Chapter 8 Troubleshooting Mechatronics Systems

Section 8.1 Key Terms

Critical thinking is the analysis of information gathered from direct observation and used as a guide for action and belief. ***Current Conditions* –** the system and equipment conditions at the time troubleshooting begins ***Equipment train*** – a grouping of mechanical, electrical, and control equipment designed to serve a common function in a larger process ***Failure identification*** – the accurate description of an operational failure ***Functional inventory*** – a complete listing of the primary and secondary services performed by the equipment trains in the larger process ***Failure mode* –** the physical or functional manifestation of a failure ***Functional failure* –** the loss of one or more primary services provided by equipment and systems ***Initial Conditions* -** the system and equipment conditions just prior to the time of failure.	***Isolation and elimination*** is the simplification of functional failures to a manageable scope ***Problem statement*** – a grammatically correct complete sentence, or sentences that summarize an operational failure ***Root cause failure analysis*** (RCFA) – the determination of the primary reasons for functional failures ***Solutions analysis*** – the association of a failed isolation test with the functional failure. ***Symptoms* –** the physical signs that indicate trouble ***System functions*** – the primary and secondary services performed by groupings of equipment trains ***SCADA*** – supervisory control and data acquisition Consists of networked PLC's, data server, operator, and engineering workstations, and a data historian server. ***Troubleshooting*** – the identification, isolation and elimination of functional failures

Section 8.2 Chapter Outline

Failure Identification
Hardware Inventory
Failure Mode Analysis
Isolation and Elimination
Solutions Analysis
Failure Mode and Effects Analysis

Section 8.3 Chapter Overview

Troubleshooting is the identification, isolation, and elimination of functional failures. Mechatronics systems utilize computers and sensors to control complex mechanical and electrical labor saving devices. Mechatronics systems apply every engineering discipline, including statics, dynamics, thermodynamics, chemistry, electrical theory, digital data communication, and computer programming. This broad range of applied engineering leads to dramatic increases in the number and type of potential failures in Mechatronics systems. Failures can range from simple to enormously complex. Yet even with this level of complexity, Mechatronics systems provide reliable, and relatively trouble-free control of automation systems. The complexity of some Mechatronics systems may demand a more structured approach to equipment troubleshooting, repair, and replacement decisions.

Troubleshooting is the culmination of the Mechatronics body of knowledge. Master troubleshooting and you have mastered Mechatronics!

For the Mechatronics Technician, troubleshooting is a critical thinking skill encompassing both science and art. Troubleshooting requires the systematic application of inductive and deductive reasoning; the careful observation and recording of data, experiences, cause, and effect; the ability to correlate seemingly unrelated data. Poor data quality often turns troubleshooting into an art instead of a science; playing the right hunches, creating new test procedures; verifying data and information. The goal of troubleshooting is to produce meaningful information to base repair / replace decisions. Once the troubleshooting sequence finds a root cause of the failure, a financial analysis of repair versus replace decisions leads to the final solution.

Even with a structured approach, troubleshooting refuses to fit in a bottle, to adhere to strict formulas, or to follow strict rules of engagement. Every troubleshooting experience is different. It requires the systematic application of the scientific technique, but often advances only through experience, intuition, hunches, and luck. We know that experience has great value in shaping troubleshooting successes, with some technicians quickly able to distill complex failures into simple and elegant solutions. We know the more troubleshooting you do, the more success you will have. So get out there and start troubleshooting Mechatronics systems!

This chapter provides a foundation for building troubleshooting experience as a Mechatronics Technician. That foundation includes an in-depth treatment of failure identification, the creation and use of a functional inventory, failure mode analysis, the isolation and elimination of functional failures, and finally a look root cause failure analysis, an in-depth analysis of the fundamental causes of a failure. Troubleshooting is the culmination of the Mechatronics body of knowledge. Master troubleshooting and you have mastered Mechatronics!

Section 8.4 Learning Objectives

After completing this chapter, you will be able to:

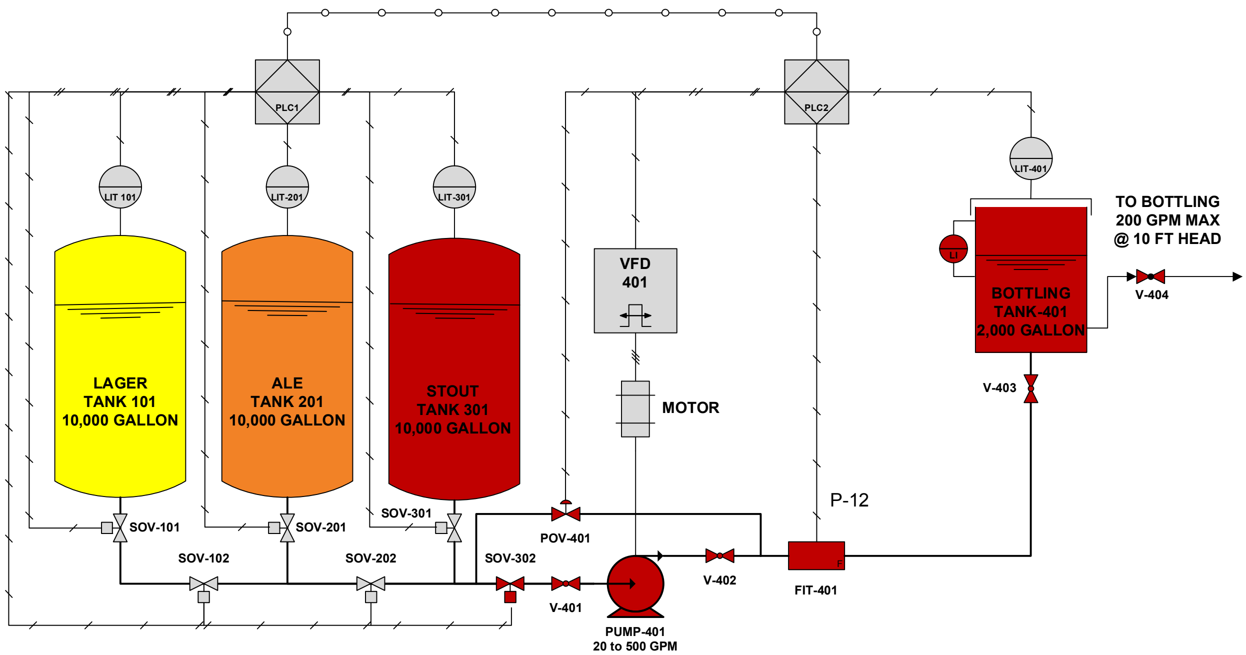
- Define
    - Failure identification
    - Functional inventory
    - Failure mode analysis
    - Isolation & elimination
    - Root cause failure analysis
- List
    - System functions
    - Experiences and observations
    - Functional failures
    - Equipment failure modes
    - Common test methods
- Compare
    - Failure criticality
    - Equipment complexity
    - Failure mode complexity
    - Test complexity
- Apply
    - Failure identification
    - Functional inventory
    - Failure mode analysis
    - Isolation & elimination
    - Root cause failure analysis

Section 8.5 Example Mechatronics System

Hands-on experience is the best way to learn troubleshooting techniques. The laboratory exercises in your Mechatronics program will provide plenty of opportunities for that experience.

For the purposes of this chapter, we will utilize the system diagram and control narrative below to illustrate troubleshooting techniques. The illustration and control narrative describes a tank and pumping system used to route beer to a bottling line at a sufficient rate and pressure to maintain bottle fill levels and line operating rates.

Bottling Day Tank Piping and Instrument Diagram



8-1Piping and Instrument Diagram for Bottling Line Supply System

Bottling Day Tank Control Narrative

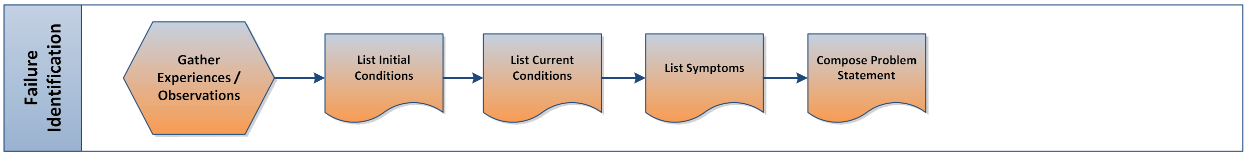
Bottling day tank 401, located on the second floor of the brewery, provides beer to the bottling line at sufficient head pressure to maintain bottle fill levels within acceptable tolerances. The system seeks to control head pressure at 10 feet in Tank-401 as monitored by level indicating transmitter 401 (LIT-401,) an ultrasonic level transducer that outputs a 4 to 20 milliamp signal proportional 0 to 15 feet of level. LIT-401 also provides HI and LO level alarms (11 feet rising and 9 feet falling) that notify operators of abnormal tank level conditions through the PLC / SCADA interface. HIHI and LOLO (12 feet rising and 8 feet falling) levels will trip the bottling line off and shutdown PUMP-401.

Primary brew tanks 101, 202, and 301 reside in the brewery cellar, and beer moves from those tanks to TANK-401 through beer transfer PUMP-401. PLC 2 controls POV-401, a pneumatically operated modulating valve that bypasses PUMP-401 to maintain a minimum pump flow of 50 GPM, protecting the pump (and the beer) from low flow overheating. Operators can select the online primary beer tank remotely through the PLC / SCADA interface by selecting solenoid operated valves SOV-101/102, 201/202, or 301/302. A variable frequency drive controlled by PLC-2 controls PUMP-401 speed and flow to meet the demand taken from TANK-401 by the bottling line. LIT-401 provides a tank level signal to PLC-2 with additional feedback provided by flow indicating transmitter FIT-401.

Level indicating transmitter LIT-101, 201, or 301 provide feedback to PLC-1 on primary tank levels. PLC-1 and PLC-2 communicate via a serial data connection to sense low level in the online primary beer tank. PLC 2 will shutdown VFD-401 on low primary tank level, thus protecting pump 401 from low flow cavitations.

Section 8.6 Failure Identification

Failure identification is the accurate description of an operational failure. This first step in the troubleshooting sequence sets the stage for all that follows. This section describes a formal sequence (Figure 8.1) that leads to accurate failure identification.



8-2 Failure Identification Sequence

Experiences and Observations

The first step in the troubleshooting sequence is to gather the experiences and observations of the people with direct knowledge of the system function. These include operators, technicians, managers, supervisors, and engineers. Often the troubleshooting sequence begins and ends with this step, as experienced staff may have already seen the system failure and may know the solution. Typically, the Mechatronics Technician joins the troubleshooting effort only when there are no easy fixes available to the operations staff, and the troubleshooting sequence must dive to a deeper level of understanding.

Useful observations and experiences include;

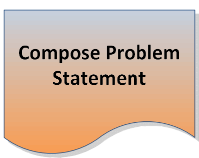
- **Initial Conditions -** the system and equipment conditions just prior to the time of failure.
  - What are the typical system operating conditions?
  - Was the system operating condition typical at the time of failure?
  - Were any repair, calibration, or modifications work recently completed?
- **Current Conditions** – the system and equipment conditions at the time troubleshooting begins
  - Are there any threats to life, property or the environment that result from the system failure?
  - What are the operating / production consequences of the failed equipment?
  - Is there any redundant equipment that can operate during repair work?
  - Are there any tripped breakers, damaged equipment, signs of system distress?
- **Symptoms** – the physical signs that indicate trouble
  - What events indicated the system failure?
  - What sights, sounds, smells, vibrations or abnormal conditions signaled the system failure?
  - What system function does not meet operating / production requirements?
  - Is the failure continuous or intermittent?
  - Did the failure occur suddenly or over an extended period?

For most troubleshooting sequences, the informal gathering of these observations and experiences provide sufficient evidence to support effective troubleshooting. Complex systems and equipment may demand a formal problem statement to focus of the troubleshooting effort.

Field Example 8-1 The Bottling Line 101 operator reports that the bottling day TANK-401 LO level alarm annunciated followed shortly by a LOLO bottling line trip. A Mechatronics Technician arrives at the scene to investigate the problem. After interviewing operations and engineering staff, she finds and records the following observations and experiences.

- **Initial Conditions**
  - Bottling Line 101 typically demands from 100 to 175 GPM flow rate, and was running at 175 GPM at the time of the trip.
  - The tank level trip began occurring intermittently several weeks ago after a flow efficiency test of PUMP-401 by engineering. The trip has increased in frequency since then.
- **Current Conditions**
  - There are no threats to life, property, or the environment because of the failure.
  - A bottling line failure results in five employees sent home and revenue losses of $2,000 per hour of downtime.
  - Bottling Line 201 and 301 are booked for other products. Bottling line 401 is down for overhaul.
  - There are no tripped breakers or signs of system distress.
- **Symptoms**
  - After bottling for 3-hours, the SCADA system annunciated TANK-401 LO level at 0915 hours followed by a LOLO trip at 0928 hours.
  - PUMP-401 exhibits no unusual conditions, noises, or vibrations prior to the trip. There are no noticeable leaks in the system.
  - Some days the system experiences no problems, and typically fails whether bottling lager, ale, or stout.

Problem Statement



Effective failure identification produces a ***problem statement***, composed of grammatically correct and complete sentences that summarize an operational failure. Without an accurate problem statement, the entire troubleshooting sequence could fail to target the actual cause of the failure. A well-constructed problem statement answers several key questions in support of further troubleshooting efforts.

- What were the operating conditions at the time of the failure?
- What system or equipment experienced or demonstrated the operational failure?
- When does the equipment or system fail, is the failure correlated to a specific time frame?
- How has the equipment or system failed to meet operational requirements?

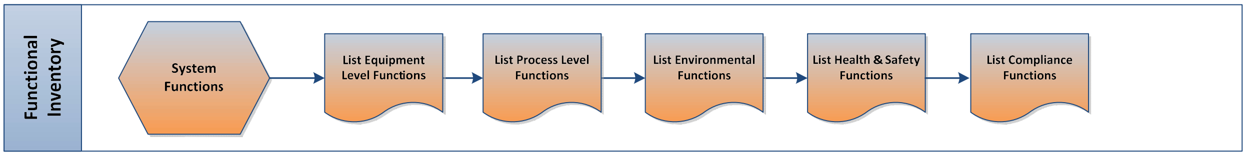
Field Example 8-2 After gathering information on conditions and symptoms, the Mechatronics technician records the answers to the what, when, and how questions. She then forms a grammatically correct complete sentence that will serve as the problem statement.

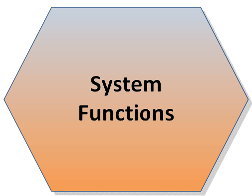
- What were the operating conditions at the time of the failure?
  - Bottling line 101 was pulling 175 GPM from Tank-401 at the time of the trip.
- What system or equipment demonstrated the operational failure?
  - Bottling system, TANK-401
- When does the equipment or system fail?
  - The bottling day tank level control system fails intermittently during bottling operations.
  - Engineering recently performed a flow test on POV-401, the beer pump recirculation valve.
- How has the equipment failed to meet operational requirements?
  - Tank-401 controls do not maintain tank levels at the design value (10 feet).

Problem Statement –Bottling day TANK-401 system intermittently fails to hold design levels during bottling operations demanding 175 GPM or greater flow rates.

Section 8.7 Functional Inventory

With a complete understanding of experiences and observations, and a well-formed problem statement, the next step in the troubleshooting sequence is to establish a clear understanding of the equipment and system functions. A ***functional inventory*** is a complete listing of the primary and secondary services performed by equipment trains in the larger process. The Mechatronics technician gains an understanding of system and equipment functions through experience, observation, and by consulting control narratives and operations and maintenance (O&M) manuals.





System functions are the primary and secondary services performed by the equipment train**.** An ***equipment train*** is a grouping of mechanical, electrical, and control equipment designed to serve a common function in a larger process. The Mechatronics Technician must establish a clear understanding of the expected equipment and system functions before attempting any further troubleshooting activities. The system functions are frequently obvious, but sometimes are subtle. Often operators and technicians misunderstand the design intent of an equipment train, believing that it performs one set of functions when the designers intended something different. Equipment and control system documents often contain functional descriptions of system that define the designers' intent for the equipment and system functions. These documents are the first and best resource for the Mechatronics Technician working to establish a comprehensive list of system and equipment functions.

Equipment and system functions fall into several categories.

- **Equipment Level Functions** – individual equipment provides low-level functions to a larger process system. For example, centrifugal pump 401 provides two functions to the bottling process 1) move beer from primary storage tanks to bottling day tank 401; 2) contain the beer within the pump body. VFD 401 provides a speed and flow control function to pump 401. LIT-401 provides tank level feedback to PLC2.
- **Process Level Functions** – the overall process provides high-level functions that directly support production. For example, the bottling day tank function sets up the bottling line for success by maintaining proper head pressure to the bottling line, assuring proper fill levels in each bottle.
- **Environmental Functions** – in addition to providing process functions, equipment and systems must also reduce the risk of environmental damage through the containment of harmful substances. An environmental function of the bottling day tank system is to protect the environment from beer spills into the neighboring watershed.
- **Health and Safety Functions** – a primary concern for any conscientious employer, many system designs include features that reduce risk and enhance employee safety. Pump 401 has a coupling guard over the motor / pump coupling to protect employees from hazardous levels of rotating energy, the motor leads are contained within a sealed junction box to prevent electrical shock.
- **Compliance Functions** – regulatory permits often require dedicated equipment and systems to comply with public health, safety, and environmental regulations. The overall bottling day tank process controls proper fill levels in bottles, and insures compliance with truth in labeling laws.

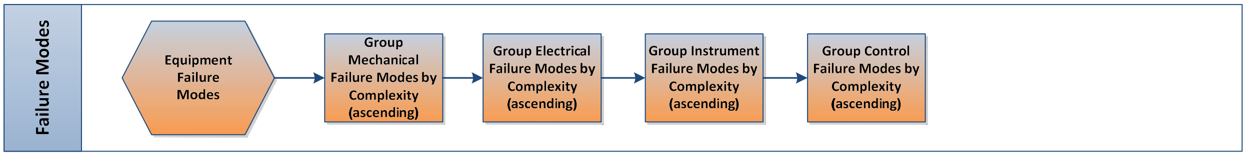
Field Example 8-2 Continuing her investigation, the Mechatronics technician quickly understands the bottling day tank system function by reading the control narrative documentation found inside the door of the PLC2 cabinet, in the plan-pocket. Primary system functions include;

- **Equipment Level Functions**
  - **Primary Storage Tanks –** store beer while maintaining brew temperature, pressure and overall quality, contain leaks and spills
  - **Pump-401 –** move beer from the primary storage tanks to the bottling day tank, contain beer within the pump body, prevent injury from pump / motor coupling contact
  - **POV-401 –** bypass beer around Pump-401 to maintain minimum flow rates through the pump, contain beer within the valve body, contain pneumatic pressure within the valve diaphragm
  - **FIT-401 –** provide a flow feedback signal to PLC2, contain beer within the meter body
  - **VFD-401 –** the primary control element provides speed control (thus flow control) for Pump-401, protect the motor from over current and under / over voltage conditions, protect operators from electrical shock
  - **Tank-401 -** store beer while maintaining brew temperature, and overall quality, provide precise head pressure to the bottling line, contain leaks and spills
  - **LIT-401 –** provide a Tank-401 level feedback signal to PLC2
  - **PLC-01** – execute main storage tank system control narratives and protect the environment, employees, equipment, and product from damage or injury
  - **PLC-02** – execute Tank-401 and Pump 401 control narratives and protect the environment, employees, equipment, and product from damage or injury
- **Process Level Functions**
  - Provide beer to the bottling line at sufficient head pressure to maintain bottle fill levels within acceptable tolerances
  - Control head pressure at 10 feet in Tank-401 as monitored by level indicating transmitter 401 (LIT-401)
  - Alarm and trip at high and low levels in TANKs-101, 201, 301
  - Alarm and trip at high and low levels in TANK-401
  - Maintain a minimum pump flow of 50 GPM, protecting the pump from low flow overheating and cavitations
  - Allow operators to select the online primary beer tank remotely through the PLC / SCADA interface by selecting solenoid operated valves SOV-101/102, 201/202, or 301/302
  - Control the flow and recirculation rates through PUMP-401 and thus the level in TANK-401
- **Environmental Functions**
  - Contain beer spills within the brewery to avoid contamination of the local water shed
- **Health and Safety Functions**
  - Preserve the sanitary conditions of the product, protect employees working on and around production equipment
- **Compliance Functions**
  - Comply with truth in labeling laws through accurate bottle fill levels, avoid environmental spills and releases

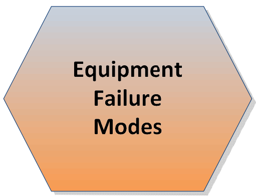
Section 8.8 Failure Modes

When you see hoof prints, look for horses, not zebras.

A ***failure mode*** is the physical or functional means of failure. A failure mode describes the way a failure occurs. All mechanical, electrical, instrument, and control equipment have multiple failure modes. We can often list common failure modes by equipment types. For example, pumps typically fail because of worn bearings, leaky seals, worn impellors, or eroded seal rings. Motors often fail from worn bearings, shorted stator windings, or broken rotor bars. Instruments fail from calibration drift, defective transducers, or faulty signal-conditioning circuits. Frequently the MechTech becomes familiar with failure modes by manufacturer, and seeks to replace troublesome equipment with more reliable components. However, reliability always comes at a cost. The prudent MechTech recognizes that those costs sometimes outweigh the value of increased reliability.



Equipment Failure Modes



A comprehensive listing of failure modes is a good investment for current and future troubleshooting activities. A written record of failure modes reduces oversights and adds value to all troubleshooting efforts. This listing should include *all likely failure modes* for the equipment and system. These listings of failure modes form the basis for advanced maintenance practices such as failure mode and effects analysis and reliability centered maintenance.

The complexity and number of potential failure modes in Mechatronics systems requires some structure to reduce them to a manageable scale. Grouping failure modes by equipment type; mechanical, electrical, instrumentation and controls helps the Mechatronics technician organize their troubleshooting efforts. ***Field Example 8-3*** lists many likely (but not all) failure modes by equipment type.

Field Example 8-3 Given the complexity of the bottling day tank system, our Mechatronics technician chooses to create a table of equipment and likely failure modes	
Mechanical Equipment	**Failure Modes**
Manual valves	
V-401, V-402	No flow - due to valve out of position (open, closed)
	Reduced flow - due to valve partially open
Automatic valves	
SOV-101, 102, 201,202, 301, 302, POV-401	No flow - due to valve out of position (open, closed)
	Reduced flow - due to valve partially open
Pumps	
PUMP-401	No flow - due to air lock, impellor worn/failed, bearings locked
	Reduced flow - leaks from mechanical seals, bowl seals, flange gaskets
Electrical Equipment	
Solenoids	
SOV-101, 102, 201,202, 301, 302, POV-401	Stuck open, coil failed
	Stuck closed, coli failed
	Stuck partially open or closed
Motors	
Motor-401	No rotation
	Motor power limited
Control Equipment	
FIT-401	Flow signal inaccurate
LIT-101, 201, 301, 401	Level signal inaccurate
VFD-401	Speed control failed
PLC-01, 02	Control logic failed

Section 8.9 Isolation and Elimnation

Isolation and elimination is the simplification of functional failures to a manageable scope. In complex automation control systems the number and variety of failure modes can be daunting to the Mechatronics technician. Effective troubleshooting requires the technician to isolate individual failure modes then test to see if that mode is responsible for the larger system failure.

When you see hoof prints, look for horses, not zebras.

The list of functional failures is the starting point for selecting isolation and elimination tests. Isolation and elimination tests should start with the simplest and progress to most complex test. ***The goal is to discover the root cause of the failure with the simplest possible test.*** Sorting the functional failures by complexity is the best opportunity for the Mechatronics technician to determine the complexity of investigative tests.

Field Example 8-4 utilizes a test complexity scale of 0 to 5, with 0 the least complex and 5 the most complex test. Failure modes are ranked according to test complexity according to the following scale.

- **0 – Tactile** – list equipment and system conditions using the human senses of sight, hearing, taste, smell, touch, feel. Transducers and sensors, infrared cameras, vibration analyzers, and ultrasonic detectors may enhance these senses.
- **1 – Simulation** – recreate operating conditions on duplicate or virtual systems. Often redundant systems can reproduce the conditions leading to a functional failure. Many sophisticated control systems allow "what-if" virtual simulations of process conditions and responses.
- **2 – Investigative** – perform wire checks, check torque values, verify insulation integrity, take voltage checks, perform calibration checks. These efforts require a larger investment in time and equipment, and can sometimes unintentionally fix or worsen the conditions that initially lead to the failure.
- **3 – Functional** – restart the failed equipment / process to capture operational data related to the failure mode. Any potential threat to safety, the environment and property is a prime consideration in deciding whether to conduct functional tests.
- **4 – Adjustments** – examples include changes to control set-points including control logic, closed loop gain values, protective device settings, mechanical alignment
- **5 – Intrusive Testing** – electrical/mechanical disassembly, component and equipment level replacements

Field Example 8-4 Isolation & elimination is complex and requires soritng by test complexity. In this example test methods are suggested and ranked by complexity

Mechanical Equipment	Failure Modes	Test Type	Test Complexity	Test Comments
Manual valves				
V-401, V-402	No flow - due to valve out of position (open, closed)	Tactile	0	Visually inspect valve positions
	Reduced flow - due to valve partially open	Tactile	0	Visually inspect valve positions
		Intrusive	5	Disassemble valve to inspect seat
Automatic valves				
SOV-101, 102, 201,202, 301, 302, POV-401	No flow - due to valve out of position (open, closed)	Tactile	0	Visually inspect valve positions and local controls
	Reduced flow - due to valve partially open	Tactile	0	Visually inspect valve positions and local controls
		Functional	3	Force valve driver to verify stroke
Pumps				
PUMP-401	No flow - due to air lock, impellor w orn/failed, bearings locked	Tactile	0	Visually inspect discharge pressure gage, FIT-401 output
	Reduced flow - leaks from mechanical seals, bow l seals, flange gaskets	Tactile	0	Visually inspect pump seals & flanges for leaks
		Intrusive	5	Inspect pump shaft rotation - separate motor/pump coupling and turn shaft by hand
		Intrusive	5	Disassemble pump for impellor inspection, replace seals, change bearings
Electrical Equipment				
Solenoids				
SOV-101, 102, 201,202, 301, 302, POV-401	Stuck open	Investigative	2	Check solenoid voltages
	Stuck closed	Investigative	2	Check solenoid voltages
	Stuck open or closed	Functional	3	Force the solenoid relay to verify proper function
Motors				
Motor-401	No rotation	Tactile	0	Check motor breaker and overload for trips
		Investigative	2	Measure running current, compare to historical values
	Motor pow er limited	Intrusive	5	Inspect motor shaft rotation - separate motor/pump coupling and turn shaft by hand
Control Equipment				
FIT-401	Flow signal inaccurate	Investigative	2	Perform flow calibration test of analog output signal
LIT-101, 201, 301, 401	Level signal inaccurate	Investigative	2	Perform level calibration test of analog output signal
VFD-401	Speed control failed	Tactile	0	Inspect VFD controls for trip indications or error messages
		Investigative	2	Verify analog input signal from PLC, perform range calibration
		Functional	3	Place VFD in manual and ramp through speed range
		Intrusive	5	Replace silicon controlled rectifiers
PLC-01, 02	Control logic failed	Tactile	0	Check PLC pow er LED
		Simulation	1	Check control logic in redundant head tank system
		Investigative	3	Review ladder logic for errors
		Investigative	3	Measure PLC pow er supply voltage
		Intrusive	5	Run PLC test program

In this example, the Mechatronics Technician approaches testing by prioritizing the simplest test on the simplest equipment. In the beer transfer process illustrated a tactile (visual) inspection of the manual valves is the quickest and easiest test of all those listed in Field Example 8-4.

Solutions Analysis

Solutions analysis is the association of a failed isolation test with the functional failure. The Mechatronics Technician must establish a cause-effect relationship between the test result and the failure. Where there is no cause-effect relationship between the two, that equipment may be eliminated as the root cause of the functional failure. In complex systems, testing may reveal equipment failures that are not related to the functional failure being examined. Another test is selected and performed, with the results compared to the failure again. This iterative process continues until a clear cause-effect relationship is found.

After performing a quick visual inspection of the manual valves surrounding Pump-401, the Mechatronics Technician observes that valve V-402 is throttled to approximately 50% of full travel. The technician talks with plant operations about the normal operating position of this pump discharge valve and learns that the valve is typically operated at 100% stroke. The operator speculates that the valve may have been left out of position after the engineering department performed a flow test on recirculation control valve POV-401 several weeks earlier. A clear cause-effect relationship exists between the throttled valve and the failure of the system at high flow rates (<175 GPM). The throttled valve would restrict the flow of beer to Bottling Tank-401.

The technician makes arrangements with operations to restore the valve to 100% stroke and to operate the beer transfer and the downstream bottling line at > 175 GPM. The test is a success, with the Tank-401 level maintained at proper level throughout the 2-hour functional test of the system. The Mechatronics Technician is declared the Hero of the Day, awarded a case of lager and given the rest of the day off with full pay.

Section 8.10 Root Cause Failure Analysis

Root cause failure analysis (RCFA) is the determination of the primary reasons for functional failures. It is used to eliminate the underlying cause of a failure, rather than the treatment of the symptoms of the failure. RCFA is an advanced maintenance technique used in many industries where complex failures can lead to threats to life, the environment and property. We will address RCFA in detail in a future chapter. In our beer process, RCFA leads to some simple changes in procedures to greatly reduce the possibility of this particular functional failure.

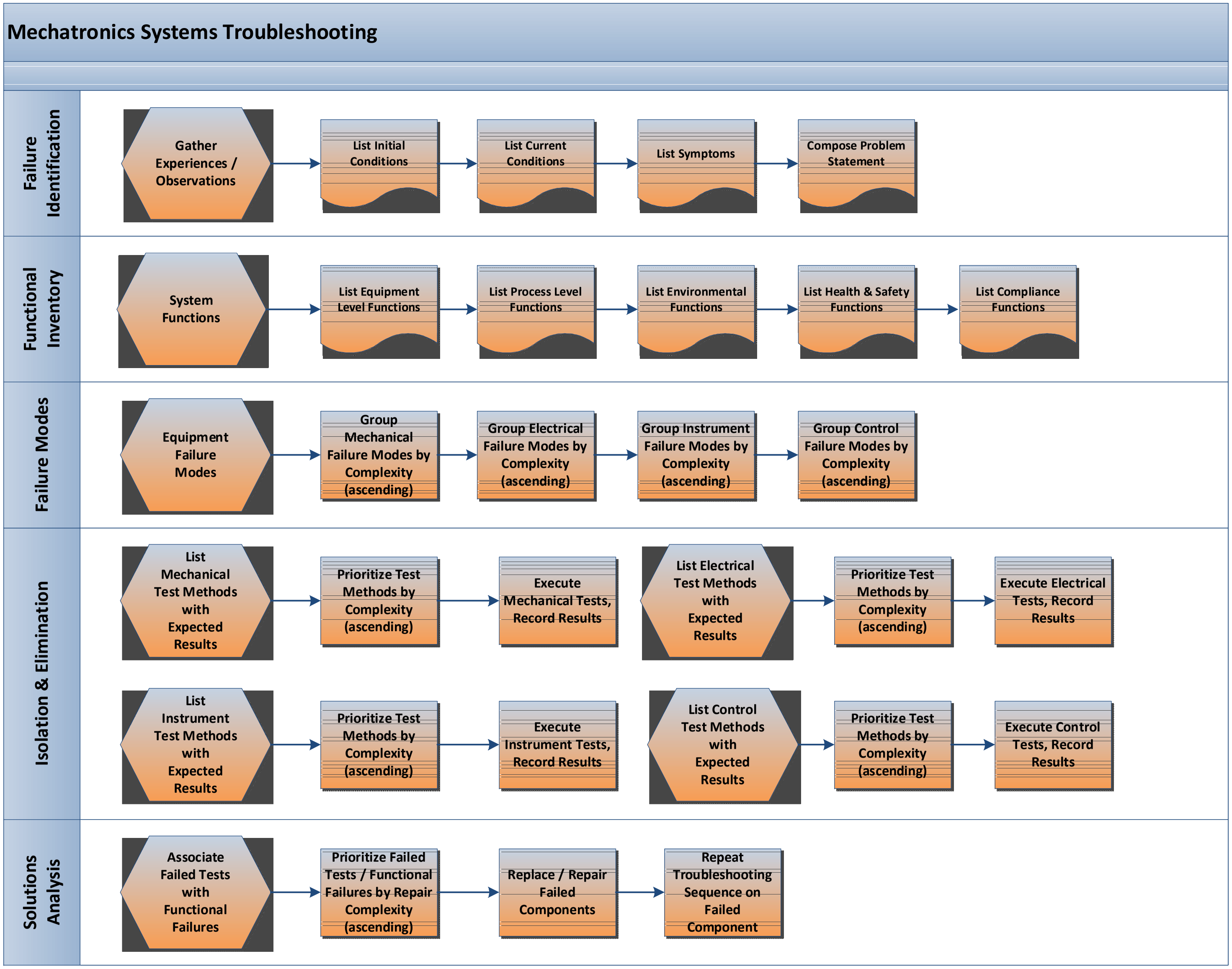
The Mechatronics Technician later conducts an informal investigation following up on the lead provided by operations; valve V-402 was left out of position after engineering performed a flow test on POV-401. Engineering revealed that they did not utilize a written procedure describing the setup and restoration of the system for the flow test. This informal and cordial conversation resulted in an assignment to the engineer that conducted the test. He was assigned to write a procedure that covered setup and restoration of the system for future flow tests.

Section 8.11 Conclusions

The complexity of Mechatronics systems requires the Mechatronics Technician to posses strong troubleshooting skills. Troubleshooting is form of critical thinking, another skill critical to success as a Mechatronics Technician. ***Critical thinking*** is the analysis of information gathered from direct observation and used as a guide for action and belief. Master troubleshooting and critical thinking, and you will find success as a Mechatronics Technician.

The troubleshooting procedures described in this chapter are a formal approach to understanding the thought processes that lead to effective troubleshooting. These procedures are best applied to complex and critical processes typical of Mechatronics systems. In reality, most troubleshooting occurs on the fly, without the need for written failure identification, functional inventories, isolation test priorities, and failure analysis. We tend to perform these steps in our minds so fast that we are unaware we are following any procedure.

Troubleshooting is as much art as science. It requires intuition as well as knowledge and analysis. The more troubleshooting experience we gain, the better we are at it. Yet even the simplest problems can elude even the most experienced troubleshooters. Without doubt the more troubleshooting we do, the better we are. So get out there and start troubleshooting Mechatronics systems!


Mechatronics Systems Troubleshooting
Failure Identification
Gather Experiences / Observations
List Initial Conditions
List Current Conditions
List Symptoms
Compose Problem Statement
Functional Inventory
System Functions
List Equipment Level Functions
List Process Level Functions
List Environmental Functions
List Health & Safety Functions
List Compliance Functions
Failure Modes
Equipment Failure Modes
Group Mechanical Failure Modes by Complexity (ascending)
Group Electrical Failure Modes by Complexity (ascending)
Group Instrument Failure Modes by Complexity (ascending)
Group Control Failure Modes by Complexity (ascending)
Isolation & Elimination
List Mechanical Test Methods with Expected Results
Prioritize Test Methods by Complexity (ascending)
Execute Mechanical Tests, Record Results
List Electrical Test Methods with Expected Results
Prioritize Test Methods by Complexity (ascending)
Execute Electrical Tests, Record Results
List Instrument Test Methods with Expected Results
Prioritize Test Methods by Complexity (ascending)
Execute Instrument Tests, Record Results
List Control Test Methods with Expected Results
Prioritize Test Methods by Complexity (ascending)
Execute Control Tests, Record Results
Solutions Analysis
Associate Failed Tests with Functional Failures
Prioritize Failed Tests / Functional Failures by Repair Complexity (ascending)
Replace / Repair Failed Components
Repeat Troubleshooting Sequence on Failed Component

