Induction motor rotor bars

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The rotor of an induction motor is a critical component and has a major influence on the motor performance. The motor designer determines the motor characteristics with the design of the rotor and rotor bars.

Changing the bar profile and or material and the performance characteristics will change. This is an important factor which the repairers of electric induction motors must note. They need to take care that when they repair an induction motor rotor they must ensure that the same material and configuration in all respects is the same as per the original design. Changes can be made but these must only be carried out after careful consideration as to the effect this will have on the operating characteristics of the motor. Induction motor characteristics are typically as indicated in Figure 1.

![Figure 1: Typical induction motor speed torque curve for two types of rotor.](image1.png)

Changing the design of the rotor by replacing the brass or other high resistance bars on the outer cage of a double cage rotor will affect the starting torque or current, efficiency and characteristic of the motor.

**Induction motor rotor construction**

Induction rotors are usually constructed from laminated steel – generally the inner portion of the stator stamping which effectively reduces waste. The rotor lamination is either pressed directly on the shaft or spider in the case of larger machines.

**Cast aluminium rotor bars**

The cage type induction motors have a variety of possible construction methods. The most common in low voltage motors is the cast aluminium type. This type of construction has many advantages; the construction is relatively easy and cost effective for manufacture. Complex rotor bar shapes are relatively easy to obtain.

![Figure 2: Cast aluminium rotor punching.](image2.png)

Typically any cast aluminium bar shape required by the motor designer can be accommodated as the only requirement is the die for stamping the laminations, and the practicality for ensuring a good solid aluminium casting. Cast aluminium rotor bars can be practically any profile as the bars are cast into the slots and will fill any shape punched into the laminations. Limitations are predominantly designing that the flow of casting aluminium can fill the slots and end-ring cavity without any cavities or blow holes. Cavities, cracks or blow holes will affect the performance of the motor.

**Copper rotor bars**

Copper bar rotors can take many forms. The bars can be simple sections such as round, square, or rectangle but can also be wedge, tear drop, keyhole etc. in cross section.

Some manufacturers use double cage construction which would consist of the inner cage (usually copper) and outer cage, which would generally be an alloy such as brass – but could be any other complex alloy.

![Figure 3: Typical solid copper rotor bars.](image3.png)
In Figure 4, the solid copper and the double cage copper/brass configurations are only a few of the possible arrangements, square, oblong, rectangular or other sections are possible. Generally, the outer cage in a double cage configuration is a brass alloy; other alloys with a suitable resistance (conductivity) can and are used at the motor designers’ discretion.

Cast aluminium rotor bars can be practically any profile as the bars are cast into the slots and will fill any shape punched into the laminations. It is important that the rotor bars are tight in the slot otherwise they will vibrate, resulting in work hardening and premature failure. Some rotors, generally only in larger ratings motors, have the bars wedged with two opposite wedges under the bar to ensure a tight fit.

<table>
<thead>
<tr>
<th>Material</th>
<th>Melting Point</th>
<th>Density Kg/dm³</th>
<th>Coefficient of expansion a/ 10 – 6</th>
<th>% Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Aluminium</td>
<td>658</td>
<td>2,6</td>
<td>23,8</td>
<td>55</td>
</tr>
<tr>
<td>Brass</td>
<td>900</td>
<td>8,4</td>
<td>18,5</td>
<td>23 – 29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dependent on alloy</td>
</tr>
<tr>
<td>Copper</td>
<td>1083</td>
<td>8,8</td>
<td>16,5</td>
<td>94</td>
</tr>
</tbody>
</table>

Table 1: Relative properties of common materials.
Broken rotor bars

It is important to note that an induction motor can and will run with a number of broken rotor bars but the performance will be effected in a number of ways. If a copper rotor bar breaks the damage can result in a major failure, damaging the stator winding and, in time, the stator core. Even in the case where the stator winding and core are not damaged it could result in server rotor core damage; this is as a result of bar currents flowing through the core and burning the core. A motor will run with one or more rotor bars broken, but, depending on the type of rotor construction, the consequences could be different. One broken bar on a copper bar rotor could result in the motor being damaged so badly it could be a write-off; the rotor bar could lift and dig into the stator core and/or winding. Cast aluminium rotors do not generally damage the stator as the aluminium seldom comes out and damages the stator but I would not like to say this is an impossibility. See Images 6, and 7. This occurred due to a stall condition the rotor got so hot the aluminium melted and run into the stator winding.

Broken rotor bars in cage induction motors can produce axial vibrations on the motor frame at specific frequencies. When a bar breaks in a cage induction motor, two scenarios exist. The first scenario is based on the assumption that no current flow in the rotor bar. In this scenario the bar approaches an open circuit and a magnetic disturbance exists around the bar. This disturbance travels with the rotor and occurs in a localised portion of the air gap. The magnetic disturbance produced by the broken rotor bar links with the stator coils, resulting in an induced current in the stator. If you consider the backward rotating component of the fundamental harmonic of the magnetic disturbance, it is evident that this component rotates at 2 x slip frequency with respect to the stator. This can be seen in the current spectrum and is use to indicate broken rotor bar when the current wave form is analysed. (There are instruments on the market using this to indicate rotor bar failures of machine in service.)

The second scenario is when a bar breaks and the current still flows in the bar by means of inter-bar currents. The current enters the bar at the healthy end, and flows along the length of the bar and leaves the bar through the core and flows to the adjacent health bars. (This often results in burning of the laminations at the site where the current enters the laminations, due to the high resistance or the connection and laminations resulting in localised heat.) This invariably occurs in large induction machines. In Images 9, 10 and 12, you can clearly see the burning of the laminations and the erosion of the slot in the laminations resulting in a loose bar which could lift and damage the stator core and windings. The presence of axial vibration components indicates that a cracked or broken bar with inter-bar currents is present in the motor. As the fault worsens, burning of the core occurs and the inter-bar current decreases owing to the increase in the contact resistance.

As the inter-bar currents decrease, the adjustment bars carry more and more current and the fault spreads rapidly to the adjustment bars because of the increase in bar temperature associated with increased bar current. Rotor bar problems reduce the starting and running torque in the motor and therefore increase the run-up time of the motor increasing the rotor and stator temperature, this increase in temperature worsens the rotor condition and could lead to a reduction in stator insulation life. It is particularly bad in the case of frequent starting operation of the motor. Owing to the difference in expansion aluminium rotors suffer from deterioration in time as the motor ages resulting in a decrease in the torque characteristics of the motor.

Causes of broken rotor bars

The most susceptible region for broken rotor bars is at the joint or the bar and end-ring.

- Bars in the region between the core and end-ring are exposes to large accelerating and decelerating forces. These forces stress the bars and fatigue is the result causing fractures
- When the motor is started, the current migrates to the top of the bar due to the skin effect. This current migration creates a temperature gradient over the depth of the bar because the top of the bar heats faster than the bottom of the bar
- This uneven expansion stresses the bar and joints causing failure
- Manufacturing defects are a further cause of failure of the bars and joints
- Poor brazing causes weak spots and possible failure. Uneven heating prior to brazing can also result in increased stresses in the bars and joints
- Thermal stresses are a common cause of broken rotor bars. Heating of the rotor during starting can lead to continual expansion
and contraction of the bar, which leads to further stressing of the bar and joints

- During stalled conditions the majority of the input power goes to the rotor resulting in overheating of the rotor possible resulting in a meltdown as shown in Images 6, 7, 12 and 13
- Unbalance voltage supply system and harmonic can cause excessive heating of the rotor due to negative phase sequence and high frequency currents in the rotor

Testing of rotor bars

There are a number of ways to test for broken rotor bars some in operational tests others static:

In operation:
Current signature
Vibration

With the rotor in a lathe or balancing machine:
Induced voltage/current (the use of a search coil near to the surface of the rotor spinning in a magnetic field and the resultant wave form in the search coil displayed on an oscilloscope)

Static with rotor on an inspection trestle:
- Visual (Copper bar rotors) and server cases of cast aluminium rotors
- Growler and noting the current as the rotor is turned or as the growler is moved from bar to bar around the rotor.
- Note: A 50 Hz growler with a search coil will indicate an induced voltage or the current method is an indication as to the condition of the bars but may not penetrate to the bottom bars in a double cage arrangement
- Passing a current through the bars by connecting a power source between the end-rings and checking the magnetic flux pattern

Conclusion

Rotor bar failures are a major concern as the effect the performance of the motor and any defect in the rotor bars whether Cast Aluminium, Copper Bar, Double Cage type or any other will get steadily worse and if not detected and rectified could result in a very serious motor failure. (Bar could lift damaging rotor core, stator core and windings). Test and inspections on the rotor bars can and should be carried out when a motor is opened for any reason. Vibration and current signatures will assist in indicating and potential rotor problems, and these can be dealt with at a convenient time as soon as possible. It is not possible to repair a cast aluminium rotor bar failure and a replacement is recommended.

Henry du Preez has a BSc degree from the University of the Witwatersrand, an MBL from UNISA, GED electrical engineering (Wits) and an Electrical and Mechanical government certificate of competency. He is a Fellow of the SAIEE and a registered Professional Engineer. He has fifty years’ experience in the heavy engineering field, industry and mines and specialises in electrical machines and transformers. He currently works as a consultant, predominantly for repair and maintenance in mining and industry. He offers training courses in the field of machine and transformers aimed at users, engineers, maintenance staff and the repair industry.

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