Simple AC Winding Tests

The question of identifying a failed motor winding in the field arises frequently. It is often impractical to remove the motor for the sole purpose of determining the condition of the winding, and most service technicians are not equipped to perform comprehensive testing. The purpose of this paper is to provide a simple reference for the non-expert to determine with reasonable certainty if a motor winding has failed using two (2) instruments: a megOhm meter (megger) capable of measuring insulation resistance to ground, and a milliOhm meter capable of measuring low resistance circuits with accuracy. It is important to note that although the tests described here are valid for testing any AC (not DC) motor rated less than 500V, many of the generalities referred to are applicable only to modern CNC machine tools.

First an overview of the most frequently encountered winding schematics for machine tool motors:

Figure 1a illustrates a motor with 3 external leads (U, V, W), and an internal Y connection.
Figure 1b Illustrates a motor with 3 external leads, and an internal Δ connection. In each case, it is clear that all 3 external leads are part of the same circuit.

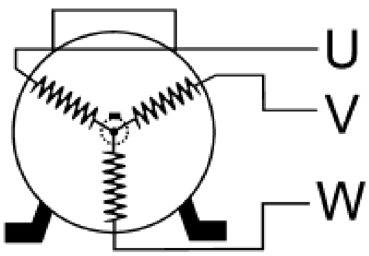


Figure 1a

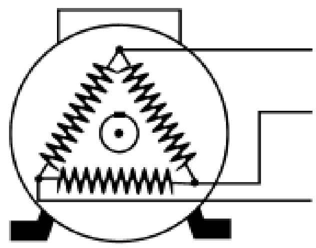


Figure 1b

Figure 2 Illustrates a motor with 6 leads. Each end of each phase is brought out external to the motor where contactors will connect them either **Y or Δ (Delta).** Often referred to as a dual winding or dual speed motor, the motor in fact has a single winding, and a fixed number of poles (or a single speed). The motor speed is varied by the inverter, and operation is optimized by connecting the winding Y at lower speeds, and Δ at higher speeds. Note that when all leads are disconnected from each other, there are three separate circuits: U-X, V-Y, and W-Z.
The motor can be tested with all leads disconnected from each other. Alternatively, it can be tested in Y by tying X, Y, and Z together, or in Δ by connecting U to Z, V to X, and W to Y.

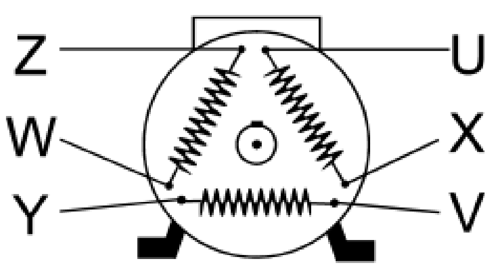
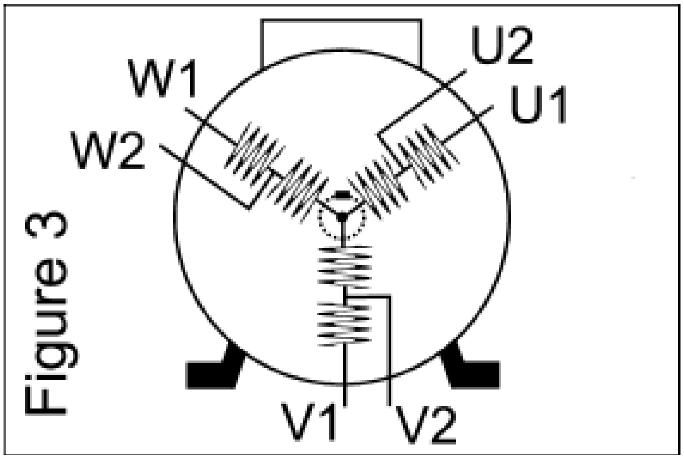


Figure 2

Endeavor Technologies, Inc.
1151 Atlantic Drive Unit 5, West Chicago, IL 60185
T 630.562.0300 F 630.562.0303
www.endtec.com

Figure 3 illustrates another motor with 6 external leads (U1, V1, W1, U2, V2, W2) connected internally in Y. Often referred to as a dual speed or dual winding motor, this motor has a fixed number of poles, or a single speed except as varied by the inverter. Optimal operation is achieved by energizing the complete winding (from U1, V1, W1) at low speed, and only half the winding (from U2, V2, W2) at high speed.
Note that all 6 leads are part of the same circuit, and have continuity to each other at all times.



These represent only the most common schematics for servo and spindle motors. There are numerous connection schemes for electric motors, including variations with 9 or 12 external leads. Please don't hesitate to contact our offices for support when working with one with which you are not familiar.

Our experience has shown that ground faults due to contamination are the leading cause of failure in electric motors in CNC applications by a wide margin. Therefore, most failures can be found by checking insulation resistance with a megger, or megOhm meter. To check a motor winding for a ground fault:

1. **First make a positive connection with one lead of the megger to ground. Verify the ground connection by connecting the other lead to another ground point. The resistance will show 0M.**
2. **After establishing a secure ground with one lead, connect the other megger lead to the "U" lead of the motor, and note the resistance after the readings stabilize. When checking motors as shown in Fig. 1a, 1b, and 3, it should only be necessary to check one phase to ground since all phases are part of a common circuit. When checking a Y/Δ (Fig. 2) motor, it is necessary to check from U, V, and W individually unless the motor leads have been connected as described above. Make sure to record all resistance readings.**
   U-G _______
   V-G _______
   W-G ______

After taking resistance readings, the question is always: what is the minimum acceptable resistance to ground? Most motor manufacturers have some pass/fail threshold for resistance to ground, but they vary considerably. It is very difficult to establish minimum requirements because readings that are troubling in some circumstances are less so in others. Experience and judgment will always have to be used. From a safety standpoint, the IEEE standard is 1M + the kV rating of the motor. So a 200V motor would have a minimum safe requirement of 1.2MΩ, and must be removed from service at any reading below that. Clearly a problem could exist at a much higher value.

Endeavor Technologies, Inc.
1151 Atlantic Drive Unit 5, West Chicago, IL 60185
T 630.562.0300 F 630.562.0303
www.endtec.com

Before deciding on a minimum requirement, it is useful to think in terms of the ideal. At Endeavor Technologies, we consider 6000MΩ to be the minimum *after cleaning and baking* a used winding, and expect a *new* winding to be greater than 50,000MΩ to ground when tested with a DC hi-pot at 2280V (for a 200V motor). If a motor has only 50MΩ resistance to ground, the question becomes "why are these readings so low?", rather than "what is the lowest good reading?" Once you determine why readings are lower than the ideal, then you can make a judgment call as to whether they are too low.

There are 2 common causes:

1. Permanent degradation of the insulation system due to age, mechanical stresses on the insulation components, and / or decay of the insulation materials. Most CNC motors are relatively new, and were made with high quality materials and good quality control. If the motor is +20 years old it is worth taking age into consideration.
2. Most commonly in machine tools, poor resistance to ground is due to some level of contamination with dirt, coolant, etc… Humidity also affects megger readings and must be factored in.

Illustrating the difficulty of setting a pass/fail threshold:

1. A clean, dry winding sprayed lightly with tap water a few times will almost immediately show a temporary short to ground. After a few hours most of the water will evaporate and the readings will be high enough to assemble and run the motor without a problem. The heat generated by the motor will cause whatever is left of the water to evaporate. Humidity causes much the same effect.
2. A 3.7kW spindle motor was causing over current alarms. The megger reading was off-scale (>2000MΩ) with a 500V megger, and the motor ran on our test stand with no alarms at all. No-load current was a bit higher than normal, and the exterior of the motor was oily along with some signs of oil in the terminal box. After disassembly, the motor was found to be full of cutting oil. Cleaning and baking the winding solved the customer's problem.

Humidity can cause a sound, clean winding to show low resistance to ground where there is no real failure. On the other hand, a badly contaminated motor might never be pulled from service if the only consideration is the megger reading. In illustration 2 given above, the tip-offs were the signs of contamination, and the fact that it took several seconds for the megger readings to reach 2000MΩ. Motor windings all have some capacitance. Contamination increases the winding capacitance to some degree, so the longer it takes for the megger readings to stop climbing, the greater the capacitance and the higher the likelihood of contamination. Contamination with cutting fluid will lead to failure eventually because it usually includes conductive debris, and because the chemicals are often aggressive enough to damage the motor insulation. If sluggish megger readings and physical examination lead to the conclusion that the motor has been contaminated with coolant, the safe course of action is to take it out of service regardless of the final resistance readings.

Each motor should be evaluated with the following (or similar) questions:

1. Is it in a humid environment? A 100MΩ reading would be less troubling in an non-air conditioned plant in Mississippi in July, than it would in an environmentally controlled plant.
2. Is the motor subjected to a lot of coolant? If the Z-axis motor measures 650MΩ, and a rotary table motor underneath the same machine measures 100MΩ, the natural conclusion would be that the lower motor is contaminated.
3. Are the resistance readings stable as the applied voltage increases? If the reading is 200MΩ at 500V, but only 50MΩ at 1000V it is likely that the insulation system is degrading, and readings will continue to worsen when the motor is under load.

Endeavor Technologies, Inc.
1151 Atlantic Drive Unit 5, West Chicago, IL 60185
T 630.562.0300 F 630.562.0303
www.endtec.com

If no faults are discovered with a megger, it is important to take comparative resistance readings of each winding phase. This *must* be done with a milliOhm meter. An ordinary multimeter is not capable of measuring low resistance circuits accurately enough. Milliohm meters utilize 4 leads rather than 2, and all must make positive contact during each measurement.

Begin by determining which motor schematic is appropriate from figures 1-3.
If testing a motor with 3 leads (fig. 1a or fig. 1b), connect one set of test leads to the U terminal, and one set to the V terminal. Adjust the milliOhm meter to read in the lowest possible scale. Record the resistance reading, and then record additional readings between V and W, and between U and W. The readings should not vary by more than 2%. Generally a variance >2% indicates an internal short circuit in the winding—a short between turns, between coils, or between phases. Small servomotors may occasionally vary by 3%, but most spindle motors will be within 1%. Motors with an internal short must be removed from service immediately.
U-V _______
V-W _______
U-W _______

Motors of the type illustrated in fig. 2 can be checked from
U-X ________
V-Y ________
W-Z ________
to avoid the inconvenience of making either a Y or Δ external connection.

Motors of the type illustrated in fig. 3 are tested just as those in figure 1; however it can be informative to take some additional readings. By measuring the resistance from U2-V2, V2-W2, and U2-W2, and from U1-U2, V1-V2, and W1-W2, the fault can be further isolated.
U1-V1 _______
V1-W1 _______
U1-W1 _______
U2-V2 _______
V2-W2 _______
U2-W2 _______
U1-U2 _______
V1-V2 _______
W1-W2 _______

It is an imbalance in the relative readings, not the absolute resistance values, between phases that indicate the presence of a short circuit.

It is important to understand that while the tests described above will find nearly every failure of a motor in a CNC application, there are some exceptions:

1. **Motors that have been wound incorrectly. It is unfortunate, but motor rewinders are sometimes confused by the unusual internal coil arrangements and connections of spindle and servomotors. Determining that such a mistake has been made requires more in-depth analysis of the winding.**
2. **Failures of an arcing nature. The diagnostic tests and equipment described here will find "hard shorts"—failures where the insulation wall has broken down completely. Arcing shorts that exist only when the motor is energized can only be found by a high voltage surge test.**

.