Installation and Start-Up Consideration for Medium Voltage Motors and Pumps

Steve Marrano, P.E.
Manager, Electrical Engineering
Pennsylvania Licensed Operator
Generalized Work Breakdown Structure for Setting/Installing Pump

Start → Get approved shop drawings equipment → Contractor reviews shop drawings equipment → Start Process Control Configuration

Start Mechanical Configuration

Start Electrical Configuration
Plant Start Up Path From Operations Perspective

1. Start
2. Confirm Desired Pressure
   - Check of System Curve vs Current Pressure Conditions
   - Check of Plant Suction and Discharge Piping
3. Confirm Desired Flow
   - Confirm Means of Setting Flow Set Point
   - Check Flow Balance
4. Start Pump
   - VFD From Local Controls OR From SCADA System
   - Constant Speed
   - Instantaneous 100% Flow
5. Verify Pump Performance
6. Check Different Combination of Pumps

**XX – Where multiple pumps are used in tandem with the pump we are starting**

Check Chemical Feed vs. Flow
Check or Flow Disturbances (e.g., Rain Events, Leaves, etc.)
Check Raw Water vs Send Out
Pump Curves

Used to Develop Conditions of Service

Performance Monitoring During Start-Up

Horse Power
Flow
Pressure
Speed

Used to Develop Operations Philosophy

Pump Mechanical Drawings

Suction and Discharge Pipe Arrange
Suction and Discharge Valves
Structural Requirements (Base Plate, Grout, etc.)
Pump Support Systems (Seals/ Packing/ Bearing/ Non Potable Water/ Lubrication

Process Support Systems that Must be Checked
Valves to Be Open/Close on Start up/Shutdown
Means of Starting/Stopping Mechanical Drive (Typically a Motor)

Equipment Checks

Vibration Limits, Temperature Limits
Alignment Limits
Means of Checking Coupling Between Pump and Driver

Check of Vibration vs Speed
Check of Imbalance vs Speed
Check of Temp on Bearings/Packing/Seals

Basic Input

Data Set (typ.)

Combination of Pumps Used
Affects on Treatment/Storage

Flow or Head vs Amps

Flow vs Speed

Head vs Flow

Check of Vibration vs Speed

Check of Imbalance vs Speed

Check of Temp on Bearings/Packing/Seals

Basic Output to Next (typ.)

AQUA
Electrical Documentation Flow

Basic Input

- Electrical Single Line Diagrams
  - Show How Loads Are Connected to Source
  - Motor Starting Method
  - Show Overcurrent Protection and Operation
  - Show Controls Connected to Power Components

- Electrical Control Schematics
  - Interconnection to Fixed Devices (Switches, Transformers, etc.)
  - Hardwired Interlocks for Start Up/Shutdown
  - Interconnection to PLC or SCADA

- Functional Control Descriptions
  - Describe Interlocks Without PLC/SCADA
  - Describe Operations for PLC/SCADA
  - Describe Alarm Shut Downs

- Electrical Plans DWGs
  - Power
  - Process Control Wiring
  - Control Interconnecting Drawings
Process Control Documentation Flow

- P&IDS
  - Schematic Layout of Piping, Non Electrical Instruments, Valves
  - Layout of Pumps
  - Graphic Description of Field Based/Supervisory Based Controls
  - Display Inputs/Outputs to PLC/SCADA

- PLC/RTU Control Panel Drawings
  - Illustrate Inputs/Outputs
  - Illustrate How Devices Are Powered
  - Illustrate Communications Interface to Other Equipment

- Functional Control Descriptions
  - Describe Normal Operations
  - Describe any Abnormal Sequences
  - Describe Setpoint Control Where Used

- Field
- Supervisory Control
  - Field
- Flow
- Level
Parallel Operation of Pumps

For 2 pumps in parallel
Head (pressure) should not change but flow increases

For 2 pumps in parallel
We shift over on the system head curve
Electrical Configuration Process Flow Chart

1. Start Electrical Configuration
2. Run conduit from source to load for power
3. Run conduit from field devices to starter/VFD/RVSS
4. Review interconnecting wiring requirements from field to starter/VFD
5. Review interconnecting wiring requirements from starter/VFD to PLC
6. Pull power wiring/conduit
7. Pull control/signal wiring/conduit
8. Terminate power wiring
9. Terminate control wiring
10. Check power wiring phasing
11. Check point to point wiring for controls
12. Check control relays are functioning
13. Perform offline testing of drive
14. Start drive
15. Perform drive tuning
16. Perform infrared testing of motor
17. Run drive and check drive wave forms underload
18. Record values of current and voltage
19. End
Typical protection features for MV induction motor (≤1500 hp) controlled by fused starters
# Motor Protection: Typical Settings

<table>
<thead>
<tr>
<th>IEEE Device Number</th>
<th>Function/Purpose</th>
<th>CT/VT</th>
<th>Typical Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>Under voltage</td>
<td>...</td>
<td>UV dropout at 80% of nominal system voltage Times: 2-3s Set 80% of system voltage with the TD set to give a delay of 1-2 s for a voltage drop from normal to zero</td>
</tr>
<tr>
<td>46</td>
<td>Negative-sequence or current unbalance</td>
<td>Phase CT</td>
<td>Negative sequence setting in percent of motor rated full-load current - 8% alarm - 12-15% trip 58.5-Hz trip</td>
</tr>
<tr>
<td>49</td>
<td>Overload</td>
<td>Phase CT</td>
<td>105% for motors with SF₆-1.0 115% for motors with SF₆-1.15</td>
</tr>
<tr>
<td>49W</td>
<td>Winding overtemperature</td>
<td>NA</td>
<td>130°C alarm 135°C alarm</td>
</tr>
<tr>
<td>51S</td>
<td>Locked rotor or fail to accelerate</td>
<td>Phase CT</td>
<td>10-15% more than slowest normal start time</td>
</tr>
<tr>
<td>50</td>
<td>Phase overcurrent or short circuit</td>
<td>Phase CT</td>
<td>1.5 to 2.0 PU locked-rotor current</td>
</tr>
<tr>
<td>51G</td>
<td>Ground fault</td>
<td>50/5 or 100/5 C30</td>
<td>2-5% of the neutral resistor current rating: time delay of three to six cycles</td>
</tr>
</tbody>
</table>
The objective is allow some inrush current to accelerate the load from rest but not too much that large current will over heat the winding. If pump and motor are brought together have the vendor prove that the acceleration time from rest to full speed will not damage motor winding insulation with excessive thermal stress.
Typical Time Current Curve Plot

Three Phase Fault Current

Single Phase Fault Current

Full Load Current

Motor Starting Characteristic

Micro Processor Based Relay for Feeder to Motor

These settings are placed on log-log paper to check to ensure motor can run without nuisances tripping but it is protected from electrical faults.
Establish hardwired interlocks done without PLC or SCADA → Confirm inputs/outputs into/out of PLC or SCADA → Establish discrete interlocks into and out of PLC or SCADA

Establish continuous (analog) control into/out of PLC/SCADA → Define HMI interface into/out of PLC/SCADA → Perform on/off control without PLC or other equipment

Perform on/off control with PLC/SCADA → Perform setpoint control with PLC/SCADA (1 pump) → Perform setpoint control with PLC/SCADA (multiple pumps)

Check interlocks and alarms through PLC/SCADA → Check HMI interface matches field conditions → End
Start Up Procedure for VFD/RVSS

1. Ensure solution and discharge valves are open (local/manual by operator)
2. Open gate valve (gate valve is electrically operated) and is opened at a console
3. Check that water is available to solenoid valves and seals
   - Check that gate valve us on open limit switch
   - Solenoid valves should be closed on cone valve before start up

4. Issue pump call to run command
   - Select from console (local) or PLC/SCADA
   - Drive/RVSS input/output contactor open

5. Open solenoid to start gate valve open
   - VFD/RVSS runs

6. Check to ensure gate valve goes 100% open

7. If gate valve doesn’t reach 100% open limit switch shut pump down
   - E-Stop can shut pump off

8. Close limit switch from fast close solenoid valve on cone valve causes pump call to stop

Note: Most of the sequencing here is done with a Rovac control circuit interfaced to control relays
Cone Valve Solenoids

Cone Valve Over View
OPERATIONS
1. USER SETS WHETHER SHE WANTS VFD OR RVSS OPERATION AT STARTER
2. USER SELECTS WHETHER SHE WANTS CONTROL FROM CONSOLE (LOCAL MODE) VS PLC (AUTO MODE)
3. IF VFD IS USED USER MUST SELECT IF SHE WANTS SPEED CONTROL FROM
   (a) VFD AT STARTER
   (b) PUMP CONSOLE VIA THE SPEED POT ON CONSOLE AND PLACING VFD/PUMP CONSOLE/REMOTE SELECTOR SWITCH IN PUMP CONSOLE POSITION
   (c) PLC VIA PLC SOFTWARE (PRESSURE/FLOW PACING ALLOWED) BY PLACING VFD/PUMP CONSOLE/REMOTE IN REMOTE POSITION

PUMP CONTROL ROOM
ACTS AS A BRIDGE BETWEEN LOCAL CONTROL (CONSOLE OR PLC VIA AOA SEL. SW.)

START STOP SPEED
START STOP SPEED

PLC
SPEED START/STOP
PLC SPEED TO VFD
PLC START/STOP

DRIVE
SOLID STATE STARTER

OR

CONTROL POWER VFD OR SOLID STARTER SELECTOR SWITCH

OR

SPEED SELECTOR SWITCH VFD/PUMP CONSOLE/REMOTE

SEE NOTE 1

SEE NOTE 3
Mechanical Testing Flow

1. Check Piping Configuration
2. Check Packing or Seal Materials are Correct
3. Ensure Valves Can Be Operated to Fully Open or Fully Closed Position
4. Check That All Pressure Gages Are Installed and Have a Means of Isolation
5. Check on Seal Water or Non-Potable Water is Connected and Functioning

6. If Motor Has Anti Reverse Ratchet Remove
7. Ensure that Coupling Between Motor and Pump are Correctly Aligned and Secure
8. Bump Motor and Check Rotation
9. Place Reverse Ratchet Back on Motor
10. Ensure Suction and Discharge valves are in Correct Condition

11. Connect Impulse Resonance Test
12. Conduct Balance Test at Full Speed
13. If Variable Speed Conduct Vibration Test From Full Speed to Min Speed **
14. Perform Infrared Analysis Around Bearings and Circumference of Motor
15. Perform Infrared Analysis on Motor Blanch Conductors

Add Weights to Eliminate Heavy Spots as Needed

16. Collect Oil Samples for Wear Particle Analysis
17. Correlate and Check Instrument Readings with Motor Readings

RTD’s
Amps vs Flow
Flow vs Head
Input and Output Contactors and Control
Power Selector Switch

VFD and RTD Interface
Overall Mechanical Testing Plan

Testing Keynotes for Mechanical Testing Equipment Drawing MT-1

1. Contractor shall furnish the labor and materials for the following tests:
   a. Check of motor grounding conductor and bonding for 5 ohms to ground or less
   b. Check of phase conductors for proper current carrying conductor phase identification and proper phase rotation
   c. Proper labeling of the current carrying phase conductors
   d. Inspection of motor lubricant for presence of solids or moisture
   e. Inspection of site glass for proper fill of motor lubricant
   f. Inspection of motor to ensure that the motor rotates freely on bearing assembly with the motor uncoupled from the pump
   g. Inspection of space heater to ensure that proper operation is available
   h. Coordination with the motor manufacturer for upper and lower limits of vibration and the units used (mils or mm and whether peak or peak-to-peak)
   i. Torque testing on all connections made in the motor terminal box
   j. Confirm motor rotation before coupling the motor to the pump.

2. Contractor shall furnish materials and labor for the following tests:
   a. Polarization index test on motor windings in accordance with manufacturer’s recommendations for the maximum applied voltage to the winding.

3. Contractor shall coordinate with pump vendor for proper bolting and rotation of the coupling between the shaft on the motor and the pump.

4. Contractor shall furnish all labor and material to verify the alignment of the shaft.

5. Contractor shall furnish all labor and materials to verify the following:
   a. Inspect all components (nuts, bolts, etc.) for signs of scaling, rust or corrosion.
   b. Ensure bolts to pump base are treated with an anti-seize lubricant.
   c. Check pump leveling and proper insertion of anchor bolts to the pump sojolete.
   d. Check that grinding is in accordance with pump manufacturer’s recommendations.
   e. Adjust suction side valves to be fully opened prior to startup of the pump.
   f. Adjust discharge valve to be partially opened in accordance with the pump manufacturer’s recommendations.
   g. Proper amount of water run to packing
   h. Proper adjustment of packing
   i. Proper adjustment of air relief valves (where applicable)

6. Running tests: The contractor shall furnish the materials and labor for the following:
   a. Determination of resonant frequency via the use of impact testing.
   b. Verification of alignment using orbital plot analysis along the shaft between the motor and the pump.
   c. Measurements of vibration on the motor bearing in the horizontal, vertical, and axial directions in the following conditions:
      1. Motor uncoupled from the pump
      2. Motor coupled to the pump and running at full speed
      3. Motor coupled to the pump and running at speeds from 70% of full speed to 100% of full speed in increments of 14 Hz
      4. Motor coupled to the pump and running at speeds from 100% to 70% of full speed in increments of 14 Hz
   d. Perform infrared measurements on:
      1. Case of the inductor
      2. Case of the pump
      3. Inside the motor termination box
   e. Perform measurements of shaft voltage

Vibration Testing Requirements
1. Measurement points 1, 2, 5, 6 are in line with discharge piping
2. Measurement points 3, 4, 7 are taken 90° from discharge piping
3. Measurement point 8 is for measurement of imbalance

G:\telligent\Co-op\Previous Work & Project Resources\CAD Drawings\Upper Moreland Submersible Pump\Upper Moreland Booster\Upper Moreland Permit Set.dwg 3/26/2016 10:54:35 AM
Iso Vibration Limits

### Vibration Severity Per ISO 10816-1

<table>
<thead>
<tr>
<th>Machine Velocity Vel.</th>
<th>Class I Small Machines</th>
<th>Class II Medium Machines</th>
<th>Class III Large Rigid Foundation</th>
<th>Class IV Large Soft Foundation</th>
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<tbody>
<tr>
<td>in/s</td>
<td>mm/s</td>
<td>in/s</td>
<td>mm/s</td>
<td>in/s</td>
</tr>
<tr>
<td>0.01</td>
<td>0.28</td>
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<tr>
<td>0.70</td>
<td>18.00</td>
<td>1.10</td>
<td>28.00</td>
<td>1.77</td>
</tr>
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</table>

Use 0.2 inches second RMS As Acceptance Criteria

### Shaft Speed (RPM)

<table>
<thead>
<tr>
<th>Mounting</th>
<th>Drive</th>
<th>Category</th>
<th>Mounting</th>
<th>Drive</th>
<th>Category</th>
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<tr>
<td>Rigid Mounting</td>
<td>Rigid Drive</td>
<td>I</td>
<td>Rigid Mounting</td>
<td>Rigid Drive</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td>Flex Drive</td>
<td>II</td>
<td></td>
<td>Flex Drive</td>
<td>III</td>
</tr>
<tr>
<td>Flexible Mounting</td>
<td>Rigid Drive</td>
<td>II</td>
<td>Flexible Mounting</td>
<td>Rigid Drive</td>
<td>III</td>
</tr>
<tr>
<td></td>
<td>Flex Drive</td>
<td>III</td>
<td></td>
<td>Flex Drive</td>
<td>IV</td>
</tr>
</tbody>
</table>
Sample Vibration Spectra Taken on Bearing in Horizontal Plane
Vertical Turbine Pump and Motor
Simplified View of Shafts for Vertical Motor, Vertical Pump

- Vertical Motor
  - Top Bearing
  - Vertical Reading Here

- Vertical Pump
  - Bottom Bearing
  - Axial Reading Here
  - Coupling
  - Bear Inaccessible
  - Check that Coupling Spins Freely

Check Phase Displacement
If $\approx$ to or Close to 180°; Check for Bent Shaft
Heavy Spot needs to be counterbalanced with another weight

Where the weight is located and how much the counterbalance weight needs to be is worked out using vector analysis

Either single plane or 2 plane balancing can be used (beyond the scope of this presentation)
Basic Concept of Mechanical Resonance

- All mechanical parts have a frequency at which they will vibrate (such as a looseness, rotating unbalance)
- The time it takes for vibration to stop depends on dampening
- In reality a machine train will have, multiple natural frequencies
- Natural frequency can change depending upon
  A. Mass
  B. Stiffness

Adding More Mass

Bearing

Adding More Stiffness

Bearing

Tends to Lower Frequency eg.

Gives us Higher Frequency eg.
Critical Speed and Resonance

Critical Speed is analogous to pushing a child on a swing (a push will cause the swing to displace in one direction or another).

If the swing is pushed again, the swing can go higher. When we can see this behavior we have reached a point called resonance (maximum amplitude).

\[
\frac{1}{\text{Time}} = \text{Frequency}
\]

This is called critical frequency because we reach maximum amplitude.
VIBRATIONS AND BALANCE TESTING

• Vibration testing tells us about the health of the machine depending upon what measurements are taken (typically velocity or acceleration) and where they are taken. For the vertical turbine pump application, measurements were made at the top and bottom motor bearings.

• Order of Testing
  a. First test for natural frequencies using impact testing with the pump and motor coupled and supported from its structural attachments. You are checking to see if there are any points of resonance. If there is a point of resonance, this should be +/- 20% of the equipment running speed.
  b. Second, attach vibration sensors to allow accessible points on the machine (bearing housings are an example). If you have a variable speed machine run the machine in 1HZ increments to check for any points of resonance.
  c. Third, develop vibration spectra to check for imbalances and looseness. Imbalance can be caused by a variety of factors and looseness can be internal (inside the machine) or external (piping or structural). Vibration spectra may show hydraulic elements (blade pass frequencies, bearing frequencies and the like. The key is to look for patterns in the vibration signature to determine if a problem exists and any possible causes.

• On a vertical machine you are more likely to see vibrations in the horizontal and vertical axes. (The motor junction box is used as a reference)

• Normally, one does not expect to see a lot of axial vibration unless you have misalignment or a bent shaft

Source: Motor Technologies, courtesy of Mike Boyer.
Get Electrical Characteristics of Motor
- Full Load Amps
- Motor Service Factor
- Motor Voltage
- Bearing Arrangement
- Motor Power Factor

Get Characteristics of Protective Device
If Relay with Breaker:
- Input Characteristics for Motor
- Input Protection Elements
- Check Coordination

Check Operation of Overcurrent Protective Device (If Relay and Breaker)
- Rack Breaker in
- Check Tripping Characteristics on Protective Elements

Check Insulation Resistance of:
- Cable
- Motor
- Any control cabinets with 600V or higher connections

Check Voltage to Line Side of Drive or RVSS

Check Controls and Interlocks Point to Point

In Test Mode Check Any Hardwired Logic

Drive Can Be Energized But Not Run

Done De-Energized

Done With RVSS or VFD Off But Voltage On Line Side of Device

In Test Mode Check Softwires Logic

Develop Test Plan

Run Drive or RVSS

Simulate Interlocks to Check Shutdowns or Startups

Electrical Testing Flow

In Test Mode Check Softwires Logic
**Electrical Testing Highlights**

- Insulation resistance testing – check integrity of insulation by applying a known test potential. Results are measured in mega ($10^6$) Ohms or giga ohms. If we assume 1 per-unit value of voltage leakage current (assuming mega-ohms result from test is in the micro-amp ($10^{-6}$) range.
  - Get test voltage values from cable, motor, transformer manufacturer.
  - Always done de-energized before motor starters (with electronic components) are connected to load.
  - On larger pieces of equipment you may examine ratio of values between 10 minute and 1 minute readings. This is done for motors.
Because the RVSS operation only allows for the pump to run at fixed speed, the plant had to be sure it could take all of the water the pump produced. The production from this pump had to be balanced not only with raw water flow but with other high service pump combinations in the plant.

VFD operation was tested in both a standalone mode (pump run by itself) AND in combination with other pumps. This was to ensure that we could run multiple pumps simultaneously.

Testing consisted of several steps as noted previously. Once plant staff were confident that the pump could operate, the pump was left running only on the day shift.

Once the plant was confident with the fact that the plant worked during the day, the plant put the pump on overnight.

Once the plant was confident with the fact that the pump worked over night, the plant has run the pump continuously on VFD.
Consider Human Factors and Operator Participation

• Start-up was used as a means to test all of the pump capabilities
• During start-up, plant personnel were actively part of starting and stopping the pump.
• Because of active participation during start-up, plant personnel were exposed to
  o Where the controls were located
  o What types of basic troubleshooting processes they could use
  o How to navigate a touch screen to operate the pump (the touch screen interface included alarm information and status information)
  o What the sequence for both start-up and shut down looked like
• Plant personnel got a chance to operate E-STOP types of controls on the pump at various locations and learned how to recover from these situations
• Plant personnel noted that we had issues with a bearing temperature sensor that was off-scale high and a possible cause of issues. Start-up personnel ensured that infrared imaging was used around the motor circumference where the temperature anomaly was located and we found a bad piece of instrumentation was the cause of the issue.
• Plant personnel grew accustomed to the sights and sounds they would be exposed to (developing an “operator’s ear”) to establish what feels correct.
Consider Documentation

- The project featured Standard Operating Procedures (SOP) written by Operations Staff to ensure that the staff could proof test the SOPs prior to going into service.
- Some video was taken (using an I-Phone) for training purposes.
- Rockwell Automation prepared some basic SOP material because a networked touch screen was used internal to the drive.
The ‘Terminal’ does not change any of the contents or features within the PF7000, the presentation of information is the only thing that is different.

The ‘Control Bar’ can be accessed through the ‘Terminal’ (the accessibility is seen in green above) and is used for Start, Stop, and Speed Reference. An example display of this can be seen below.

Excerpt from SOP