Considerations for Planning and Scheduling Part 2
Reactive Maintenance Planning

Howard W Penrose, Ph.D., CMRP
President, SUCCESS by DESIGN

Introduction

In the first paper we discussed the Workflow Concept (WFC) and Design for Maintenance (DFM) processes for improved accuracy in planning and scheduling planned maintenance tasks. The other type of maintenance that occurs, regardless of the type of maintenance performed, is reactive maintenance as the result of random failure. All systems have the chance of failing unexpectedly, so methods must be in place to handle these situations in order to have the least impact on the planning and scheduling process.

Where programs are advancing through towards higher levels of maintenance, random equipment failure can be an opportunity for maintenance. However, the reaction is often to over-react and over-provide resources to the problem at hand. The challenge is that too few resources, or too many resources, will both have the same negative impact on solving the reactive issue. The opportunity can be outlined in a reactive maintenance plan for specific equipment in which there is a method of fault identification, fault rectification, root-cause-analysis at whatever level is appropriate, and planned maintenance to be performed when the machine or system is idle.

In this paper, we will provide an overview of how the reactive maintenance plan can be developed. In Part 3, we will discuss how to blend the Reactive Maintenance Plan with the Planned Maintenance program.

The Reactive Maintenance Process

Once a system or component ceases to perform the function required by the owner, the equipment is considered failed. At this point, the random fault has occurred with an urgency based upon the criticality of the equipment. The correct process to address the failure is as follows:

1. Fault Identification: At this point, discovery of the fault occurs, the failure is controlled and troubleshooting is performed;
2. Fault Rectification: This is the repair or replacement of the failure;
3. Root-Cause-Analysis: Using the evidence and findings of the fault and fault rectification, an RCA should be performed. The depth of the RCA should directly relate to the criticality. For instance, for a minor failure that is not repetitive or does not meet a pre-set value, a simple 5-Why process may be followed. For a critical failure, or one that exceeds a pre-set value, a more rigorous process should be followed.

4. Additional planned maintenance that can be performed on the faulted equipment should be considered a possibility. This may include additional testing to detect latent problems.

In order to ensure that these steps are performed as effectively as possible, a written process must be developed.

Fault Identification

Troubleshooting equipment or system failure can be time consuming and dependant upon the skills and knowledge the maintenance first responders. Knowing the available skills, as outlined in Part 1, the maintenance planner can select the appropriate first-responders. The challenge is then left to troubleshooting and the correct selection of inspection and technology techniques.

The tools that can be used to determine the appropriate troubleshooting and inspection techniques include the results from Reliability-Centered Maintenance (the Failure Modes and Effects Analysis), a Failure Modes, Effects and Criticality Analysis (FMECA), the manufacturers' manuals, historical data, knowledge capture and/or other processes such as Root-Cause-Analysis studies. The results of each of these opportunities should be put in the form of a logic analysis or troubleshooting chart, as shown in Attachment 1.

The development of such a chart involves, first, a combination of the above information as well as the instrumentation available and the abilities of the maintenance personnel. Such a chart provides direct troubleshooting abilities as well as provides confirmation tests, inspections and pass/fail values. The long-term benefit of such charts, in particular for critical machines, is greater control over the time, effort and selection of skills through the understanding of the length of time such tasks should take. This information can come from the time studies performed for preventive maintenance.

It should be noted that some failures will require efforts well beyond the ability of these charts, which would instead provide a guideline. However, they will reduce the time to troubleshoot and bring a system back online very quickly, controlling the impact of random failures as well as providing information on the number, type and capability of personnel required.

Fault Rectification

The fault rectification process requires that repair specifications are developed, for outsourced repair, internal bestpractices/procedures for common fault repair or replacement. The development of an overall spares identification program combined with agreements with vendors will also provide a level of stability and control over the random failure.

Fault rectification information can be an extension to the troubleshooting charts mentioned in the previous section. The development of the process/procedures will assist in the development of training, the selection of vendors and an early indication when outsourcing is required.

Root-Cause-Analysis

Root-Cause-Analysis (RCA) is a critical process for Reactive Planning. The criticality of the random failure and how repetitive the failure is, will determine how rigorous the RCA process should be. Attachment 2 is an example of a simple RCA 5-Why process whose information can be used to improve both planned maintenance systems as well as improving the reactive maintenance process.

The selection of trigger points should be selected based upon the severity of the failure. For instance, if the failure is not repetitive and the impact does not exceed $100,000 or impact delivery more than 4 hours, then a 5-Why analysis is performed. If it exceeds those requirements, a more rigorous program requiring greater experience is justified, such as the application of the PROACT® system of RCA.

Additional Planned Maintenance

As part of the Reactive Maintenance Plan, any additional planned maintenance should be added. For instance, if a fan system motor fails, inspection of belts, sheaves, fan bearings, cleanliness, and other inspections can be performed. These should be planned around the availability of the personnel assigned to the random fault as much of the time personnel are on location, they are idle. Random faults should be considered an opportunity to inspect and improve availability of the system once it comes back online.

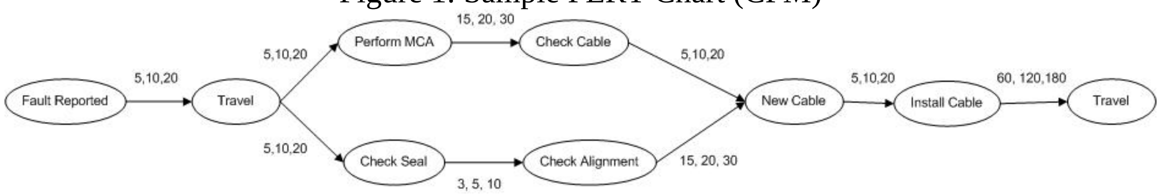
Time Planning of Reactive Maintenance

Random faults should be considered a 'job shop' style process and qualifies for the application of a Critical Path Method (CPM) for determining how much time is required to perform the maintenance, especially because there can be a minimum and maximum time for each sub-task. The times for the CPM should be obtained from the time studies performed for preventive maintenance plus any historical times. The three times selected for each branch of the CPM are the fastest, average and slowest.

In this example, we will discuss a 500 horsepower electric motor and pump application. The motor fails to start and trips immediately. The trouble chart is reviewed and a technician with an MCA (Motor Circuit Analysis) device is sent out as well as a second technician to check the pump seal packing and the alignment if the motor winding is good. The motor is checked from the starter, following appropriate safety rules, a problem is found, so the motor connection box is open, the connection split and both the cable and motor are tested. In the meantime, the second technician is checking the packing. The cable is found bad and new cable is obtained. Once the material is provided, both technicians are used to install the new cable and the machine is energized. The 5-Why analysis is performed and it is determined that a previous FMEA did not identify cable testing as a requirement on this machine. It is determined, however, that the test is not cost effective on its own, and it is determined that MCA will be performed on a quarterly basis.

In a PERT chart, three numbers are shown associated with each task. These are: The minimum time, the average time and the maximum time. The CPM is then presented as shown in Figure 1. The advantage of this type of chart is that it can be hand-sketched if one does not already exist.

Figure 1: Sample PERT Chart (CPM)



While this example is very simple, it does demonstrate the process. In fact, it now gives us three numbers associated with the reactive fault: Minimum – 95 minutes; Average – 180 Minutes; and, Maximum - 290 Minutes. We also know that the number of personnel required for this project is two.

The numbers for the PERT chart can be obtained from time studies performed for predictive maintenance. Additional times, such as disconnecting both sides of the cable and cable installation will require separate time studies performed in the same manner as Part 1.

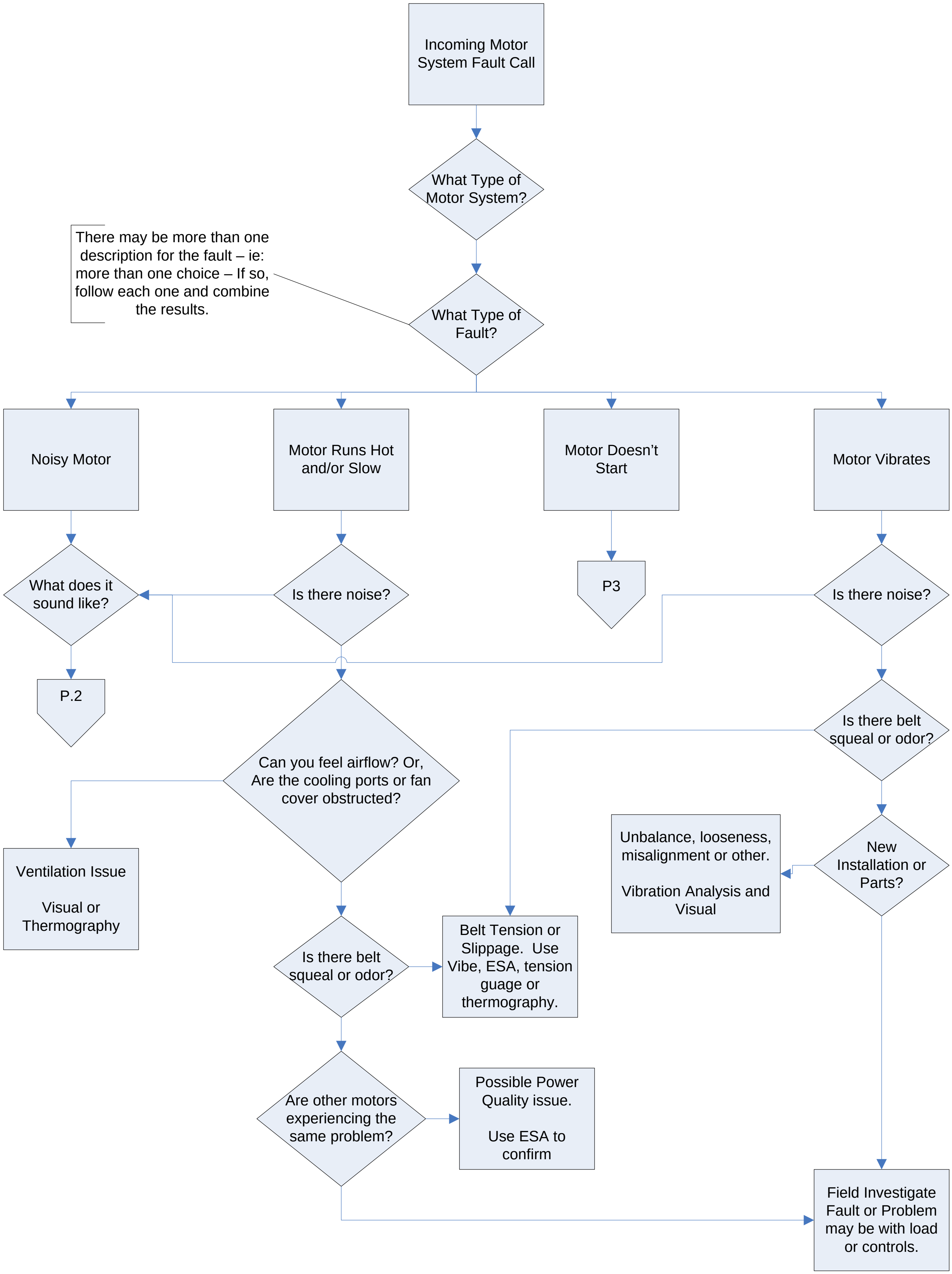
Conclusion

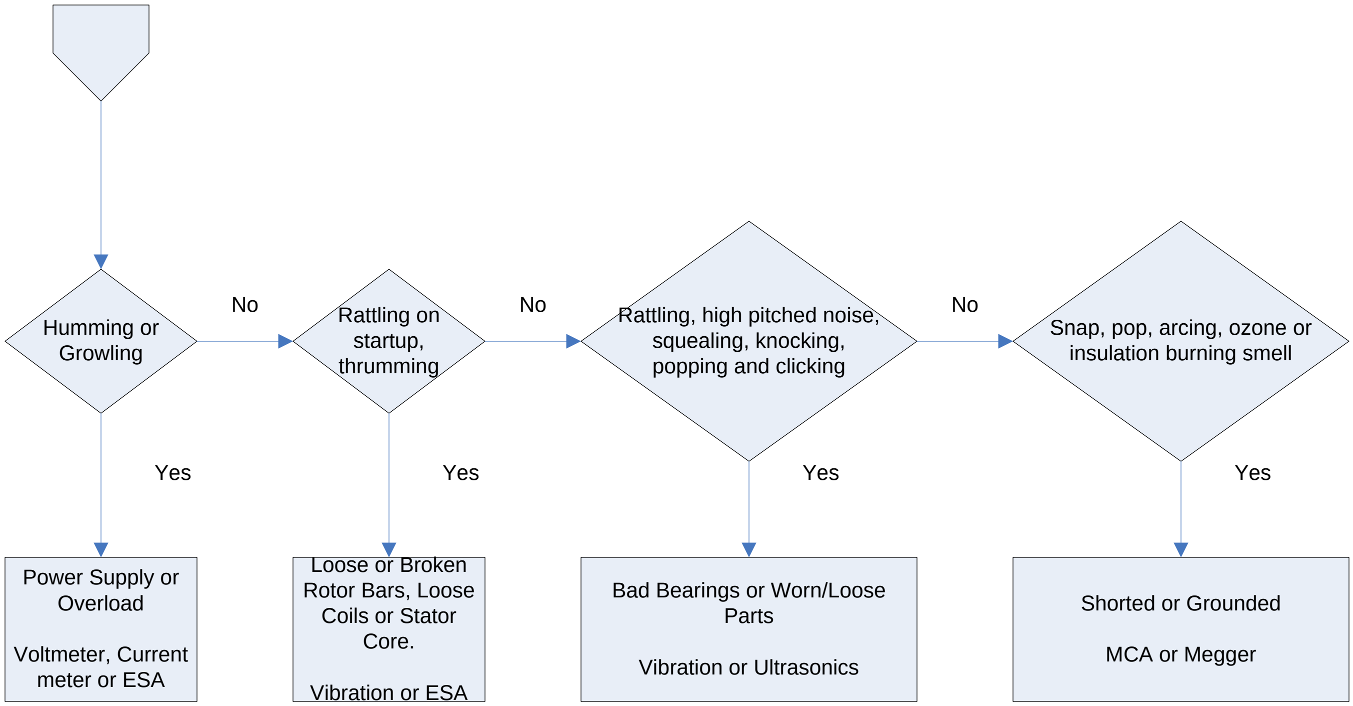
While not as precise as the planned maintenance portion of planning and scheduling, the reactive maintenance process can be brought under some level of control. This is done through the development of a reactive maintenance plan which encompasses fault identification, fault rectification, root-cause-analysis and the performance of other planned maintenance practices on the faulted equipment. Such a plan allows the planner/scheduler and management to estimate the time on task, assign the correct and right number of personnel, confirm availability of parts and determine if steps can be performed to avoid future serious or repetitive problems. In the next paper, we will discuss how to combine the planned and reactive planning components followed by a paper on developing your maintenance budget around this process.

About the Author

Howard W Penrose, Ph.D., CMRP, is the President of SUCCESS by DESIGN Reliability Services. SUCCESS by DESIGN specializes in corporate maintenance program development, motor management programs and maintenance and motor diagnostics training. For more information, or questions, see http://www.motordoc.net, contact info@motordoc.net or call 800 392-9025 (USA) or 860 577-8537 (World-Wide).

Attachment 1: Sample Troubleshooting Chart 3-Phase Induction Motor


Incoming Motor System Fault Call
What Type of Motor System?
There may be more than one description for the fault – ie: more than one choice – If so, follow each one and combine the results.
What Type of Fault?
Noisy Motor
Motor Runs Hot and/or Slow
Motor Doesn't Start
Motor Vibrates
What does it sound like?
Is there noise?
P3
Is there noise?
P.2
Can you feel airflow? Or, Are the cooling ports or fan cover obstructed?
Is there belt squeal or odor?
Ventilation Issue
Visual or Thermography
Unbalance, looseness, misalignment or other.
Vibration Analysis and Visual
New Installation or Parts?
Is there belt squeal or odor?
Belt Tension or Slippage. Use Vibe, ESA, tension guage or thermography.
Are other motors experiencing the same problem?
Possible Power Quality issue.
Use ESA to confirm
Field Investigate Fault or Problem may be with load or controls.



Check for single-phasing due to an open conductor, blown fuse or bad connection.

Check for under or over voltage. Should be +/-10% of nameplate voltage.

Check running current against nameplate to see if the motor is overloaded.

Voltage unbalance greater than 5%

Pole Pass Frequency Sidebands of line frequency in current (ESA) less than 35dB down = bad rotor bars.

Stator slots times running speed +/- line frequency less than 75dB down = loose stator, coils or coil ends (ESA)

# of rotor bars x running speed with running speed sidebands (Vibe) may have harmonics = rotor bars. # of stator slots x running speed = stator faults. Raised noise floor.

Vibration will show signatures with a raised noise floor.

Bearings will be related to the bearing multipliers x the running speed and may have harmonics.

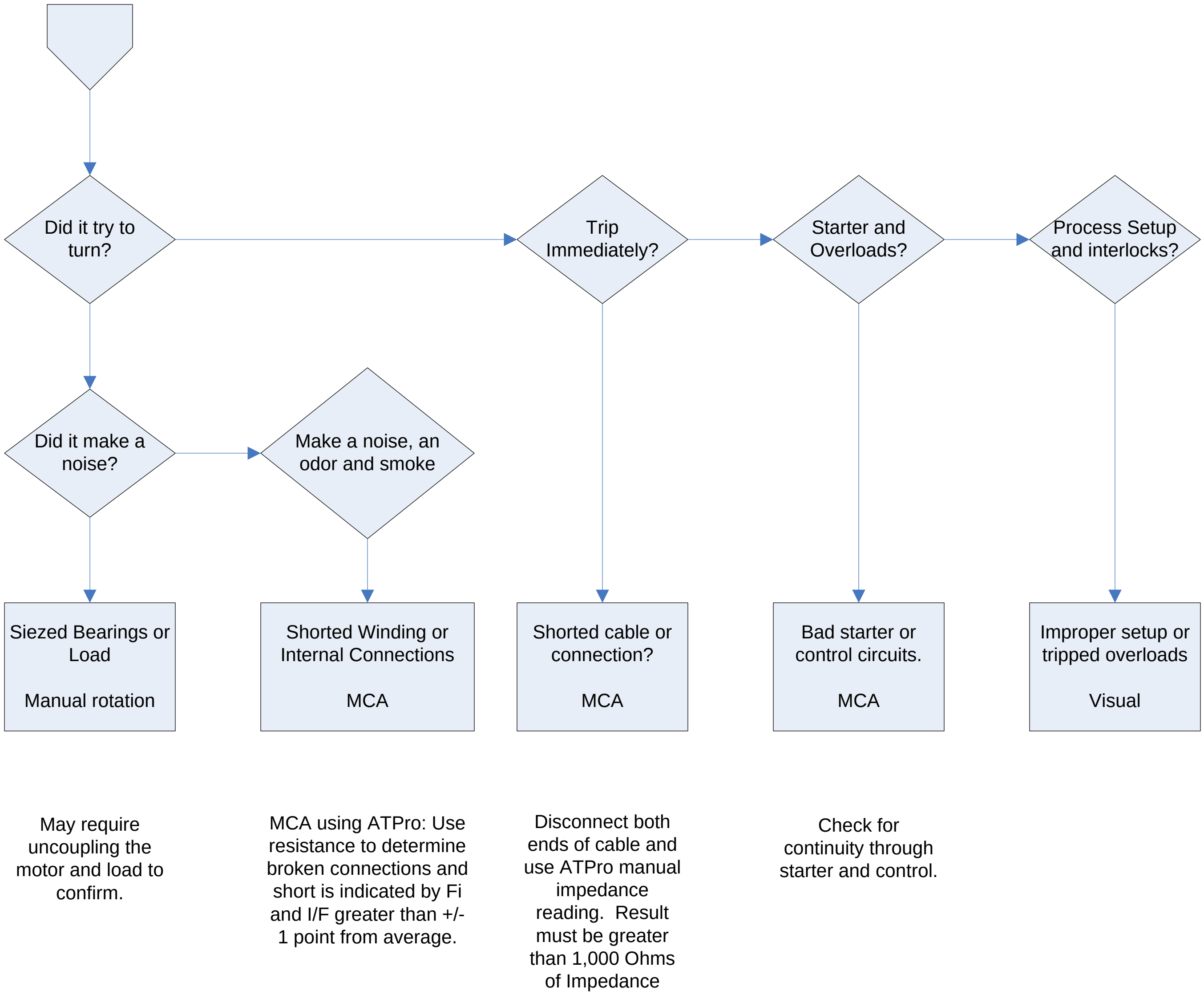
Sound-Bourne Ultrasonics may help pinpoint the source of noise.

Bad bearings will make a hiss or rumble with ultrasonics.

MCA test results greater than +/- 1 point Fi or I/F using ATPro will indicate a short.

Insulation resistance below 5 MegOhms on less than 1,000 volt motors and below 100 MegOhms on motors over 1,000 volts is considered poor condition.

NOTE: Insulation resistance will not detect winding shorts. MCA testing includes insulation resistance testing.



Did it try to turn?
Trip Immediately?
Starter and Overloads?
Process Setup and interlocks?
Did it make a noise?
Make a noise, an odor and smoke
Siezed Bearings or Load
Manual rotation
Shorted Winding or Internal Connections
MCA
Shorted cable or connection?
MCA
Bad starter or control circuits.
MCA
Improper setup or tripped overloads
Visual
May require uncoupling the motor and load to confirm.
MCA using ATPro: Use resistance to determine broken connections and short is indicated by Fi and I/F greater than +/- 1 point from average.
Disconnect both ends of cable and use ATPro manual impedance reading. Result must be greater than 1,000 Ohms of Impedance
Check for continuity through starter and control.

Attachment 2: 5-Why Analysis Best Practice

Root-Cause-Analysis (RCA) Best Practice

Best Practice

If a failure event that impacts safety/regulatory, production, expensive equipment, or repetitive failures (more than once per year) of any value, or repetitive failures occur, a Root-Cause-Analysis (RCA) must be performed corrective actions implemented where economically or safetly reasonable.

Procedure

1. Failure occurs. Reference the RCA Worksheets. Continue the RCA process if:
   1.1. The failure is a repetitive failure;
   1.2. It is a safety or regulatory related failure;
   1.3. The failure interrupts production;
   1.4. Or, the failure incurrs significant cost
2. Containment Action: Containment action is the first step in the process. These are actions taken immediately following awareness of the event to stop the event from occurring and preventing or minimizing impact from the failure. This is referred to as the Immediate Corrective Action.
   2.1. Stop the event from occurring
   2.2. Once the event has been stopped, determine what and how much damage has been done
   2.3. Contain effects of the damage
   2.4. Notify affected personnel and departments
3. Define the problem: Clearly define the actual problem. The steps involved in problem definition are:
   3.1. Forming a team
   3.2. Identifying the problem
   3.3. Gathering and verifying data
4. Forming the team: Assemble a team of stakeholders in the problem. Include personnel who know the process, have the data and experience, and the ones that will have to implement the corrective actions. This may include Maintenance, Management, Operations, Safety, Training, Vendors, etc. Without the full buy-in and support of the stakeholders, long-term solutions are unlikely. All members must be able to contribute information, technical expertise, management support, advice or facilitiation. In larger issues, the team may be dynamic, with members changing as expertise is required.
   4.1. It is acceptable to determine the need for outside RCA assistance or facilitation, where cost effective.
5. Identifying the problem(s): In order to provide a valid corrective action, the problem must be clearly and appropriately defined. Frequently, the failure identified is not really the problem, but the symptom of the problem.
   5.1. What is the scope of the problem?
   5.2. How many problems are involved?
   5.3. What is affected by the problem(s)?
   5.4. What is the impact on the plant/facility?
   5.5. How often does the problem occur?

5.6. Once defined, the problem must be stated in simple terms. The event question must be short, simple, concise, focused on one problem and starts with ‘Why?’ It must not tell what caused the event, instruct what to do next, or explain the event.

6. Gather and verify data: When the problem is identified, it is time to begin collecting data. The data must be factual and data may have to be obtained several times during the process. Initial data gathering starts at the scene and must be obtained immediately. Take note of who was present, what is in place, when the event occurred and where the event happened. Types of data to collect include:
   - 6.1. Location: The site, building, facility, department, field, equipment or machine where the event took place.
   - 6.2. Names of Personnel: Personnel, visitors, contractors, etc.
   - 6.3. Date and time of event
   - 6.4. Specifications: What are the requirements?
   - 6.5. Operational Conditions: Start-up, shutdown, normal operations or other
   - 6.6. Environmental Conditions: Noise levels, visual distractions, lighting, temperature, humidity, weather, etc.
   - 6.7. Communications: Verbal or written, what orders or procedures were being followed?
   - 6.8. Sequence of Events: In what order did things take place?
   - 6.9. Equipment: What was being operated?
   - 6.10. Physical Evidence: Damaged equipment or parts, medical reports.
   - 6.11. Recent Changes: In personnel, equipment or procedures.
   - 6.12. Training: Classroom, OJT, none
   - 6.13. Other Events: Has there been other similar occurrences?
   - 6.14. Ensure that gathered data is correct and complete.

7. Analysis: When the problem is identified, and preliminary data has been gathered and verified, the analysis can begin. The procedure recommended by this best practice is referred to as the 5-Why process. It is named this because it normally takes 5 ‘why’ questions to get to the logical end of the cause chain. Not all cause chains will be complete in 5 whys, some will take 7 and others will reach their end in 3. The answers to the why questions form a chain of causes leading to the root cause. The answer to the first Why is the direct cause. The logical end of each chain (problems can branch out) is a root cause and the causes in between the direct cause and the root cause are contributing causes. There may be no contributing causes, but there is always a root cause – the best and logical place to stop as identified by the team. This place is where continuing to ask why adds no value to prevention or recurrence, reduction or cost savings.
   - 7.1. For example, if the event is:
     - 7.1.1. A procedure does not exist or needs revision – why doesn’t it exist (and stating that someone didn’t know is not acceptable) – What was the systematic reason for the lack of knowledge?
     - 7.1.2. Operator (or maintenance) not trained and/or qualified – Why was the operator not trained (stating that training was not conducted only restates the finding) and why is an unqualified operator performing work?
   - 7.2. There may be multiple branches and multiple root causes. Each branch will need to be analyzed and worked down to its logical end. Many of these identified causes, may not directly relate to the problem at hand, but point to issues that still need to be addressed to prevent future problems.

8. Impact: Review the original problem statement and ensure that it is correct with the additional information that is know at this stage in the process.
9. Solution: These are the solutions to the root cause, of which some may have been addressed as part of the containment action (step 2).
   9.1. Preventive Corrective Action: These are the actions taken to prevent recurrence. They focus on breaking the cause chain completely by fixing the contributing cause and the root cause.
   9.2. Preventive Action: Is a series of actions that positively change or modify system performance. It focuses on the systemic change and places in the process where the potential for failure exists. Preventive Action does not focus on individual mistakes or personnel shortcomings. In determining solutions, consider the following:
      9.2.1. Feasibility: The solutions need to be feasible within the plant/facility's resources and schedule;
      9.2.2. Effectiveness: The solutions need to have a reasonable probability of effectively solving the problem;
      9.2.3. Budget: Solution costs must be within the budget of the plant/facility and also appropriate for the extent of the problem;
      9.2.4. Employee Involvement: The departments and personnel affected by the problem need to be involved in creating the solution(s);
      9.2.5. Focus on Systems: The solution(s) should be focused on systemic issues. Operators do make mistakes, but that is not usually the root cause of the problem.
      9.2.6. Contingency Planning: All solutions are developed with a certain expectation of success. Critical elements of the solution should have contingency plans available to prevent failure of the entire solution.
   9.3. Guidelines for solution development:
      9.3.1. There may not be an absolute correct solution.
      9.3.2. Do not rush to a solution and be willing to think about alternatives over a reasonable period of time.
      9.3.3. Always be willing to challenge the root cause as a symptom of a larger problem.
      9.3.4. Never accept an assumption as fact without significant data.
      9.3.5. Does the corrective action reduce the risk of the event recurring to a reasonable level? Are there any adverse effects for the application of the corrective action?
   9.4. If a corrective action is deemed unacceptable, note the reasons for rejecting the action.
   9.5. Set responsibility for accomplishement and defined timelines.
10. Assessment: The assessment portion of the RCA includes both follow up and assessment of the corrective actions, if any.
   10.1. Schedule Follow-Up date.
   10.2. Follow-Up: Corrective actions must be assigned to someone who is responsible to assure that the actions are implemented as stated. When verifying implementation, it is important to take things literally. Was everything accomplished as you stated in the report? Where the tasks accomplished per the established timeline?
   10.3. Assessment: Once the action has been implemented, the actions must be assessed to determine if they are effective. In order to determine effectiveness, the criteria must be defined by which effectiveness is measured and what is acceptable. Assessing the effectiveness of actions taken will be a significant step in reducing non-sustaining corrective action.

11. Complete RCA: Close the RCA if it is determined effective, or return to the cause chain to review corrective actions taken and if the root cause requires more definition.
12. Record and Archive findings.

5-Why Analysis Worksheet

Supervisor:__________________________ Date of Event:_______________

Equipment:_____________________________ Time of Event:_______________

Type(s) of Event(s): *(Note: You may perform 5-Why on each of the following issues)*

____ Maintenance ____ Training ____ Supplies ____ Meeting

____ Material Flow ____ Part Availability____ Leadership ____ Equipment Failure

Priority Ranking:

____ One-Time Issue ____ Repetitive Failure ____ Safety/Regulatory

____ Operations ____ Equipment Cost Other: _____________________

Containment:

Containment Action: ____

____

Downtime (in minutes): ______ x Per Minute Cost: $_______ = Loss: $________________

Team Members (name, affiliation, phone, email):

Investigation (add paper as appropriate):

Problem Definition (State as Simply as Possible)

5-Why Analysis: *(Add sheets as necessary for each fault chain event – Type of Event)*

Why? ____

Answer: ____

Why? ____

Answer: ____

Why? ____

Answer: ____

Why? ____

Answer: ____

Why? ____

Answer: ____

Root Causes:

____

____

Counter Measure (Preventive Actions):

____

____

Responsibility: ________________________________ Deadline: ________________

Verification:

____ No recurrence in _____ months Signed: ______________________________

____ Close-Out RCA ____ Continue RCA ____ No Further Action (File) RCA Hours: ______

RCA Flow Chart