Monthly Informative Application Guidelines, with respect to *Motors & Drives* to keep you better INFORMED.

APPLICATION GUIDELINE #31

(Rotor Construction – Die Cast and Copper Bar)

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Dependant upon application and customer performance priority, Toshiba motor designs use both die cast aluminum (low pressure and/or high pressure) or copper bar rotor construction. Both these construction techniques (Die Cast or Copper Bar) have their advantages.

HIGH PRESSURE DIE CAST ALUMINUM ROTOR CONSTRUCTION:

Toshiba employs a high-pressure method of aluminum die-cast rotor construction where the rotor laminations have specially formed holes or punching through which aluminum flows during casting. These holes form rotor bars and define the bar geometry, which is a major contributing factor to the torque, current and efficiency characteristics of the motor. For a majority of designs, Toshiba uses a double-cage rotor design which yields high locked rotor torque, high pull-up torque, and low inrush current while maintaining higher efficiencies when compared to the same ratings with different cage designs. The rotor bars are cast integrally with large end rings. Large end rings are used to increase the heat dissipation capability of the rotor assembly and are designed to reduce current densities, lower I^2R losses and increase operating efficiency. In addition, Toshiba's high pressure die-cast rotor design yields a much higher inertia carrying capability than the values shown in NEMA MG 1 section 20.42, which is especially important in applications which require a large inertia carrying capability such as fans, mills and centrifuges.

On lower horsepower ratings, laminations for the stator and rotor are punched from the same sheet, at the same time, with the outer doughnut-shaped punching forming the stator lamination, and the inner punching forming the matching rotor lamination. In this process, stator-core slots and rotor bar slots are all punched in a single stamp. On higher horsepower ratings, rotor and stator lamination blanks are punched from sheets as before except stator slots and rotor bar slots are stamped separately by semi-automated single stamp operation punch presses.

Toshiba die-cast rotors are cast vertically. First the laminations are stacked on a mandrel and then compressed under high pressure before the molten aluminum is injected, or "shot" into the core. It is at this time, before injection, that the core is given a quality check for proper size based on the motor rating. First a weight check is done and then a core length measurement is taken while under pressure. After confirming the proper length, the rotor core is ready to be shot. Molten aluminum that has been heated to a preset value is then forced upwards, under pressure, from the bottom end mold, through the rotor core, to the upper end mold. One or both of the end molds (depending on the motor design) will also form the cooling fins for the rotor. The aluminum temperature, shot velocity, shot pressure and shot time are all very critical in forming a casting with minimum porosity, and are therefore, kept under very strict control. To verify this, the rotor core is weighed carefully before and after casting, and the allowable net aluminum weight is required to fall within a tight band.

The rotor bars, end rings, and cooling fins are all cast as one integral unit, as opposed to some rotor manufacturing processes which attempt to attach cast end rings to pre-assembled aluminum rotor bars. The Toshiba integral casting method results in an assembly which is very rigid, and which is able to withstand the stresses of thermal expansion or high pulsating torque applications without concern for relative movement between the bar assembly and rotor core. In this case there exists really only two components - the rotor laminations and the die-cast aluminum which forms the squirrel cage, and binds the lamination together.

The heated rotor core is then fitted with a shaft and is quenched via water immersion. This process, also called "hot drop", quickly shrinks the rotor to the shaft. This quenching process provides the additional benefit of separating the rotor bars from the core iron, creating an oxide layer of naturally formed protective insulation which will reduce eddy current losses. By creating this oxide layer of insulation and separating the aluminum bar from the core iron, overall motor efficiency is increased. On smaller units, rotor/shaft assemblies are shrunk fit (via hot drop) and secured by keys. On larger units both methods are employed along with a tack weld to further assure trouble free operation.

After casting and rotor insertion are complete, the rotor/shaft assembly is then placed in a lathe, where the outside diameter is machined to a smooth finish to ensure a uniform air gap between the rotor core and stator core assemblies. The diameter of all assemblies are closely monitored and are kept within stringent tolerances. Some manufacturers will machine the rotor core before shaft insertion. A very common problem with this type of processes is non-concentricity between the center line of the shaft and the machined surface of the rotor. A uniform air gap is critical to the proper distributing magnetic force (flux). This magnetic force directly affects slip, mechanical balance, electrical noise and efficiency. By machining after shaft insertion and referencing the shaft centerline in this machining process, consistency of process can be maintained thus providing optimum performance, motor life and operating efficiency.

The assembly is sometimes fitted with an internal cooling fan (if TEFC design), and moved to an IRD balancing station, where the shaft is rotated and the assembly is checked for runout. A balance test is then conducted. Any rotor assembly that does not meet the tight tolerance limits of balance will be rejected. The assembly is then spun to determine the balance correction required, if any. The appropriate balance weights are then riveted on, and the rotor is spun again to ensure the proper correction has been applied. After precision balancing, all rotor assemblies are painted with a special water resistant, rust inhibiting paint to protect against moisture and corrosion.

Before shipment, every motor is given a three phase locked rotor test. This quality testing procedure confirms final electrical performance by double checking the integrity of the rotor casting and assuring a consistent, high quality match between the completed stator core and rotor core assemblies.

LOW PRESSURE DIE CAST ALUMINUM ROTOR CONSTRUCTION

The industry standard method of die casting, which we refer to as high pressure die casting is limited in application to low voltage motors and smaller HP medium voltage motors. As mentioned above, the process consists of injecting aluminum upwards under high pressure through the lamination stack through the bottom end ring mold ultimately reaching the upper end ring mold. A slight negative pressure is drawn on the upper end ring mold. The injection process is quite violent out of necessity. The aluminum must be injected rapidly so as to not solidify in the rotor bar slots in the lamination stack. This rapid injection causes turbulence in the upper end ring mold which can result in small voids and in an upset condition, larger voids. Small voids are taken into account by the rotor design. Larger, unacceptable voids are detected by Toshiba by a three part rotor testing which consists of weighing the rotor stack before and after casting, imposing a maximum balance weight restriction and by performing a locked rotor test after assembly. Reliable rotors are manufactured using this process, but there is a physical size limitation hence, Toshiba utilizes a unique process called low-pressure die casting for larger HP motors.

Low pressure die casting process consists of preheating the lamination stack to allow a much lower pressure injection of the aluminum into the rotor slots in the laminations. An open ended oversized die is used on the upper end bell which eliminates the turbulence of high pressure die casting. The resulting end ring is actually an oversized end ring “block”. The lower die is also oversized producing an end ring “block” as well. After the rotor has cooled, the end rings with integral cooling fins are machined from the “blocks” at each end of the rotor using a computer controlled three axis lathe (similar to the lathe used to machine steam turbine blades).

The low pressure process produces an extremely rugged one piece, cast rotor which is virtually void free with all the performance and reliability advantages of die cast rotors but without the size limitations of conventional high pressure die casting. Toshiba manufactures motors up to 2500HP at its MIE works facility utilizing this process. (As a point of interest, the MIE works facility also produces copper bar rotors.)

COPPER BAR ROTOR

In the quest for expansion into larger horsepower production and increased requirements for design flexibility, Toshiba's Houston factory developed a copper bar rotor design. Toshiba's copper bar rotor design assures long reliable life due to the following construction and design features:

The rotor bars and end rings are made from Oxygen Free High Conductivity (O.F.H.C.) copper which helps to eliminate the possibility of Hydrogen imbrittlement during rotor fabrication and brazing. It also helps prolong the life of the rotor assembly especially under abusive applications. A conservative design which keeps the rotor bar temperature rise to below 250ºC during a start. The melting temperature of copper is 1000+ ºC and the melting temperature of the silver brazing material is 600 - 700 ºC. This assures that the rotor assembly is not unduly thermally stressed during startup. The rotor is designed with the end ring located inside the rotor bars and silver brazed in place which integrates the rotor bars and end rings together in an assembly, preventing thermal deformation or movement of the rotor bars during start-up or load changes.

Before offering this motor to customers, it was most important that the reliability of the design be verified. This resulted in the arrangement of a plug start/stop life test program, which is described below. The motor selected was a 300hp 1800rpm TEFC 4160v motor. A study was made to determine the shortest possible repeated cycle time for the following:
1) Apply power across the line (motor uncoupled)
2) Turn power off and begin coast down
3) Prior to stopping, re-apply power across the line in the reverse direction.

The following cycle time of 50 seconds was established which could be repeated many times without overheating the motor: **POWER ON** for 5 seconds, then **POWER OFF** for 45 seconds, then **REAPPLY POWER** (end of cycle). This cycle limited rotor temperature to 150^0C. A control panel was manufactured to continually apply this start/plug reverse, including a counter to verify the total cycles applied. The start/plug reverse cycle was repeated until a total of 100,000 cycles occurred. During the life test, the following tests / inspections were performed:

Number of Plugs	Commercial Test	Load Test	Visual Inspection
0	X	X	X
28,000	X		X
56,000	X		X
69,160	X	X	X
100,000	X	X	X

The motor passed the 100,000 cycle test with flying colors. There was no sign of weakening or failure in either the rotor or the stator assembly. (It should be noted that the Toshiba vacuum switchgear also held up to this strenuous duty cycle.)