump. Supplementary oil cleaning can be achieved by a separate system (Kidney Loop Oil Filtration System) in series with the existing lubrication system, which reduces failures caused by dirty oil.

In addition, the competence, professionalism and reputation of the original suppliers could also imply the installed technology levels. Compared to those from large and well-known manufacturers, the lubrication system parts supplied by small and unnamed companies would get lower scores.

| Chart 3 Lubrication System Technology Rating Criteria | |
|---|---|
| **Technology Levels of the Parts/Items** | **Score for Installed Technology Level** |
| The technology has not been changed significantly since the part was installed; and the installed technology was supplied by brand name companies with great reputation | **8 – 10** |
| The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation. | **4 – 7** |
| The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation. | **0 – 3** |

Operating Restrictions - Rating Criteria for Lubrication System Parts

The lubrication system operating restrictions refer to the limitations on normal operation range of oil pressure and flow rate, based on the original design and current condition of lubrication system parts. Operational limitations play a role in determining the serviceability of lubrication system unit: the greater the limitations, the greater the heat generated and/or excess oil bypassed back to the oil reservoir.

The operating restrictions may be sourced from the system itself. The operating ranges of maximum/minimum oil flows and pressures are constrained due to the original design and/or currently deteriorated lubrication system physical condition (e.g., hot bearings and severe vibrations).

Chart 4 describes the ratings of lubrication system operating restrictions.

**Chart 4 Lubrication System Operating Restrictions Rating Criteria**

| Operating Restrictions or Off-Design Conditions | Score for Operating Restrictions |
|---|---|
| The design standard has no changes, and the original design has no constraints on the required operation. No known design and operational deficiencies. | 8 – 10 |
| Minimal restraints: Special operational requirements are needed to avoid minor maintenance issues. The operation range can be expanded with revised equipment selection and design. No known design and operational deficiencies. | 5 – 7 |
| Moderate restraints: Special operational requirements are needed to avoid major maintenance issues. The operation range and performance can be significantly improved with revised equipment selection and design. | 3 – 4 |
| Severe limitations: The equipment do not meet the operational criteria or not tested as required or has a known design and operational deficiency. | 0 – 2 |

Maintenance Requirement – Rating Criteria for Lubrication system Parts

Maintenance of an oil lubricated bearing is directly connected to the quality of the supplied oil used for lubrication and cooling. Any contamination of the oil either with debris or water will increase the likelihood of a bearing failure. Oil filters are usually positioned downstream of the oil coolers to prevent carbon steel (iron sulfide) particles from entering the machinery components and causing pre-mature wear/failure. A displacement flush is conducted typically based on a time interval vs. cleanliness (particle levels) to facilitate the removal of soluble and insoluble contaminants that would not typically be removed by system filters.

The amount of corrective maintenance that either has been or must be performed is an indication of the lubrication system condition. No corrective maintenance is an indication that the lubrication system is in good shape. Severe corrective maintenance requires scheduled or forced outages to perform.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;
- Previous failures related to the lubrication system parts;
- Failures and problems of lubrication system parts with similar design.

The results of lubrication system maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5 to score the lubrication system parts.

| Chart 5 Lubrication System Maintenance Requirement Rating Criteria | |
|---|---|
| **Amounts of Corrective Maintenance** | **Maintenance Requirement Score** |
| Minimum level (normal condition): A small amount of routine preventive maintenance is required (e.g., Oil Sampling). No corrective maintenance. | **9 – 10** |
| Low level: Small amounts of corrective maintenance (e.g., less than 3 staff days per unit per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis. | **7 – 8** |
| Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages (e.g., Pump Replacement). | **5 – 6** |
| Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., Cooler Rebuild/Replacement). | **3 – 4** |
| Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required. | **0 – 2** |

Data Quality – Rating Criteria for Lubrication system Parts

The Data quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of lubrication system parts. The more current and complete inspection, testing and measurement results, the higher the Data Quality scores. The frequency of normal testing is as recommended by the organization. Reasonable efforts should be made to perform visual inspections and data collection (measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports and etc.). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3-7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of lubrication system parts are developed in Chart 6.

| Chart 6 Lubrication System Data Quality Rating Criteria | |
|---|---|
| **Data Availability, Integrity and Accuracy** | **Data Quality Score** |
| High – The Lubrication System maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff. | **8 – 10** |
| Medium – One or more of routine inspections, tests and measurement were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team. | **5 – 7** |
| Low – One or more of routine inspections, tests and measurement were completed 24-36 months past the normal frequency, or some of results are not available. | **3 – 4** |
| Very Low – One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, or significant portion of results are not available. | **0 – 2** |

## 6.0 Lubrication System Condition and Data Quality Indicators

In Table 1, the final condition score of the lubrication system, i.e., the Condition Indicator, *CI*, can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,5} F(K) \times F(J)} \qquad (1)$$

The lubrication system Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \qquad (2)$$

Here *M* = the total number of parts/items associated with a lubrication system; *K* = the identification No. of lubrication system parts (from 1 to *M*); *J* = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a lubrication system part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; *F*(*J*) = the weighting factor for a condition parameter; *F*(*K*) = the weighting factor for a lubrication system part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific lubrication system testing, such as the efficiency/index test and paint film quality test, would more directly reveal the condition of the lubrication system.

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