

APPLICATION NOTE

Applying handheld test tools to preventive maintenance

Unplanned downtime caused by equipment failures costs manufacturers millions of dollars of revenue every year. In some industries, the labor costs alone associated with downtime are calculated by the second. In an era of extreme competitiveness, no one can afford to let that kind of money slip through their fingers.

Preventive maintenance—measuring key indicators on critical equipment to discover impending failures and then scheduling maintenance before equipment failures and downtime—is far more cost-effective and efficient than waiting to perform maintenance when failures occur.

To implement a proactive maintenance program, it's important to know not only which equipment needs repair, but also the root cause of impending failures. Using test tools to regularly measure key indicators on critical equipment helps technicians uncover the root causes of emerging failures.

Preventive maintenance with planned downtime enables maintenance managers to:

- Minimize the amount of time a facility is out of operation.
- Make the best use of personnel.
- Have the spare parts on hand that are required to make repairs.

This application note describes using the following test tools to make measurements, track equipment condition over time, and diagnose failure conditions:

- Digital multimeters (DMMs)
- Clamp meters
- Infrared thermometers
- Insulation resistance testers
- Thermal imagers
- Vibration testers

Preventive maintenance cost savings

According to the U.S. Federal Energy Management Program's Operation and Maintenance Best Practices Guide (energy.gov/eere/femp/downloads/operations-and-maintenance-best-practices-guide) the following are average savings from predictive maintenance programs:



Average savings from preventive maintenance programs

Return on investment	Up to 1,000 %
Reduction in maintenance costs	25 to 30 %
Elimination of breakdowns	70 to 75 %
Reduction in downtime	35 to 45 %
Increase in production	20 to 25 %

Integrating tools and programs

Preventive maintenance programs vary from highly sophisticated—with expensive continuous online monitoring and automated alerts—to more traditional offline programs that rely on inspection routes and manual measurements.

Monitoring tools also vary in complexity, from digital spot infrared thermometers to thermal imagers, vibration analyzers and power quality tools, to permanently mounted and networked sensors. Investigative tools vary from handheld digital multimeters, clamp meters, and insulation resistance testers to specialized motor circuit testers.

Many facilities mix and match, depending on their equipment and scale of operations. What's different is that these technicians are repurposing tools traditionally used for troubleshooting for proactive maintenance measurement programs.

Measurement guidelines

Preventive maintenance measurements aren't that different from troubleshooting tests. You're looking for signs of potential failures, so you take measurements related to failure modes.

1. For each type of equipment, identify the potential failures and related key indicators.
2. Determine what measurements can reduce the likelihood of problems.
3. Determine how often equipment needs to be measured.
4. Collect and track the results, watch for trends, and initiate repairs as needed.
5. Integrate all of your maintenance technologies into one data tracking and analysis software system such as Fluke Connect® so technicians and managers share the same equipment lists, histories, reports, and work orders.

When the data is correlated from all the technologies used, the operating condition of all assets can be analyzed and reported in an integrated format.

Measurements with handheld test tools

Equipment	Key indicators	Measurement	Test Tool
UPS/PDU	<ul style="list-style-type: none"> • Intermittent tripping • Process interrupts 	RMS voltage, rms current, frequency (Hz), connection resistance, data log readings over time for anomalies	IR, DMM, TI
Transformer	<ul style="list-style-type: none"> • Heat • Buzzing 	Temperature, impedance at neutral ground bond, voltage balance, current balance, loose connections	IR, DMM, CM, TI
Panels/switchboards	<ul style="list-style-type: none"> • Intermittent tripping • Hot circuit breakers 	Voltage balance, current balance, data log readings over time for anomalies, loose connections, temperature	IR, DMM, CM, TI
Controls (VFDs Disconnects)	<ul style="list-style-type: none"> • Process anomalies • Change in system performance 	Voltage balance, current balance, inrush current, voltage sags, connection resistance, data log readings over time for anomalies	IR, DMM, CM, TI
Lighting panels	<ul style="list-style-type: none"> • Flickering lights • Buzzing 	Voltage balance, current balance, inrush current, voltage sags, connection resistance, data log readings over time for anomalies.	IR, DMM, CM, TI
Motors and other equipment (gearboxes, pumps, fans, chillers, A/C units, generators)	<ul style="list-style-type: none"> • Heat • Intermittent tripping • Noise • Visible or measured vibration 	Inrush current, insulation resistance to ground, temperature, nameplate rating, overloading, voltage balance, current balance, resistance, connection motor start capacitor, mechanical misalignment, imbalance, mechanical looseness, poor bearing condition	IR, IRT, DMM, CM, IRT, TI, VIB

Key: Infrared thermometer (IR), digital multimeter (DMM), insulation resistance tester (IRT), clamp meter (CM), thermal imaging (TI), vibration (VIB).

Note: These recommendations are not a complete set of preventive maintenance measurements.

Insulation resistance to ground

Caution: Before testing cabling and motors, disconnect any electronic controls—misapplication of high voltage test equipment can destroy them.

Regularly conducting the following insulation resistance tests on loads and connections can help detect imminent equipment failure.

- Ground testing line and load circuits at the starter will identify the resistance to ground of the starter, line circuits to the disconnect, and load lines to the motor and starter windings.
- General thresholds: ac devices can safely operate at not less than two megohms to ground and dc devices can safely operate at not less than one megohm to ground.

- When measuring the resistance of a three-phase motor between the load legs of the starter, you should see high resistance and roughly equivalent measurements between phases.

Note: Insulation resistance to ground tests conducted with an insulation resistance tester require disconnecting the components or cabling to be tested from the power system. Remember to incorporate this requirement into planned downtime.

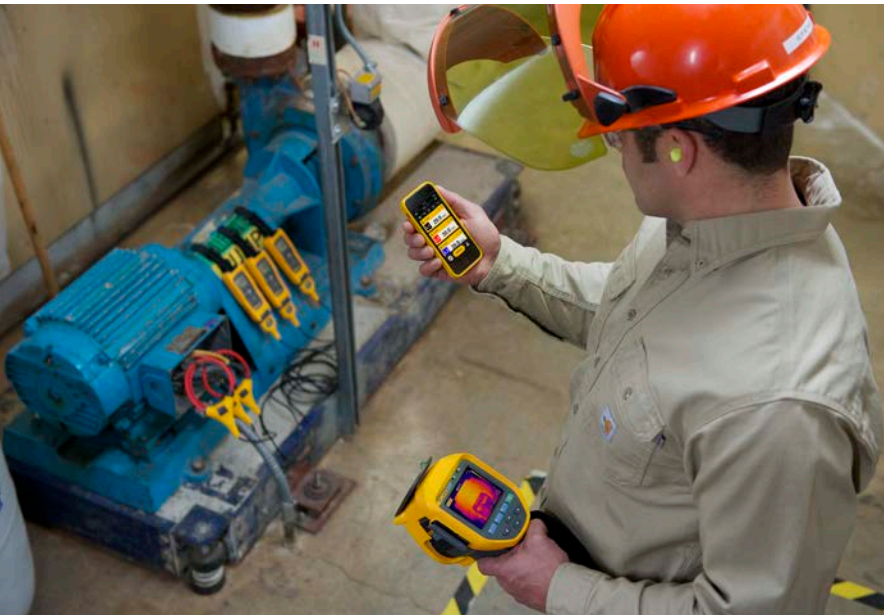
Temperature

Infrared thermometers are a low-cost monitoring option for quick, frequent measurements of specific components while equipment is operating. Use your knowledge of the equipment to identify key hot spots to track, compare those temperature readings to operational limits, and watch for upward trends.

For example, scan the bearing housings on motors, the switches in circuit breaker panels, and the wiring connections at all equipment. For the best measurements, get as close as is safely possible to your target, make sure you're not measuring a reflective surface, and compensate for emissivity.

Thermal imaging

Thermal imaging tools play a key role as screening tools in a preventive maintenance program. You can use them to quickly measure and compare heat signatures for each piece of equipment on an inspection route without disrupting operations. With a thermal imager you can quickly survey a much larger area than an infrared thermometer, and see how the temperatures of different areas relate to each other.



If the temperature or thermal pattern is markedly different from previous readings, you can use other maintenance technologies—vibration analysis, motor circuit analysis, airborne ultrasound, and lubricant analysis—to assess the severity of the problem and the time needed to repair it.

Thermal imaging applications

- Monitor and measure bearing temperatures and condition in large motors or other rotating equipment.
- Identify “hot spots” or “cold spots” in electronic equipment.
- Identify leaks and determine fluid levels in sealed vessels and tanks.
- Find faulty insulation in process pipes or other insulated processes.
- Find faulty connections in high power electrical circuits.
- Locate overloaded circuit breakers in a power panel.
- Identify fuses that are at or near their current rating capacity or that are improperly installed.
- Identify problems in electrical switch gear.

- Capture process temperature readings.
- Perform other equipment-specific troubleshooting and diagnostics.

Vibration testing

Most industrial equipment is designed to operate smoothly and with minimum vibration, so when vibration is present, it’s often an indication of problems with or deterioration in the condition of the equipment. As conditions within machinery change, the amount of vibration often also changes. If the underlying causes of excessive vibration are not corrected, the unwanted vibration alone can often cause additional damage.

Vibration data is typically collected using an electronic data collection device and an accelerometer. Measurements are taken by placing the accelerometer near each bearing location along the drivetrain, using the most appropriate attachment method (for example, a magnetic mount or a mounting pad). You must take care to ensure proper sensor placement in order to collect good data.

Quick tips

- Locate the sensor as close as possible to the bearing, or on a solid structural member leading to the bearing.
- Sensor position should be parallel or perpendicular to the floor whenever possible.
- Avoid mounting the sensor on thin surface areas (such as fan shrouds) and cooling fins.
- Attach the sensor to a clean, flat, bare metal surface if at all possible. Thick layers of paint, grease, oil or other matter will reduce both the holding force of the magnet and the high frequency response of the sensor.
- If possible take measurements on both ends of the motor.
- For consistent data over time, it is important to place the accelerometer at the exact same location on a machine each time you take a measurement.
- Do not take bearing measurements from a foundation or fabricated base.
- Do not mistake seal locations for a bearing measurement location on pumps.

The vibration from a drive train may change depending on the load and the temperature of the motor. The one exception to this rule is machines that have misaligned drive shafts. It is recommended to take vibration measurements when the machine is running in a **steady state and at normal operating temperature**. Machines tested while still cold may have significantly different vibration signatures than those at normal operating temperature because temperature affects shaft alignment and operating clearances due to thermal expansion. In the case of pumps, cavitation, air ingestion or discharge pressure will affect vibration readings, and pumps should not be tested with the discharge valves closed; however, if they



must be tested in a recirculating condition, the recirculating valve may be partially closed to achieve a normal discharge pressure.

When the data has been collected, it must be analyzed to determine the source, location and severity of the faults. It is recommended to consult with a trained professional or consider using the Fluke 810 Vibration Tester to extract meaningful indicators of machine health.

Used regularly as part of a preventive maintenance program, vibration test equipment can often identify potential mechanical problems weeks, if not months, prior to a catastrophic failure.

Resistance

Caution: Resistance measurements must be made with the circuit power off. Otherwise, the meter or circuit could be damaged.

A digital multimeter can check the resistance across most connections. High resistance readings can signal degraded connections, which can cause reduced supply voltage, nuisance tripping, and potential equipment failure.

- High resolution DMMs can also measure the resistance across relay and circuit breaker contacts. Resistance goes up as the contacts degrade.
- IR thermometers can also identify high resistance connections, which show up as hot spots when compared to a good connection.

DMM Notes: Most DMMs measure down to 0.1 ohm and some measure as high as 300 megohm. For accurate low resistance measurements, use the DMM's REL function to eliminate test lead resistance.

DC and AC current

Caution: After measuring current with a DMM, don't forget to move test leads back to their voltage-measuring connections before attempting a voltage measurement.

Loads may draw slightly higher current as they age. Regularly measuring current can help you track equipment reliability. Use either a clamp meter or a DMM combined with a current clamp to measure current.

Voltage balance

A greater than two percent voltage imbalance can reduce equipment performance and cause premature failure. Use your DMM to check voltage between phases for voltage drops at the protection and switchgear delivering power from the utility and at high priority equipment.

Voltage imbalance can be calculated with the following formulas:

$$\text{average volts} = (\text{ph1 volts} + \text{ph2 volts} + \text{ph3 volts})/3$$

$$\text{Percent voltage unbalance on ph1} = ((\text{ph1 average voltage})/\text{average volts}) \times 100$$

Note: Voltage drops across the fuses and switches can also show up as imbalance at the motor and excess heat at the root trouble spot. Before you assume you've found the cause, double check with a thermometer.

Current balance

Another root cause for equipment overheating is current imbalance. Use a clamp meter or an ac current clamp with your DMM to check the current draw on each of the three legs. To determine average current, sum the current from all three phases and divide by three. Then, calculate the percent imbalance by subtracting the actual on one leg from the average amps, then divide by the average amps and multiply by 100. More than 10 percent current imbalance can be a problem.

$$\text{average amps} = (\text{ph1 amps} + \text{ph2 amps} + \text{ph3 amps})/3$$

$$\text{Percent imbalance on ph1} = ((\text{ph1 average amps})/\text{average amps}) \times 100$$

Inrush current

If a motor isn't performing correctly or if your circuit is tripping unexpectedly, check inrush current at startup with a clamp meter or a DMM designed to capture inrush current. Inrush current can reach up to twelve times the normal operating current—much higher than the circuit breaker rating—without tripping the breaker, as long as the circuit isn't overloaded. Evaluating inrush current depends on comparisons of inrush measurements over time for that motor.



Safety and test tool rating requirements

Before you start using your digital multimeter (DMM) or other test tools for proactive maintenance, make sure you understand the limitations of your tool and the safety precautions that go along with it.

- Choose a DMM rated for 1000 V CAT III/600 V CAT IV and a clamp meter rated for 600 V CAT III.
- For DMMs, look for true-rms, resistance of 0.1 ohms or less, capacitance test to 9,999 microfarads, and frequency. If you're tracking data over time, get a DMM with data/event logging capabilities and fast Min/Max, sufficient memory, extended-life batteries, an optical port, and software for downloading measurement results to your computer.
- For typical industrial and commercial motors, choose an insulation resistance tester with a minimum of 500 V output and resistance measurements to several gigohms.
- Determine how close you can safely stand to your equipment during temperature measurements and use that to determine what distance-to-spot ratio your infrared thermometer must support. A distance-to-spot size ratio of 50:1 allows accurate measurement within 8 feet, depending on target object emissivity.
- Consider wireless test tools that let you take measurements from a safe distance and monitor on a smartphone.
- Ensure the voltage rating on your test probes matches your test environment. Insulation resistance testing typically requires high voltage probes, as do some DMM tests.
- If you must make live measurements in a three phase environment, wear the appropriate personal protective equipment (PPE), use the three-point test method, and if possible, keep one hand in your pocket to prevent current transfer.

Three-point test method:

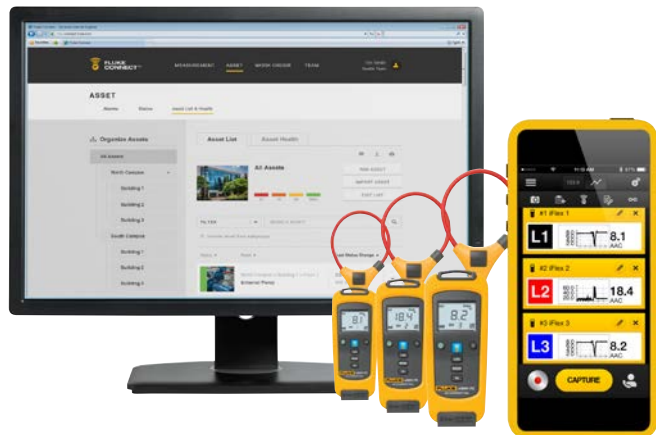
1. Test a known live circuit.
2. Test the target circuit.
3. Test the live circuit again.

This verifies that your meter worked properly before and after the measurement, and ensures you know whether a circuit is live. Another option to verify test tool functionality is to use a proving unit such as the Fluke PRV240.

Data Management

Capturing electrical, temperature and vibration data during normal operation and troubleshooting is an important aspect of preventive maintenance. The traditional approach involves jotting individual measurements down on a notebook and later, if ever, transferring the data onto clipboards, spreadsheets or into a computerized maintenance management system (CMMS). Then, measurements are compared to assess equipment health. Test tools with wireless capability, such as those part of the Fluke Connect platform, can capture baseline and troubleshooting data and using a smartphone to transfer the data to the cloud. This wireless workflow eliminates transcription errors and saves time. Securely stored in the cloud, the data can be compared, trended and analyzed from anywhere. Such analysis helps identify degradation of equipment that might be early indications of failure. Maintenance can be planned before operations are impacted.

For more information on connected workflows, visit flukeconnect.com



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