Designing Squirrel Cage Rotor Slots with High Conductivity

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I. INTRODUCTION:

There has been, in recent years, an effort to make cast copper rotors for industrial use induction motors. The objective is to make motors more efficient because of the higher conductivity of copper. In addition, the reduced losses in such motors may lead to better design flexibility and therefor motors which are more compact.

In this paper we examine the tradeoff between running efficiency and starting performance. In order to understand how induction motors work it is necessary to have a good model for the conduction properties of the conductors in the slots of the rotor. We employ a simple model that has been developed for this purpose.[i] We propose to examine the frequency response of the rotor bar impedance for indications of how the motor will work, taking into account not only running efficiency and starting performance but also stray load losses which are also affected by rotor bar impedance.

II. ROTOR IMPEDANCE

For illustration, Figure 1 shows a comparison of torque vs. speed for two identical notional induction motors, differing only in the value of rotor resistance, commonly noted as R_2. The characteristic curve with higher resistance would, for all load torques, operate at a somewhat lower running speed (and hence higher slip and lower efficiency) than the machine with the lower resistance. On the other hand, starting torque is lower for the low resistance rotor and this might lead to unsatisfactory performance in some applications.

The use of copper as the conductor of induction motor rotors would typically lead to improvements in efficiency, relative to motors using aluminum. This is often done in large motors in which squirrel cages are fabricated from bars of material brazed to end rings. In such machines it is common to employ 'starting' bars of higher resistivity material. Our objective here, however, is to discuss ways of designing rotor slots for fabrication by casting a single material, as is commonly done with aluminum as the rotor conductor material.

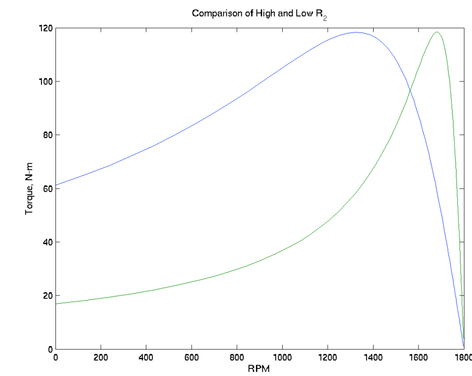

Figure 1: Notional Torque Speed Curves

In some induction motors, what is called the 'deep bar' effect, or distribution of rotor currents due to eddy currents, is taken advantage of. When the rotor is stationary or turning slowly the frequency of rotor currents is relatively high, the currents crowd to the top of the rotor bar and the resistive part of impedance is relatively high.

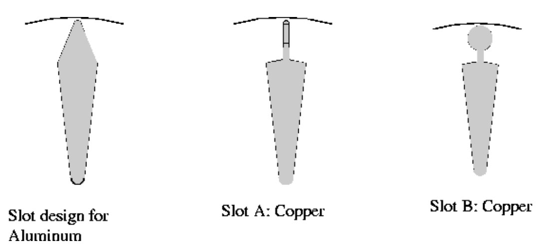

Figure 2: Comparison of Slot Shapes

Shown in Figure 2 are three different possible slot shapes. On the left is the shape used in the original cast aluminum rotor. It has a characteristic tapered shape so that the teeth between rotor bars are of uniform section. It tapers toward the rotor surface.

Figure 3 shows the real and reactive parts of the impedance of the slot designed for aluminum with two different materials: aluminum and copper.

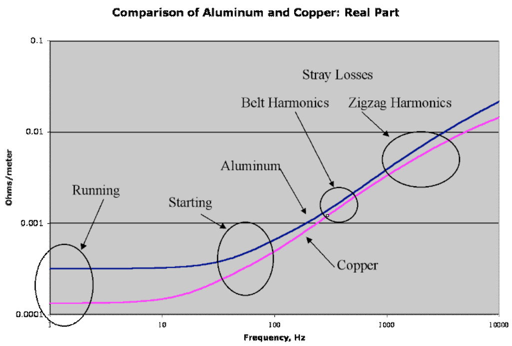

Figure 3: Aluminum and Copper Impedance

The frequency range shown in Figure 3 encompasses not only starting and running frequencies, but also the frequencies of currents in the rotor bars due to the various space harmonics of the stator winding. As can be seen in the figure, the copper rotor has substantially lower resistance over the whole frequency range, but the difference is largest at running conditions. At higher frequencies the smaller skin depth of copper causes the impedance of those bars to increase.

Now the question at hand is this: Can we shape the rotor bars to take advantage of the higher conductivity of copper to produce good running efficiency and yet have satisfactory starting performance? We do not believe we have found the optimum bar shape yet, but we can at least illustrate the question with a comparison of the two other bar shapes shown in Figure 2. Figure 4 shows a comparison of the slot impedance of those two bars over the same frequency range.

The first copper bar was designed with a narrow top within which the relatively high frequency currents of starting flow, producing a higher resistance at start. Note that this is only partially successful, as the second bar design, B actually results in larger resistance at starting. This is because the narrow slot between the top, starting bar and the rest of the conductor is effective at isolating starting frequency currents to the starting bar. At the same time, note that Bar A results in higher resistance at harmonic frequencies, indicating possibly higher stray load losses.

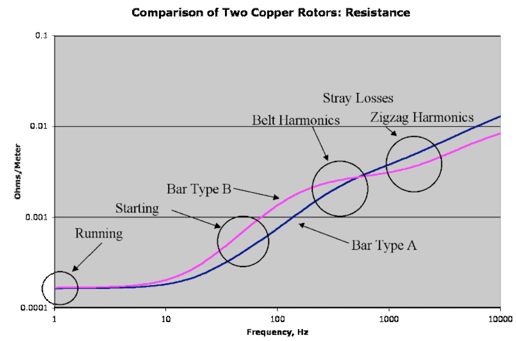

Figure 4: Comparison of two copper rotors

III METHODOLOGY

To establish the resistances we use a simple technique for representing the rotor bar as a ladder network (see reference 1). The bar is divided into a relatively large number of slices, oriented in a direction perpendicular to the rotor surface. The resistance and inductive reactance of each of these is estimated using standard techniques. A more sophisticated technique might have been used[ii]. In this case it was felt that the accuracy achieved by the ladder network would be sufficient.

IV CONCLUSION

This work is not finished. Remaining are verification that the frequency response technique will give adequate results when compared with measurements on actual motors (that work is in process). Further optimization of slot shapes will follow experimental verification.

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i Modelling of Rotorbars with Skin Effect for Dynamic Simulation of Induction Machines, J. Langheim, Conference Record, IEEE Industry Applications Society Annual Meeting, 1989, pp 38-44.

ii Calculation of cage induction motor equivalent circuit parameters using finite elements, S. Williamson, M.J. Robinson, Proc. IEE (Part B) Vol 138, No. 5 pp 264-276, (1991)