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CHAPTER 8. Reliability Centered Building and Equipment Acceptance

8.1. Introduction

a. During the course of new construction, major repair, or rehabilitation of facilities, it is not unusual to discover installed systems or equipment that are out of alignment and balance, that contain latent defects from manufacturing and installation, or that simply do not operate as intended. For example, evaluations of new construction of at least two NASA Centers revealed that 85- to 100-percent of the rotating equipment was misaligned, out-of-balance, or contained defective bearings. These types of systems or equipment defects result in premature failures, which require unbudgeted corrective action by O&M staff. Given today's tight facilities O&M budgets, each Center should, for new construction, major repair, or rehabilitation of facility projects, employ an acceptance process that includes the use of PT&I to verify system and equipment condition. This should be done prior to acceptance of the work and the contractor's departure from the job site and turning the keys over to the operations and maintenance staff. The expected end result is a facility that is safer and is less costly to maintain. The acceptance process can achieve these results by:

(1) Ensuring there are no latent factory or installation defects;

(2) Verifying building systems and equipment performance through functional performance testing; and

(3) Providing full documentation and training for the O&M staff to improve their performance.

b. Building and equipment acceptance is one element of a larger, more comprehensive construction quality program known as "Commissioning". Currently, there are three variations of commissioning being practiced - Traditional Commissioning, Total Building Commissioning and NASA's customized application of a portion of Commissioning called Reliability Centered Building and Equipment Acceptance.

8.1.1. Traditional Commissioning. Traditional Commissioning involves performing random tests and checks on facility systems to ensure that they are properly balanced, functionally operational and comply with the design intent. It systematically checks operating parameters such as pressure, temperature, minimum and maximum air flow, lighting levels, electrical amperage and voltage, torque, fluid volumes, and other thermodynamic measures at key locations, as well as balanced conditions. It is a method of acceptance testing that, when performed on a random basis at random sampling points, checks to ensure that the outcome indices at those points are in compliance with the outcome requirements stated in the design specification. Although the method ensures that the installation meets the design requirements, Traditional Commissioning reflects the conditions in a snapshot in time, specifically on the day(s) that the system is being inspected for acceptance. Also, it generally fails to emphasize the quality of the equipment installation itself, such as latent manufacturing and installation defects. Even if the installation is in compliance with the design and reflects the proper process parameters at the time of equipment acceptance, these undetected defects may result in premature equipment failure and operational and maintenance headaches due to

misalignment or similar condition discovered at a later date. The problem then becomes one of many warranty issues, which based on past, typical NASA history, often are inadequately enforced.

8.1.2. Total Building Commissioning. Total Building Commissioning is a cradle-to-grave systematic process of ensuring that facility systems are planned, designed, installed, tested, and capable of being operated and maintained to perform according to the design intent and the user's needs. The Total Commissioning process is optimally applied to all phases of a construction project - program planning, design, construction/installation, acceptance and postacceptance/ occupancy. Commissioning team involvement begins at the earliest stages of project planning, where its expertise in such areas as system sizing, code compliance, maintainability, user friendliness, product quality and reliability, ergonomics and projected life-cycle costs, is applied to the design. The commissioning staff is also involved in monitoring the quality of the construction in terms of workmanship and specification and code compliance throughout the construction, using Traditional Commissioning tests and inspection procedures for quality assurance and for system acceptance. Finally, the quality team monitors the installed system following acceptance to ensure that there are no latent installation defects or degradation of system performance and operational quality. This rigorous commissioning process is intended to provide the following benefits:

a. Ensure that a new facility begins its life with systems at optimal productivity.

b. Improve the likelihood that the facility will maintain this level of performance.

c. Restore an existing facility to high productivity.

d. Ensure facility renovations and equipment upgrades function as designed.

8.1.3. NASA's Building and Equipment Acceptance. NASA's application of Commissioning is a customization of a portion of the Traditional and Total Commissioning processes that NASA calls Reliability Centered Building and Equipment Acceptance. NASA recognizes there can be substantial benefit even when commissioning concepts are applied only to the acceptance phase of a construction project. These benefits can be gained during acceptance by using available PT&I technologies in addition to traditional operational parameters to identify latent manufacturing, shipping, and installation induced defects. Identifying and correcting these defects can reduce premature failures, increase safety and reliability and decrease life-cycle costs. NASA's portion of the Commissioning concept concentrates on facility and equipment acceptance rather than on Total Commissioning's cradle to grave detailed oversight and evaluations because of the following:

a. NASA's placing safety as a top priority.

b. The current Federal budget process involving project funding from numerous autonomous and nonintegratable sources

c. NASA's emphasis on reducing life-cycle costs within available and limited resources.

d. The institution of a strong and vibrant RCM program in place Agencywide.

8.1.4. Many of the problems, safety concerns and associated costs inherited during the O&M phase are the result of i nadequate or nonexistent standards and procedures for equipment acceptance. Thus, the focus of NASA's equipment acceptance is on ensuring that the contractor detects latent manufacturing and installation defects through an effective quality control program before final acceptance of the installation by the Government.

8.1.5. This chapter provides a brief overview of NASA's Acceptance program. Refer to the NASA Reliability Centered Building and Equipment Acceptance Guide for more detailed information and extensive discussion of the subject.

8.2. RCM - Integral to Acceptance

The RCM approach takes a life-cycle view of facilities and collateral equipment and seeks to ensure that facilities and collateral equipment are properly built and installed in order to reduce the probability of premature failure. A key element in the transition from good design to full operation is the construction and acceptance phase.

8.2.1. Initial Planning and Design. The long-term reliability of an installation or refurbishment begins with the initial planning and design. The initial criteria and equipment design determines the inherent equipment reliability, maintainability, and supportability. Moreover, as discussed in Chapter 7, Reliability Centered Maintenance, about 95 percent of the total equipment cost is determined by the end of the planning and design phase. Even though expenditures for plant and equipment may occur later during the acquisition process, their cost is committed at an early stage. The decision to include a facility in the RCM program, including PT&I, is best made during the planning phase. As RCM decisions are made later in the life cycle, it becomes more difficult to achieve the maximum possible benefit from the RCM program. It has been estimated by NASA facilities and collateral equipment designers that the cost to make a system change, once the system is built, is anywhere from 10 to 1,000 times more than if the change was incorporated during the system design. Clearly, the planning and design phase of facilities and collateral equipment life cycle is the time to focus on the ability to sustain operation through the use of effective acceptance testing, proper trending, necessary maintenance, and the performance of timely repair, when needed.

8.2.2. Construction and Acceptance. Contracts for construction work at NASA Centers shall require contractor responsibility for an adequate quality control program in place for the proper installation of the facility and equipment in accordance with the design requirements. Throughout the installation and at the time of acceptance, PT&I must be performed to verify that not only is the installation acceptable, i.e., that there are no latent factory or installation defects, but also that the required baselines are established. Consequently, any contractor performing work at NASA centers must have an understanding of the RCM process and how it affects the project. NASA contracts shall require the contractor to use personnel who are trained and certified in the appropriate PT&I technologies for acceptance testing to ensure that the results are accurate and consistent. The Center's Construction Manager is responsible for ensuring that all interim testing is performed and that the results meet the specifications and are documented and included with the final acceptance documentation. It is the Construction Manager's responsibility to ensure that the acceptance testing has been performed and to determine if the acceptance testing results are within the required tolerances. When all acceptance criteria have been met, the final responsibility of the Construction Manager is to collect all of the required documentation, including all manufacturers manuals, drawing redlines, and all acceptance testing data, and deliver it to the appropriate Center operations and maintenance personnel.

8.2.3. Maintenance and Operations. Even though maintenance is a relatively small portion of the overall life-cycle cost, 3 to 5 percent of a facility's operating cost, RCM is still capable of introducing significant savings during the Maintenance and Operations phase of a facility's life. Savings of 30 to 50 percent in the annual maintenance budget are often obtained through the introduction of a balanced RCM program. O&M personnel are ultimately responsible for the proper operation and maintenance of systems and equipment. However, how the facility and its equipment will be operated and maintained must be considered during the planning, design, and construction phases. During these phases, maintenance and operations needs are best served by carefully and realistically identifying and defining the PT&I and PM requirements. Although the performance of maintenance and operations occurs during the operations stage of the life cycle, some preparatory activities can be carried out during the acceptance stage. These activities can include O&M personnel selection, training requirements, procedure preparation, review of specifications, and the collection of baseline condition monitoring data from the Construction Manager. Refer to Chapter 7, Reliability Centered Maintenance, of this document and to the NASA Reliability Centered Maintenance Guide for Facilities and Collateral Equipment for guidance on the use of RCM during facilities operations and maintenance.

8.3. Acceptance Testing

8.3.1. After construction is complete, it is important to verify that the systems and equipment are operating in accordance with the construction specifications. NASA's contracts shall accomplish this by requiring the contractor to verify, as an element of the contractor's quality control program, that the equipment specified is properly installed in accordance with design and local codes and standards, that there are no latent manufacturing or installation defects, and that individual and integrated systems and equipment operation is in accordance with the design intent. During NASA's acceptance process, individual equipment is acceptance-tested using PT&I, that focuses on equipment performance, and by traditional thermodynamic testing. By providing this initial baseline data for comparisons and trending it allows for the planning and scheduling of PM or repairs in advance of failure.

8.3.2. Facilities contain a myriad of equipment and systems, from the simplest light switch to a computer-controlled air conditioning system. While, all equipment can benefit from the reliability centered acceptance process it must be understood that even though an acceptance test is available, it is not always cost effective to perform. The decision to perform reliability centered acceptance should be based on the RCM techniques in the NASA RCM Guide for Facilities and Collateral Equipment and the NASA Reliability Centered Building and Equipment reliability centered Acceptance Guide.

8.3.3. Table 8-1 indicates the most appropriate and commonly used PT&I technologies with respect to the most common acceptance testing applications. These PT&I tests have become some of the most effective methods for testing new and in-service equipment for hidden defects.

8.3.4. Preliminary and final acceptance testing and documentation of the test results is to be performed by the contractor as part of the contractor's Quality Control program. The contractor must correct all detected deficiencies, and the condition monitoring data shall be retaken prior to acceptance of the facility and/or equipment by NASA. The NASA Center must observe and monitor this condition testing, analysis and documentation as part of its Quality Assurance program and ensure that the contractor provides all preliminary and final condition monitoring and analysis data to the Construction Manager.

8.4. Acceptance Scope

The acceptance scope includes but is not limited to the following:

a. Documenting the design intent. Verifying that equipment and systems have been properly installed in accordance with the contract documentation and the manufacturer's written installation instructions.

b. Verifying the performance of each piece of equipment and each system, documenting the equipment and system performance and ensuring that there are no latent manufacturing and installation defects.

c. Verifying that equipment has been placed into operation with the manufacturer's observation and/or approval.

d. Verifying that adjusting, balancing and system testing has been properly performed.

e. Assembling and submitting record drawings

PT&I Technology	Equipment to be Tested																
	Air	Brine Chillers	Bearings	Coolers	Circuit Breakers	Diesel	Electrical	Gearbox	Heat Exchanger	Hydraulic	Main Drive	Motor (Auxiliary)	Piping/Tank	Pumps (all)	Rheostat	Optating	Valves
Airborne Ultrasonics	–	–		–	–	–	–		–		–				–	–	–
Electrical Testing																	
Insulation Resistance					–	–	–				–	–				–	
MCE											–	–					
MCSA											–	–			–	–	–
Other					–	–	–					–			–	–	
Process Parameters																	
Operation Data	–	–		–	–	–			–	–	–	–	–	–		–	
Recip Trap	–					–											
NDE/NDT																	
Acoustic Emissions													–				
Eddy Current																	
Imaging/ Thickness			–										–				
Magnetic Particle	–										–						
Temperature																	
Contact	–	–	–	–		–		–	–		–						
Infrared			–	–	–		–		–		–	–	–	–	–	–	–
Tribology																	
Oil Condition	–	–	–			–		–		–	–						
Particle Count										–							
Wear Particle	–	–	–			–		–									
Valve Testing																	
Electrical																	–
Pneumatic																	–
Vibration Analysis																	
Proximity			–								–						
Seismic	–	–	–			–		–			–	–	–	–		–	
Torsional	–					–											

Table 8-1. Applicable PT&I Technologies

f. Training Center and/or the User's personnel in the proper operation of each piece of equipment and each system.

g. Documenting warranty start and end dates.

h. Assembling and submitting all records of Code authority inspections and approvals.

i. Validating the accessibility of all work relative to the maintenance requirements of each piece of equipment and promptly advising NASA of items of noncompliance.

j. Identifying, documenting and reporting all deficiencies of the work relative to the contract documents for tracking and correction through a deficiency-tracking program.

8.5. Applications

8.5.1. Roofs. Roofs are normally constructed layer by layer and comprised of many different types of materials. Moisture must not be allowed to enter the roof structure or materials during the construction phase, as any trapped moisture will eventually degrade the roof and structure and can cause a premature failure of the roofing system. Whereas traditional roof inspections usually look for the effects of leaks, infrared thermography should be used to look for wet insulation caused by water ingress during construction, improper installation or roof boundary failures.

8.5.2. Insulation/Building Envelope. Building insulation is installed during construction but in most cases, prior to the building being completed. Consequently, acceptance inspections must occur before the walls and ceilings are completed. On completion of the insulation installation a construction detail showing the insulation material type, amount, and location must be generated and submitted by the contractor. This information shall be forwarded to the appropriate RCM official for inclusion in the maintenance database. Infrared Thermography or ultrasonic mapping should be used during acceptance to identify insulation voids, insulation settling, and areas of moisture intrusion.

8.5.3. Piping Systems. Industry standard acceptance tests for water, plumbing and air systems first require a pressure test of all piping and fittings. During this test an ultrasonic scan should be performed on all accessible aboveground piping to help discover any leaks. For hot water systems, after the pressure and hydro tests are completed, and after piping insulation has been installed, the system should be charged with hot water and an infrared scan be performed to verify insulation integrity. For steam systems, ultrasonic scans should be performed on steam traps.

8.5.4. Mechanical Systems

8.5.4.1. Vibration Analysis. Analysis of system and equipment vibration levels is one of the most commonly used PT&I techniques to determine the condition of the rotating equipment and its structural stability in a system. It will detect deficiencies associated with wear, imbalance, misalignment, mechanical looseness, bearing damage, belt flaws, sheave and pulley flaws, gear damage, flow turbulence, cavitation, structural resonance and fatigue. Vibration measurements in the acceptance process must be performed by technically qualified persons, trained, experienced and certified in vibration measurement and be taken under specified operating conditions. Test documentation, including machine layout drawings indicating vibration measurement locations, must be submitted and validated and signed by the NASA construction manager or other authorized official prior to final equipment acceptance.

8.5.4.2. Balance. Only 10- to 20-percent of rolling element bearings achieve their design life. Premature bearing failure is frequently caused by excessive vibration caused by imbalance and misalignment. Acceptance testing for precision balance by the contractor at the time of equipment acceptance of motor rotors, pump impellers and fans is one of the most critical and cost effective techniques for achieving increased bearing life and resultant equipment reliability. NASA contracts shall require that balance measurements be performed by a technically qualified person trained, experienced and certified in machinery balancing.

8.5.4.3. Alignment. The forces of vibration from misalignment cause gradual deterioration of seals, couplings, bearings, drive windings and other rotating elements where close tolerances exist. The use of precision equipment and methods, such as reverse dial and laser systems to bring alignment tolerances within precision standards, by the contractor at the time of acceptance is necessary. Precision alignment will increase the average bearing life, decrease maintenance costs, and increase machinery availability.

8.5.4.4. Lubrication and Hydraulic Fluids. Lubricating and hydraulic fluid analysis is performed during acceptance for three reasons: to determine the machine mechanical wear condition; to determine the fluid condition; and to determine if the fluid has become contaminated. There is a wide variety of tests to provide information on these, usually packaged by independent testing laboratories to address all three areas. In addition to assessing the condition of the fluids at the time of equipment acceptance, these tests are necessary to provide a baseline for future RCM actions.

8.5.4.5. Ultrasonic Testing. Airborne ultrasonics is used by the contractor during equipment acceptance to hear noises associated with leaks, corona discharges, and other high frequency events. In addition to evaluating heat exchangers, ultrasonics can be used to verify boiler casing and associated piping integrity and the proper operation of steam traps.

8.5.4.6. Infrared Imaging. See paragraph 8.5.5.1, Infrared Imaging.

8.5.5. Electrical Systems

8.5.5.1. Infrared Imaging. Infrared Thermography (IRT) is a noncontact technique used during acceptance to identify hot and cold spots in energized electrical equipment, large surface areas such as boilers and building walls, and other areas where "stand off" temperature measurements is necessary. More specifically, IRT is used to detect faulty conditions in transformers, motor control centers, switchgear, substations, switchyards and power lines. In mechanical systems, IRT is used to identify blocked flow conditions in heat exchangers, condensers, transformer-cooling radiators and pipes and to verify fluid levels in large containers such as fuel storage tanks. Paragraphs 8.5.1. through 8.5.3. discuss IRT's applications specific to structural systems.

8.5.5.2. Power Factor Testing. Providing the optimum power factor maximizes the efficient use of electrical power. Power Factor, sometimes referred to as dissipation factor, is the measure of the power loss through the insulation system to ground. It is a dimensionless ratio that is expressed in percent of the resistive current flowing through an insulation to the total current flowing. Consequently, the power factor test is used for making routine comparisons of the condition of an insulation system and for acceptance testing to verify the equipment was manufactured and installed properly. The test is nondestructive, and regular maintenance testing will not deteriorate or damage insulation. Its most frequent applications are with electric motors, circuit breakers, motor control centers, switchgear, and transformers.

8.5.5.3. Insulation Resistance Testing. An insulation resistance test is a nondestructive Direct Current (DC) test used during acceptance to determine the condition of the of insulation of electrical systems. It indicates that the insulation under test can withstand the voltage being applied. The insulation resistance is generally accepted as a reliable indication of the presence of contamination or degradation. Its most frequent applications are with motors, switchgear, motor control centers, circuit breakers and transformers.

8.5.5.4. Insulation Oil Testing. High and medium voltage transformers, some high and medium voltage breakers, and some medium voltage switches are supplied with mineral oil as an insulation medium. Performing oil tests prior to turnover is needed to ensure that proper oil is installed and that the necessary inhibitors have been added. Further, when insulation systems are subjected to stresses, such as fault currents and overheating, combustible gas generation can change dramatically. In most cases these stresses can be detected early on; the presence and quantity of the individual gases can be measured and the results analyzed to indicate the probable cause of generation.

8.5.5.5. Motor Circuit Evaluation (MCE) and Motor Circuit Analysis (MCA). MCE is used during acceptance to evaluate the condition of motor power circuits. Any impedance imbalances in a motor will result in a voltage imbalance. Voltage imbalances in turn will result in higher operating current and temperatures, which will weaken the . insulation and shorten the motor's life. MCA is a method of detecting the presence of broken or cracked rotor bars or high resistance connections in end rings. While MCA is an effective test on in-service motors it is not generally used for acceptance testing. It is, however, normally performed at initial startup so a baseline can be established. 8.5.5.6. Battery Impedance Testing. As a battery ages and begins to lose capacity, its internal impedance rises. This is a parameter that can be trended, comparing the current value with the original value, taken at acceptance, with previous readings, and with other identical batteries in the same battery bank. Additionally, battery impedance testing will indicate the existence of an internal short in the battery, of an open circuit in the battery, and premature aging due to excessive heat or discharges. There are no set guidelines and limits for this test. Each type, style, and configuration of battery will have its own impedance so it is important to take these measurements during acceptance to establish a baseline.

8.5.5.7. Airborne Ultrasonics. Deficiencies in electrical systems, such as corona discharges, loose switch connections, and internal arcing in deadfront electrical connections can all be discovered during acceptance using ultrasonic test devices. Corona discharge is normally associated with high voltage distribution systems and is produced as a result of a poor connection or insulation problem. The discharges generally occur at random, are the precursor to a failure, and are in the ultraviolet region and not normally detectable using thermography.

8.6. Acceptance Data Sheet

Acceptance data is to be recorded on a formal Acceptance Date Sheet and provided to the Center Construction Manager as part of the facility or equipment documentation package. A separate sheet must be filled out for each equipment unit being evaluated during the acceptance process and may result in a voluminous total package. Refer to the NASA Reliability Centered Building and Equipment Acceptance Guide for Acceptance Date Sheet samples.

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