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*GE Industrial Systems*

# *Instructions for Choosing the Optimal Rotor Construction*

*These instructions do not purport to cover all of the details or variations in equipment nor to provide for every possible contingency to be met in connection with installation, operation, or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes, the matter should be referred to the General Electric Company.*

# Choosing the Optimal Rotor Construction

This paper is intended to address the various rotor constructions available in Small Industrial AC Motors, specifically the differences between cast rotors and fabricated rotors in 360 – 500 frame motors manufactured by GE Industrial Systems in Owensboro, KY.

A cast rotor can be manufactured using a pressure die-cast process or a spin-cast process. Which process is used is generally determined by the size of the rotor. End ring molds are placed on each end of the rotor core and molten conductive material (usually aluminum) is forced through the end rings molds and rotor slots. The end result is a solid, "one-piece" rotor. Fan blades cast into the end rings provide additional surface area for cooling the rotor and provide air movement for cooling the stator windings and rotor.

Fabricated bar rotors use axial bolts to hold the rotor core together. Fabricated bars are pushed through each rotor slot and brazed to a separate end ring on each end. Internal cooling is provided either by extending the length of several of the rotor bars, or by means of separate fans pressed onto each end of the shaft.

The majority of motors in the Small IAC scope (140-500 frame) have cast aluminum rotors. <u>This construction offers the best combination of performance, cost, and manufacturing ease. In most cases, the standard cast aluminum rotor is the best choice.</u> However, there are certain instances when a different construction is necessary.

A standard NEMA B motor has several key CTQ's. There are lower limits on locked rotor torque (LRT) and breakdown torque (BDT), an upper limit on locked rotor amps (LRA), and high efficiency is usually a criteria. A cast aluminum rotor is an excellent choice because of the flexibility in the design of the slot. The casting process provides opportunities for complex shapes at costs the market will bear. The use of a multi-cage rotor slot significantly improves the ability to design a high-efficiency motor with high torque and low starting amps. (This applies to NEMA C motors as well.)

On a NEMA D motor, there is a need for high slip and significantly higher locked rotor torque. The key factor to achieving both these requirements is higher resistance in the rotor bar. Special slot designs can be used to increase the rotor bar resistance to a point, but in many cases a lower conductivity rotor bar is needed. The conductivity needed depends on the motor rating and the amount of slip required. It would not be practical to equip a factory with the capability to cast many different types of rotor conductor materials, so fabricated rotor bars are used to provide various levels of rotor conductivity. GE Industrial Systems does have one alternate low conductivity alloy for casting high-slip rotors in 140-400 frames. In the 140-320 frame range, this low conductivity can provide NEMA D performance. In 360-400 frames there are cases where even lower conductivity is needed, so fabricated bars might be used in those frame sizes instead of the cast material. In 440-500 frame sizes, fabricated bars are always used whenever low conductivity is needed. The decision to use a fabricated bar rotor or a cast rotor for a NEMA D motor is driven by manufacturing practicality.

Besides NEMA D motors, there are a few other cases where performance dictates the need for a fabricated rotor as opposed to a cast rotor. In the quest to offer the maximum horsepower and highest efficiency possible in a 500 frame motor, some of the highest horsepower ratings in a 5013 frame require the higher conductivity of a copper bar rotor. Copper has a higher thermal capacity than aluminum and its lower resistance means lower losses in the rotor. Using a large, copper rotor bar allows for a cooler, more efficient motor. However, the lower resistance also results in reduced locked rotor torque and increased starting amps. Within the NEMA B scope, the increased flexibility of the slot geometry usually makes cast aluminum the best choice. For large motors above the NEMA design letter scope, the locked rotor torque requirements are lower and the locked rotor amps limits are less rigid, so there are opportunities to benefit from a copper bar rotor.

The following example shows the difference in the performance characteristics of a copper bar rotor versus a cast aluminum rotor for a 1000HP 1800RPM 4160V DP motor in a 5013 motor (the same stack length was used for both motors).

Copper Bar Rotor

| LRA | LRT | BDT | Temp Rise | Efficiency |
|---|---|---|---|---|
| 730% | 80% | 280% | 71.4°C | 96.4% |

Cast Aluminum Rotor

| LRA | LRT | BDT | Temp Rise | Efficiency |
|---|---|---|---|---|
| 690% | 121% | 273% | 82.0°C | 95.9% |

As the example shows, the copper bar rotor has a lower temperature rise and higher efficiency, but at the cost of reduced locked rotor torque and higher starting current.

Another example shows a comparison of a 350HP 1800RPM 460V TEFC NEMA B motor in a 509 frame (same stack length and fan used for both motors).

Copper Bar Rotor

| LRA | LRT | BDT | Temp Rise | Efficiency |
|---|---|---|---|---|
| 630% | 83% | 225% | 69.1°C | 96.1% |

Cast Aluminum Rotor

| LRA | LRT | BDT | Temp Rise | Efficiency |
|---|---|---|---|---|
| 640% | 115% | 245% | 66.0°C | 96.3% |

In this example, the copper bar rotor has no performance advantages over the cast aluminum rotor. In fact, due to the advantages of the multi-cage slot, the cast aluminum rotor provides a lower temperature rise and higher efficiency in addition to the higher locked rotor torque.

In many cases the requirements for high inertia starting seem to favor copper bar rotors with copper's higher temperature range and higher thermal capacity. However a well-designed multi-cage cast aluminum rotor can have a higher starting torque with reduced starting amps and larger cross-sectional area of slots that results in lower rotor temperatures during starting and decreased acceleration time.

The main criteria for selecting the appropriate rotor construction are performance issues. There are also some mechanical issues and miscellaneous factors that can be addressed. In general, either type of construction (cast or fabricated) provides a sturdy rotor that is unlikely to fail. Depending on the manufacturing process, a cast aluminum rotor could have a lower dynamic imbalance, resulting in reduced forces within the rotor structure. (A typical balancing operation doesn't actually correct the unbalance, but rather adds an equal but opposite directed force to counteract the unbalance.) Also, cast aluminum bars are inherently tight in their respective slots. One issue with bar rotors is bar/lamination vibration, which can cause arcing/sparking, vibration, and fatigue failures during “normal operation” (for this reason, bar rotors are not suitable for use in hazardous environments).

The selection of the best rotor construction for a given application depends on the type of motor being built and the application in which it will be used. In high horsepower ratings requiring Medium AC and Large AC motors, casting becomes impractical so fabricated rotors are used more frequently. For Small AC motors (140-500 frame), except for a few special cases, a cast aluminum rotor usually makes the most sense. The choice of rotor construction should be based on motor performance, and the motor manufacturer is best suited to recommend the ideal construction for a given application.

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