# No-load Current Basics: Practical Guidelines For Assessment

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*How much no-load current should I expect when testing a motor? We would like to have a ratio of no-load amps / full-load amps, for quality control purposes.*

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Many of us expect a motor to draw approximately one-third of rated current, when operating from rated voltage on our test panel. That is a good rule of thumb—most of the time. While there are lots of exceptions, most of them are predictable.

To explain the rule of thumb and the exceptions, we will use some terms familiar to most readers:

FLA = Full-load amps
NLA = No-load amps; this is magnetizing current *plus* some losses (mostly windage)
Flux = Lines of magnetic force
AGD = Airgap density; in lines of flux per unit area
V = Applied voltage

Here are some exceptions you probably recognize:

- The higher the flux density, the higher the no-load current will be as a percentage of FLA.
- The lower the speed, the higher the no-load current, as a percentage of FLA.
- The ratio of $\frac{\text{NLA}}{\text{FLA}}$ is inversely (though not directly) proportional to hp.

## Practical Guidelines

The intent of this article is to explain why those statements are valid and, in the process, to offer practical guidelines for assessing no-load current. Many of us apply these principles daily.

Knowledge is power. We should, whenever possible, improve our knowledge by gathering facts:

- Use the *AC Motor Verification & Redesign Program* to check densities before rewinding the motor.
- Keep records of tests for comparison of identical machines.
- Get information from the manufacturer to supplement your records.

Before we get to the simple table of "expected" values for no-load current, we will lay out some tools to use for understanding the exceptions to that "one-third of FLA" guideline. First, let's review our basic understanding of the relationship between voltage, flux and torque.

$$\text{Torque} \propto \text{AGD}^2 \propto \text{V}^2$$

## Effects Of Applied Voltage

For any given motor, flux density changes in proportion to the applied voltage. Torque produced by the motor varies as the *square* of the flux. If we change the voltage applied to a motor, we expect the current to change proportionally.

We apply this principle every time we start a motor at reduced voltage. Remember that motor that was too big to start on the test panel? You simply brought it up to speed at a fraction of rated voltage. Then you were able to switch up to rated voltage.

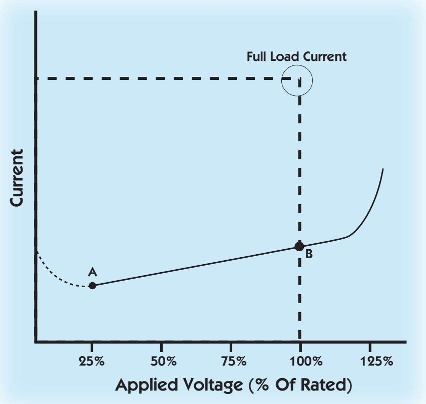

Figure 1. Graph of applied voltage against current.

**Figure 1** illustrates what happens when we run an uncoupled motor at varying voltage. As long as the motor will maintain speed, we can reduce the voltage and expect a more-or-less linear change in current.

To demonstrate this, use a motor without an external fan. Operate the motor at rated voltage and record the current. Decrease the voltage slowly, recording both voltage and current. Now graph the results, and the result will be similar to **Figure 1**. Along the straight portion of the line, the flux changes in proportion to the applied voltage. Consequently, we can expect the current to change proportionally also—within limits.

If the applied voltage is too low, the motor slows down and the current increases (left of Point A in **Figure 1**) as the motor tries to develop enough torque to keep turning. The speed decreases because the torque is too low to overcome friction & windage losses.

$$\text{Slip} \propto \frac{1}{\text{AGD}^2} \propto \frac{1}{\text{V}^2}$$

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Next slowly raise the voltage above rated voltage, again recording the voltage and current. As the voltage increases, the current increase will remain linear until we reach saturation (Point B, **Figure 1**). When the stator core becomes saturated, it takes a disproportionate amount of current to increase the level of flux.

Between Points A and B, voltage graphed against current will be more-or-less linear.

That is one reason we should test run all repaired motors *at rated voltage*, and record the voltage and current on all phase leads. The no-load test run is a *critical* step in quality assurance. (See the February 2004 *CURRENTS* article "Avoiding High No-Load Amps.")

Some manufacturers are very frugal with active materials (steel and copper cost money, after all), and some applications require a high hp or kW rating in a small physical package. From **Figure 1**, we can expect such a "high flux" motor to draw relatively high no-load current. It is also more sensitive to higher-than-rated voltage—which may push the core into saturation. On the other hand, the motor is usually more forgiving of under-voltage conditions, compared to a conservatively fluxed motor.

We can expect designs that operate at or near the knee of the saturation curve to draw higher no-load current than those operating along the linear portion of the curve.

*What about conservative designs, such as older U-frame machines?*

Those, as well as two-pole machines, motors designed for high ambient temperatures (kiln motors) or high altitude use, are deliberately "fluxed low" —meaning they are designed to operate well below the knee of that flux curve. We should expect relatively *low* no-load current. While more tolerant of high voltage, they are more susceptible to low voltage conditions.

## Different Designs Affect Rule

Four-pole machines dominate industry, so the "one-third of rated current" rule is appropriate. But while one 4-pole motor might be a conservative design for a variety of reasons, another might be fluxed higher. So we should expect the conservative design motor to draw a bit less than our rule of thumb. Likewise, the high-flux design might be expected to draw a bit higher than the one-third rule. Knowing the influence of flux density, we can evaluate motors that deviate from our usual expectations.

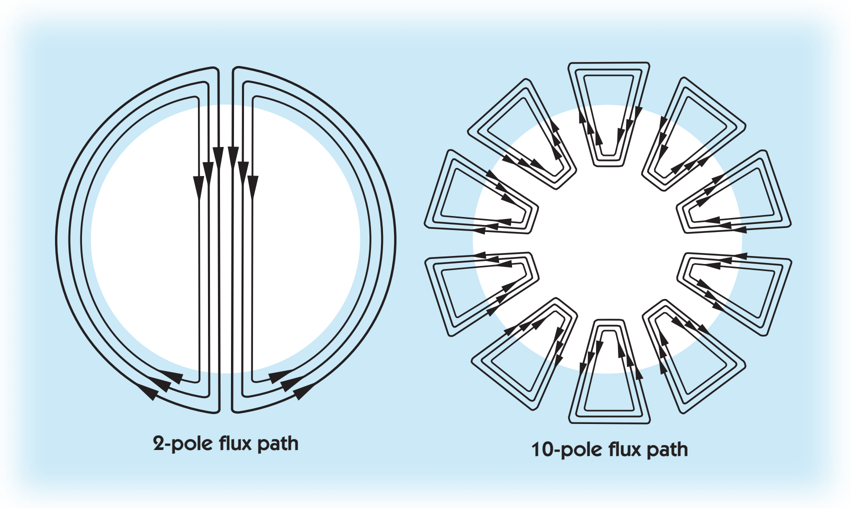

Figure 2. 2-pole and 10-pole flux path connection.

## Flux And Airgap

Because very low-speed machines are less common, a motor that draws three-fourths of rated current gets our attention. That anomaly is easy to explain. **It takes more current to drive flux through air than through steel.**

A common test used by our industry—the open-stator test—demonstrates this. We apply one-sixth of rated voltage to an open stator, with the expectation that it will draw close to rated current. Why does it draw full-load current with only a fraction of rated voltage? There is no rotor to complete the flux path, so the flux must travel through air. That requires a lot more current—hence the lower voltage used for the test.

**Note:** Some service centers use higher than 1/6th of rated voltage, and expect higher than FLA. But open stator tests at higher voltages make it difficult to interpret the results.

The greater the distance flux has to travel through a non-ferrous medium, the higher the current required. For each trip around a stator, the flux in each phase has to cross the airgap twice per pole. Compare a 2-pole machine to a 10-pole. **(Figure 2.)** For each revolution around the stator, the 10-pole flux must cross the airgap 20 times, while the 2-pole flux only has to cross it four times. *It takes more current to force flux across the airgap than through the steel core.*

## Consider Number Of Poles

It should be no surprise that low-speed machines draw relatively high no-load current. The no-load current

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### Table 1

| Poles of 3-phase induction motor | Expected no-load current as a fraction of FLA | Approximate percent of FLA |
|---|---|---|
| 2 | 1/4 to 1/3 | 25-33 |
| 4 | 1/3 to >3/8 | 33-40 |
| 6 | 1/3 to <1/2 | 33-45 |
| 8 | 1/3 to >5/8 | 33-65 |
| 10 or higher | 3/5 to >FLA | 60-110 |

After calculating the flux densities, we can better evaluate the ratio of no-load current to full-load current. The higher the flux density, the higher the ratio current is likely to be.

- The higher the flux density, the higher the no-load current will be as a percentage of FLA.
- The lower the speed, the higher the no-load current, as a percentage of FLA.
- The ratio of $\frac{NLA}{FLA}$ is inversely (though not directly) proportional to hp.

increases incrementally with the number of poles. (At the risk of being redundant, more poles = higher magnetizing current.) To minimize the effect, machines with more poles are designed with closer airgap between rotor and stator.

The ratio of NLA/FLA varies in inverse proportion to the motor size and hp (kW) rating. Depending on the design, the ratio could be twice as large for a 10 hp motor as for the same manufacturer's 300 hp motor.

## Consider Scale, Manufacturing Tolerance

Part of the explanation is one of scale and manufacturing tolerance. The average bore diameter of an 8-pole 300 hp motor is 5 times the bore of the typical 10 hp 8-pole motor. The 300 hp motor has an airgap of approximately 0.040" (1 mm). If everything was to scale, the 10 hp 8-pole airgap would be only 0.008" (40/5 = 8).

We know that airgap must be uniform within 10% to avoid electrical noise and rotor pullover issues. Ten percent of 0.008" is less than 1 thousandth—hardly practical. Even the bearings have more internal play than that.

The manufacturer has little choice but to allow higher magnetizing current with a larger airgap distance. Knowing this, we should anticipate the NLA variation based on hp rating as well as the number of poles.

(It is also impractical to design small cores specifically for low speeds, so a 4-pole core is used.)

Because there are a lot more 4-pole machines in industry than any other speed, we grow accustomed to the no-load motor drawing approximately one-third of FLA when operating uncoupled at rated voltage. Verifying this on the test panel offers a quick quality control tool. If a motor is misconnected, we can catch that by measuring the no-load current. Note that we consider "no-load" as being "uncoupled" while many of our customers interpret it as meaning "the mile-long conveyor is not loaded with rock." There is a big difference between those two conditions.

**Table 1** shows typical expected no-load current for evaluating motors when we test them uncoupled. The exceptions we have discussed can be used to evaluate each motor so that we can make a reasonable judgment as to whether or not test results outside these guidelines make sense.

After calculating the flux densities, we can better evaluate the ratio of no-load current to full-load current. The higher the flux density, the higher the *expected* no-load current is likely to be.

## Exceptions To Every Rule

Remember that there are exceptions to every rule. **Table 1** gives a quick reference of expected ranges, but we have to consider each motor individually. In general, we expect higher no-load current for motors with more poles, especially for smaller motors.

If we rewound the motor, someone *should have* used the *AC Motor Verification & Redesign Program* to check the flux densities. Armed with that information, we can better assess the actual NLA. If there is any question, compare the results to historical records for tests of identical motors.

Finally, the NLA is affected by the grade of steel, annealing condition, and small variation in airgap. A manufacturer's published NLA may vary by 25% or more. In rare cases a motor may draw higher current operating at no-load conditions than at rated load. But while that might be plausible for the 10-pole motor, it surely spells trouble for a 2-pole. So keep those principles in mind next time you test run a motor that falls outside these rules.