

## #1: Electric Motor Failure Modes

### —New Methods for Low Resistance Protection

*Brief: 90% of motor and generator electrical problems occur at start-up, mostly due to low insulation resistance. These are trickier than over-current or mechanical failures, but new products and techniques can reliably insure against low resistance failures...automatically and safely.*

When electric motors or generators fail during use, it invariably means extensive equipment repair or replacement...the high cost of which is often minor compared to the impact of unscheduled system downtime. Understanding the most common failure modes is essential to minimizing their impact in an operating environment.

### Types of Failure

Electric motors typically fail due to one of three causes:

- low resistance (electrical ground)
- mechanical (bearing failure, vibration, etc.)
- over-current (electrical overload)

“Low resistance” is one of the most common failure causes. Also known as “Monday Morning” or “Start-up” failure (these are the circumstances in which it usually strikes), low resistance is traditionally the most difficult electrical problem to protect against, since it can occur *either* through conventional, predictable wear...or in sudden, catastrophic fashion.

A combination of protective devices and/or

predictive maintenance tests and procedures has long helped users guard against mechanical and over-current failures. These will be omitted from this discussion, as they are widely dealt with in the literature.

⇒Devices or systems to “automatically” protect against low resistance failures, however, are recent developments...and have *not* established uniformly good reputations for effectiveness, or—more importantly—for *safety*. [See Tech Talk #2 for a full discussion of the pros and cons of such devices.]

### Distinctions Between Failure Modes; How is Low Resistance Different?

#### Mechanical Failures

Mechanical failures happen for a wide variety of reasons, including inadequate lubrication, unbalance and vibration, and misalignment. What most mechanical failures have in common is that they happen *gradually*; they display characteristic warning signs which intensify over time. An increasing assortment of sophisticated analytical techniques and services can detect impending mechanical failure at ever-earlier stages, allowing corrective measures as part of

an overall, scheduled preventive maintenance program.

Any good electrical apparatus shop can recommend suitable diagnostic tests and instrumentation. A number of reputable organizations—some national in scope—will arrange contractually to conduct analyses of the type and frequency necessary to prevent mechanical breakdowns in rotating equipment. For all practical purposes, mechanical failures can be averted through routine preventive and predictive maintenance.

### Over-current Failures

Over-current failures happen most often when operating conditions cause devices to draw substantially more current than their rated load capacity. They tend to happen suddenly, and are not conducive to preventive procedures or predictive measurements. Fortunately, there is a wide range of reliable devices available to limit or prevent over-current failure. Typically, these are wired into the circuit and “programmed” for a specific amount of current above rated load, which they will allow for a “programmed” period of time...after which they act quickly to shut down the current flow.

Devices of this sort have become omnipresent. They are available for retro-fit, but are increasingly found specified with original equipment motors and generator sets, and as an integral component of motor control centers. A detailed review of the pros and cons of each type of over-current protection would fill volumes. For this discussion, it's sufficient to know there are enough over-current devices to choose from to match almost any application and budget.

### Low Resistance Failures

It's been estimated that 90% of motor and generator electrical problems occur at start-up. A high percentage of *these* problems are caused by low insulation resistance...traditionally the most difficult type of failure to prevent.

When a new or rebuilt motor or generator is first placed in service, insulation resistance will likely exceed 1,000 megohms (1,000,000,000 ohms). [Note that resistance should *routinely* be checked before initial operation.] During de-

vice operation, insulation performance can fall to dangerous levels through A) gradual decay, or B) precipitous failure.

With innovative technology, carefully applied, it's now possible to “insure” rotating electrical equipment, guarding against both types of low resistance failures. In addition, insulation performance can readily and consistently be monitored over time to be charted with unprecedented accuracy, facilitating cost-effective *predictive maintenance*.

When implementing this prevention, it's essential to do it:

- ***safely***...with no risk to personnel or equipment.
- ***automatically***...so there's no need to remember to test regularly.
- ***reliably***...unlike devices which test at a small fraction of rated voltage.
- ***accurately***...to record precise insulation readings over time.
- ***economically***...so every rotating electrical device can be protected.

A method such as the Tru-Meg™ system is the *only* way to assure that: A) expensive and/or critical equipment has the best possible “insurance” against electrical failure, and B) the protective system itself is *safe*. (Beware: some “cures” are worse than the disease!)

## Gradual Decay

Insulation resistance inevitably degrades over time, eventually reaching a point at which it's not safe to operate equipment. Experts disagree on exactly when repair or replacement becomes necessary, but a common rule of thumb says that insulation resistance must be 1 megohm for each 1,000 rated volts, plus 1 megohm.

(e.g. 5,000 volts = 6 megohms, minimum)

All agree, however, that no electrical equipment should be operated if resistance is 1 megohm or less; most agree that anything below 5 megohms—regardless of operating voltage—merits a “caution” light and *ASAP* attention.

The *rate* at which insulation resistance decreases varies with a large number of factors—some con-

trollable, some not. Easily the most significant is equipment operating temperature, generally determined by both the ambient environment and by load. (see below re: Variable Frequency Drives). With each 10° C increase, resistance typically drops **50%**.

More heat in device windings has a two-fold effect: resistance is lower as long as the temperature is elevated, *and the useful life of the insulation is also reduced*. In fact, for each 10° C rise in operating temperature, insulation life is cut by half. The good news is that the rate of resistance degradation is usually quite constant over time, and hence predictable. Thus, above minimum safe levels\*, *the change in resistance readings over time is much more important than the resistance level at any given point*.

In the past, the only method of measuring actual resistance was to use a hand-held megohm-meter. These instruments have a number of inherent limitations, but the most serious drawback by far is that they require a trained user to take the time to make and record measurements on each piece of equipment in the shop...and to remember to do so at frequent intervals.

A tool and/or method to automatically test resistance *each time* a device is started—creating an *accurate log* of megohm levels, and calculating the *rate of change*—is of immense value.

## Precipitous Failure

Despite the above comments on steady, predictable change in resistance levels...there might not be any warning signs. Windings that check out in the 50-100 megohm range can suddenly drop—as much as two orders of magnitude, to *less* than 1 megohm—overnight.

A common cause is environmental change. If a facility is shut down for one or more shifts and allowed to “cool off,” moist outside air is often drawn in, causing condensation to form on idle equipment. Until the space is heated and the humidity lowered—or until auxiliary heaters can dry off the equipment—it will not be safe to operate. Relatively mild climatic shifts can also cause this effect...even overnight.

This same kind of failure can occur under other

conditions...*even when the windings have just checked out at high ohms*. Examples include: sprinkler activation; oil or other contaminants

\* Accepted industry practice is one megohm per rated kilovolt, plus one.

spilled onto machinery; even an over-zealous janitorial staff, eager to “hose down” a dirty housing.

The sobering fact is that even *trained* personnel can make mis-steps in this area. In a classic case, a shop foreman with many years' experience arrived after a weekend shut-down to find “dew” on equipment housings. His statement to his operators? “Don't worry—when we start the motors, they'll spin the water right off.” When energized, of course, the motors were shorted out, resulting in considerable repair costs and unscheduled downtime.

In recent years, a number of products and systems have been introduced as the “answer” to this thorny problem—as a means of reducing or eliminating the risk. In concept, in execution, or both, these “solutions” have serious shortcomings...even to the point of compromising worker safety.

Only the Tru-Meg automatic tester/monitor/fail-safe system can safely meet the challenge.

⇒No matter how thorough the preventive and predictive maintenance programs, and no matter how diligent the operating crew, catastrophic resistance failure can still occur.

## About Variable Frequency Drives...

Recent innovations in variable frequency drives and controllers have brought these devices into widespread use. Reduced price and low maintenance make variable frequency initially attractive. Their high efficiency also yields reduced operating costs, which can be a compelling incentive.

The drawback to the variable frequency approach is that it reduces expected equipment life. Partly due to mechanical factors, such as increased vibration and noise, but mostly due to significantly higher operating temperatures... which both lowers effective resistance, and accelerates insulation degradation.

Where variable frequency drives are employed, insulation life expectancy will be reduced; it's even *more* important here to monitor resistance levels to prevent equipment failure.

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*L.Y. Wagner received his doctorate from Purdue University, and has been active in the electrical apparatus industry since 1976, focussing on field applications research. Dr. Wagner is Chairman of Motor Guarantee Corporation.*

## **Motor Guarantee Corporation**

1363 East 41<sup>st</sup> Street  
Cleveland, OH 44103  
(216) 881-MEGS