Electric Machine Design Course

Rotor Design for A-Synchronous Induction Machines

Part 1

Lecture # 20

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Rotor design of AC Induction machines

Since the majority of AC induction machines used around the world are fitted with aluminum die cast squirrel cage rotors it might be falsely assumed that the design of these rotors is a trivial matter.

Note that most all of those widely used AC machines around the world were designed run on world grid power with fixed voltages and frequency. (60 Hz in USA & 50 Hz in some other countries)

Considerable effort was put forth (by trial and error testing perhaps) to come up with the current standard NEMA type rotor slots shown in the next slide.

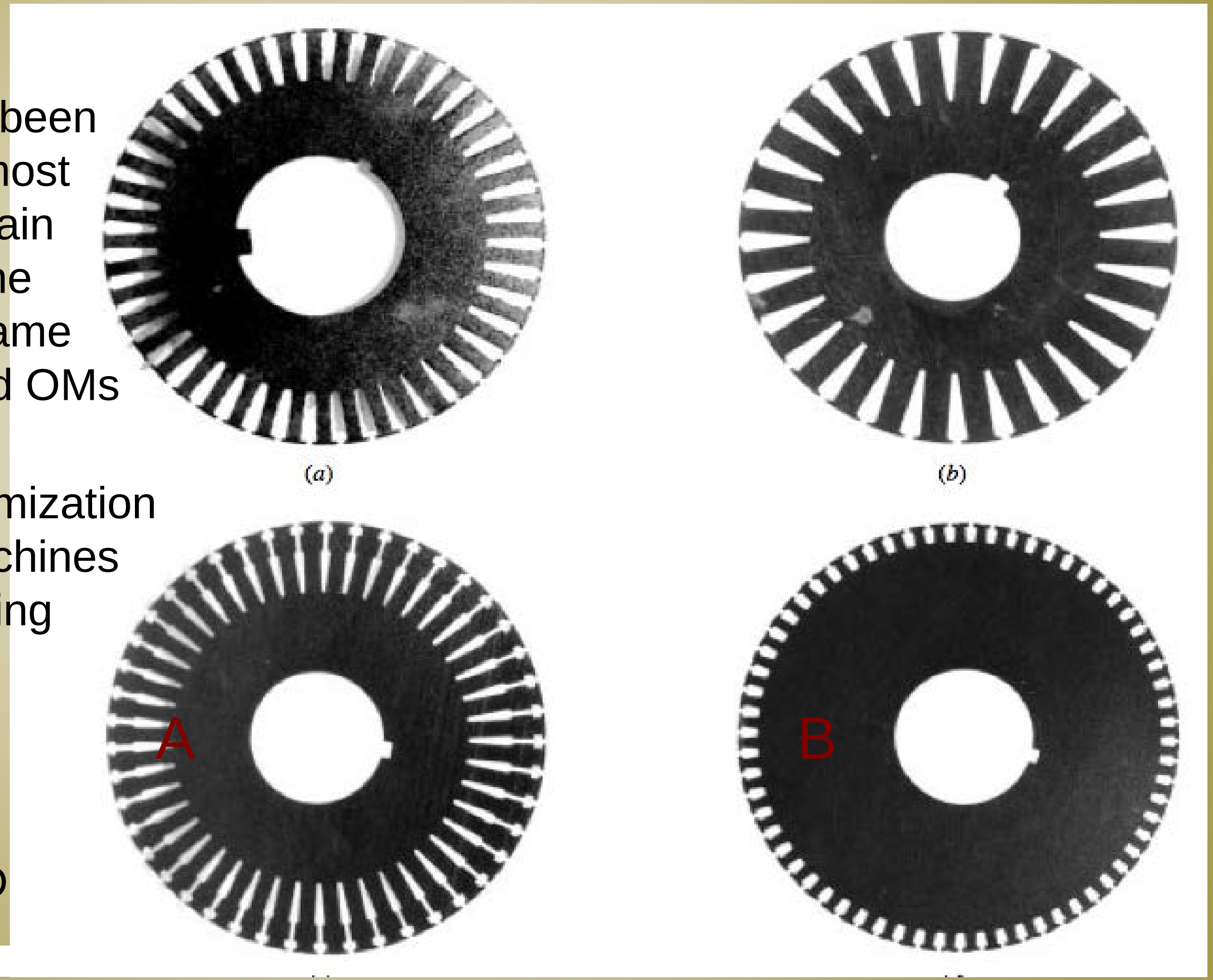
The purpose of the different configurations are a result of various application load requirements such as connected load inertias as well as starting torque requirements against breakaway friction.

NEMA type A, B, C & D, rotor laminations

Stator designs have been much the same for most IM machines. The main differences lie with the rotor designs. The same is true for inverter fed OMs

Rotor bar shape optimization grid powered AC machines based upon the starting torque requirements

These rotor slots optimized for GRID powered machines



Rotor cage considerations

The rotor is made electrical steel laminations and stacked to form a rotor core.

Traditional grid powered machines use dies cast aluminum rotor cages (since the 1930s & currently up to 30” diameter and 50” long core lengths).

The rotor cage consists of axial current conductors called “bars”

These bars are most economically cast in place as integral with a full washer like ring at each end of the rotor core. (called a squirrel cage)

This cast in place aluminum cage assembly forms the secondary shorted turn of the IM which is considered an AC transformer with a rotating secondary.

The current flows due to induction by the stator phases creating poles to form the same number of poles in the cage in the rotor.

There is only one turn per coil for all caged IMs no matter the stator phase turns (Amazing I think !! One would seldom design a transformer that way!!)

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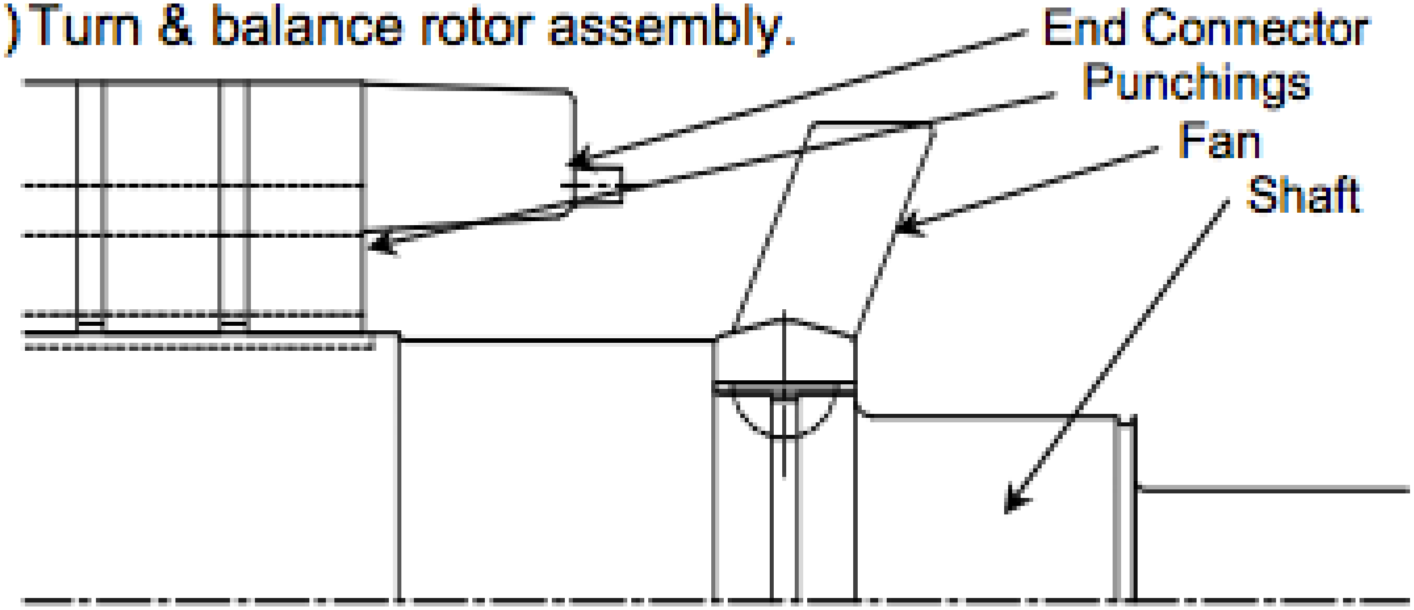
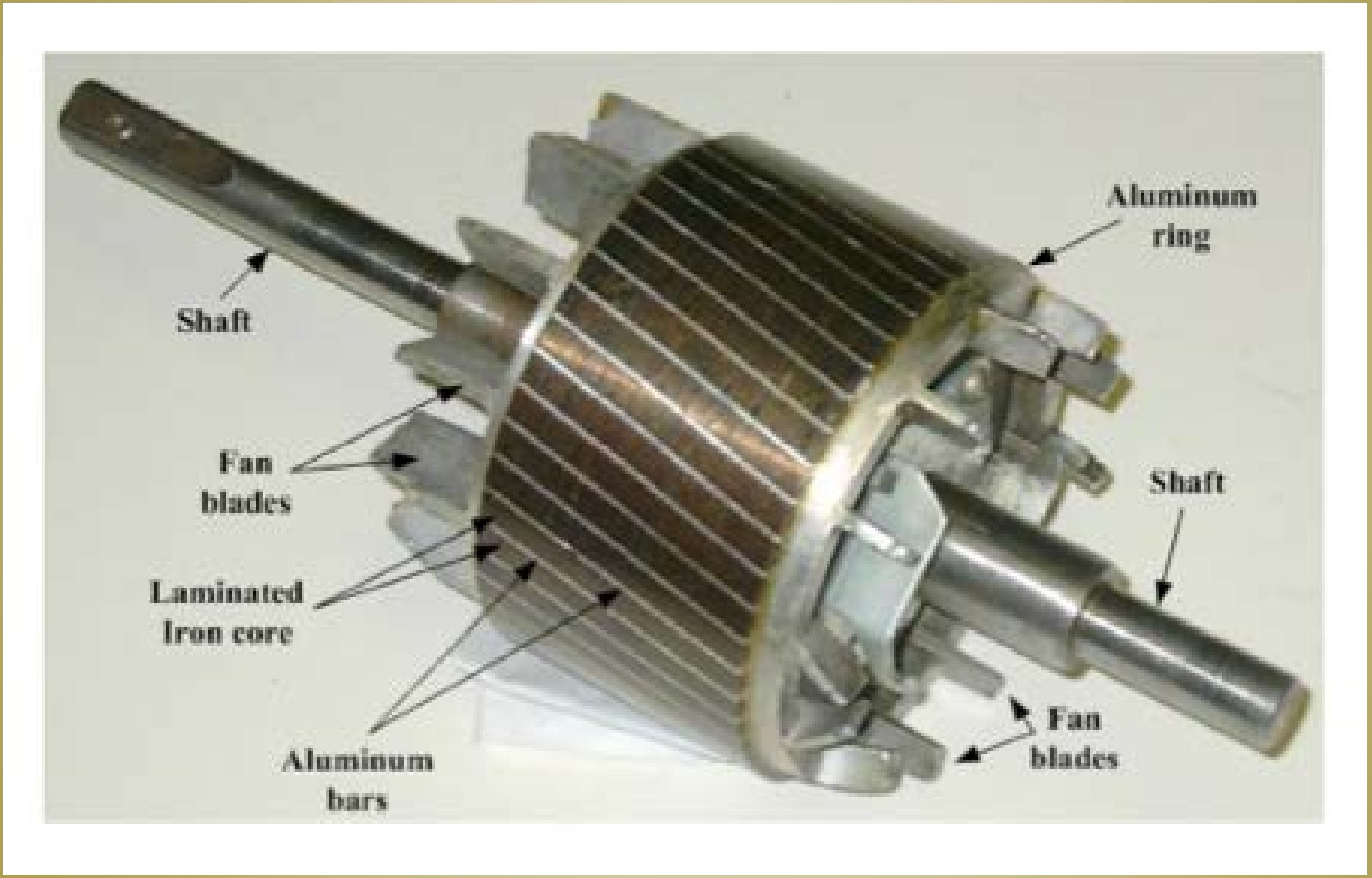
Aluminum die design determined cage quality

The aluminum rotor is constructed utilizing the following steps:

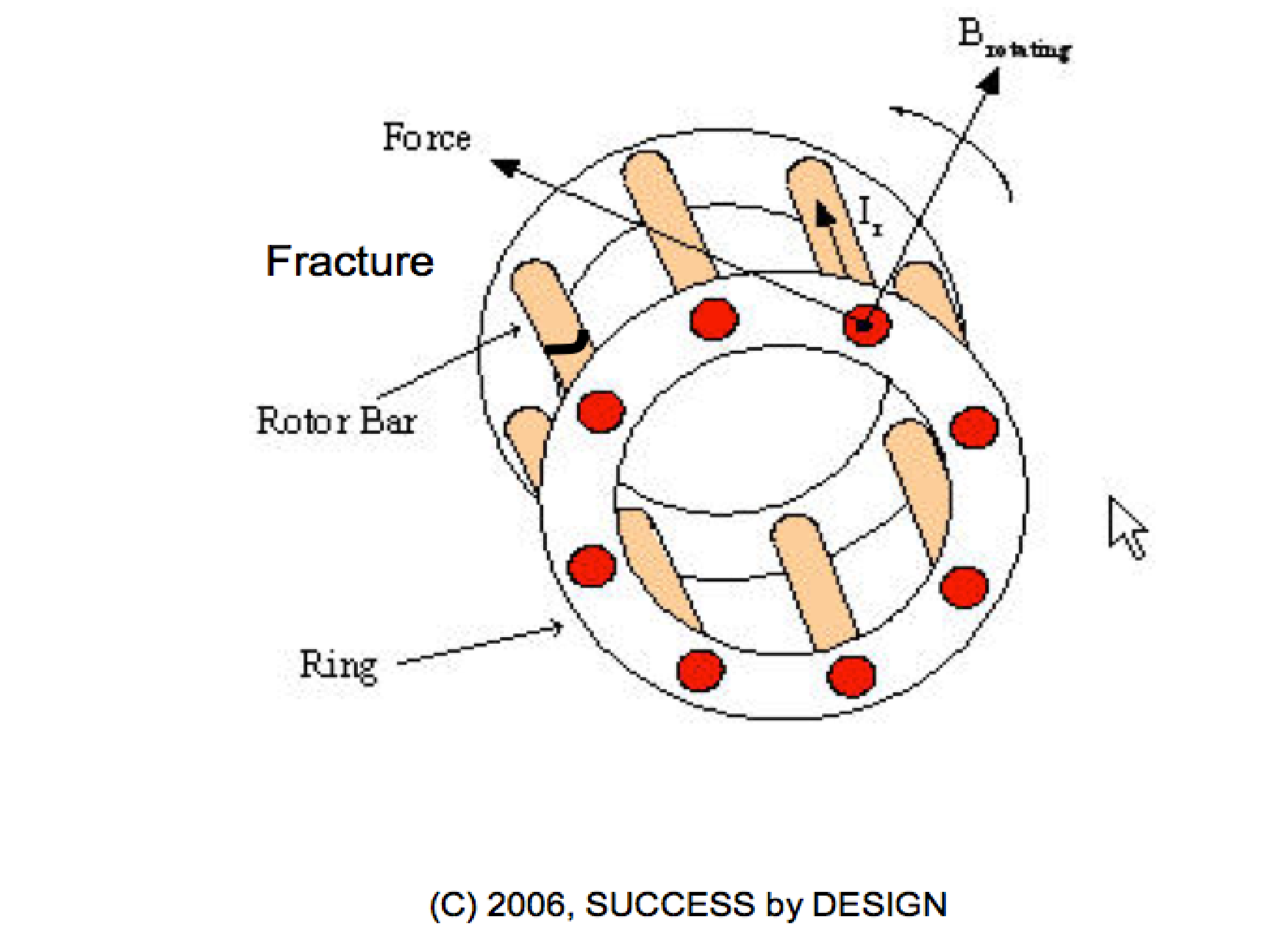
1.) Stack rotor punchings on a stacking mandrel.
2.) Insert punching/mandrel stack in end connector mold.
3.) Die cast (i.e. inject aluminum) rotor.
4.) Insert shaft into hot rotor core.
5.) Turn & balance rotor assembly.



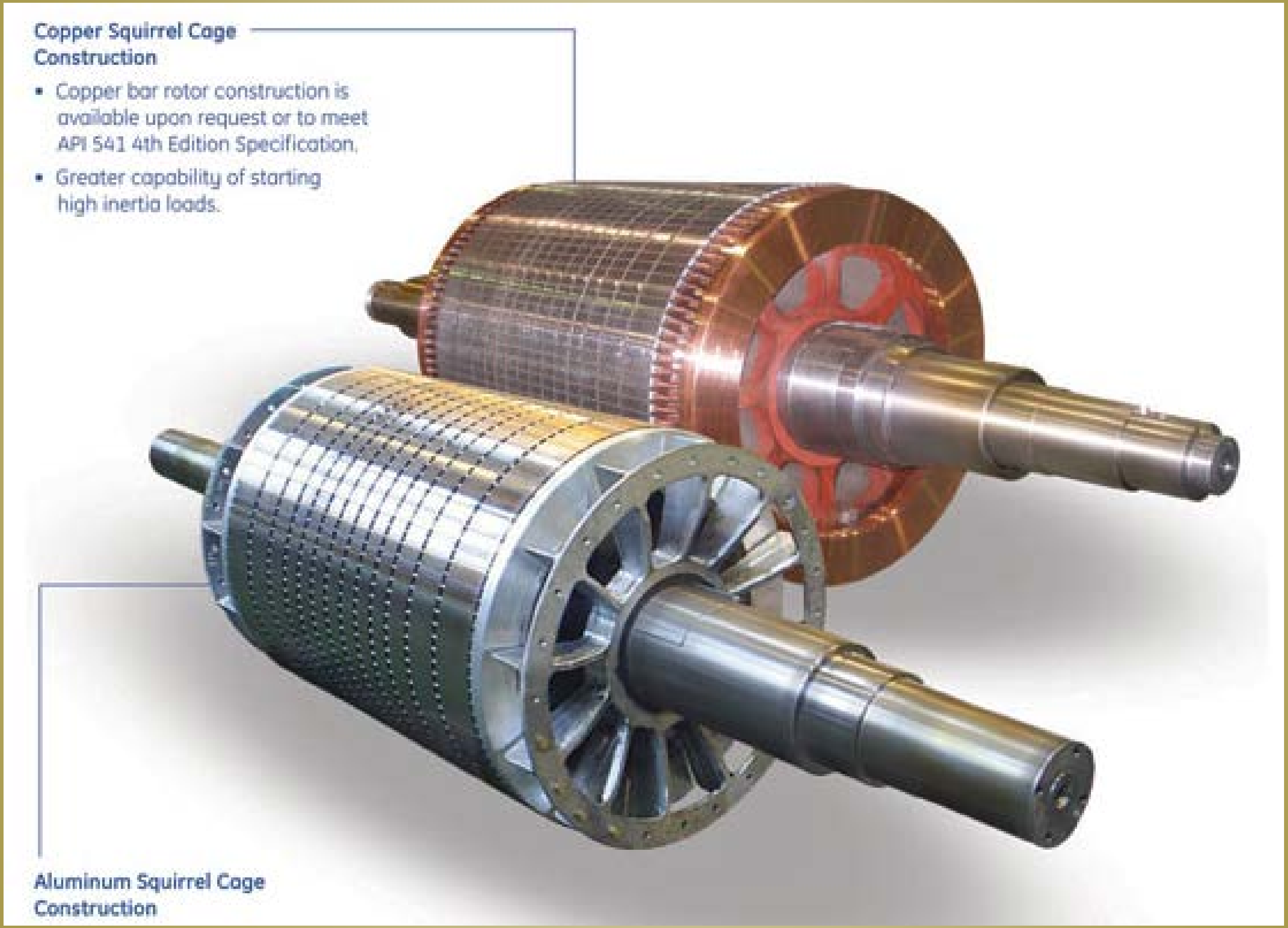
Typical die cast aluminum caged rotor



Magnetic forces on end rings



Copper vs Aluminum Cage Rotor



Important die casting details for both Al & CU rotors

1- Precise tooling lamination stamping ID and stacking mandrel

2- Rotate laminations relative to die locations for straight stack

3- Die casting and clamping pressure mush be maintained

4- Die castings must not produce porosity in bars

.

5- Controlled shot temperature and vacuum die cavity

.

6- Shaft should be inserted into hot core before it cools

.

7- Recommended casting parameters for Al & Cu die casting

	Al	Cu
Temperature	1200 F	2000 F
Shot Pressure	2000 PSI	6500 PSI
Clamp Pressure	2400 PSI	7800 PSI

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Siemens

Fabricated IM rotors from AL or Cu

Larger low volume machines as well as prototypes frequently utilize fabricated rotors no matter the bar and end ring material.

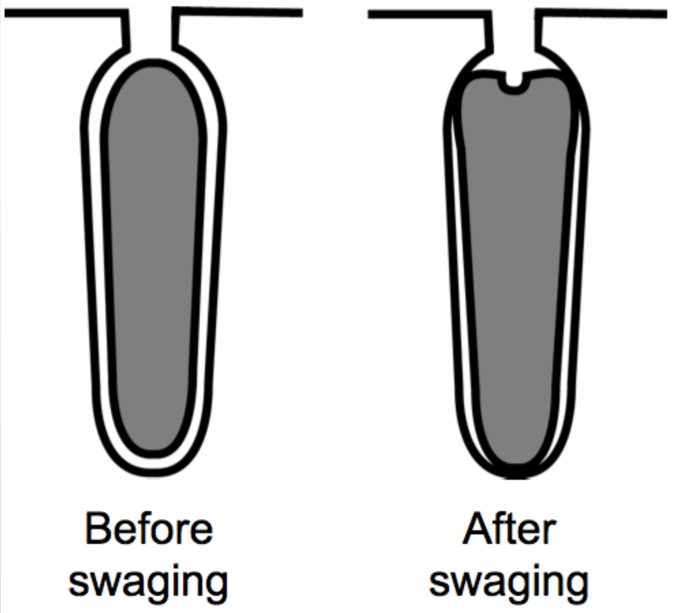
Welded construction can be used for either Al or Cu rotors.

Excessive bar and core temperatures must be avoided due to stresses.

Axial clamping pressure must be controlled & maintained during welding

Bars must be tightened by shimming or center swaging through the slot openings with special blade tools under high pressure.

Bar Vibration Frequency = 2 x slip% x frequency
High AC rotor currents cause vibrating bar forces



Fabricated AC rotors

Use of fabricated caged rotors of aluminum or copper

- Tear dropped bars are extruded, cast or machined
- Parallel sided bars are lower in cost to make which results in tapered rotor teeth
- Bars must be restrained in slots to prevent movement

End rings must be attached to bars correctly by:

- Oven high temperature brazing
- Induction soldering
- Welding by laser, plasma, TIG/MIG & most recently by *stir welding*

Finish machining and balancing are required

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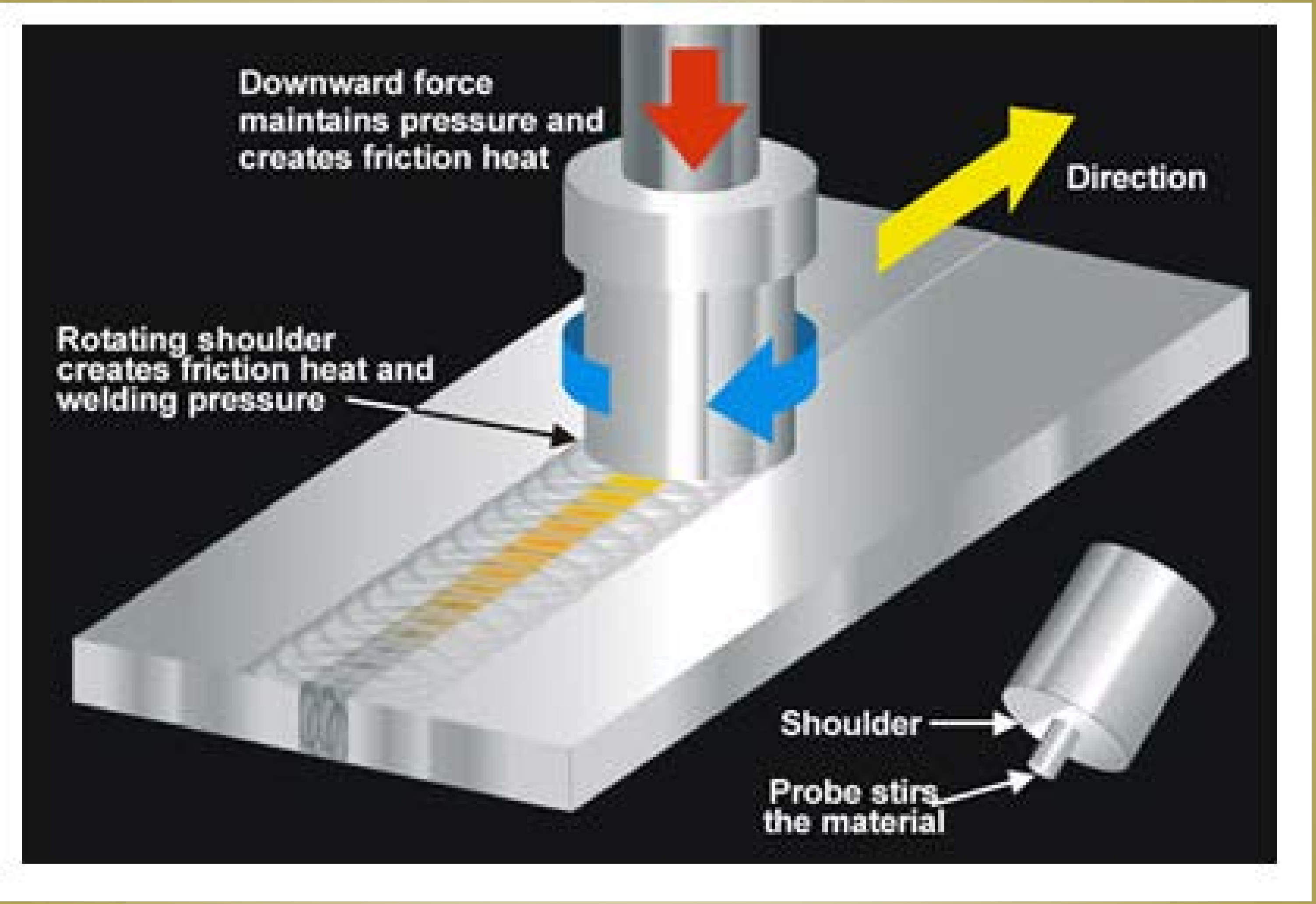
Friction Stir-Welding



Friction stir-welding first used extensively for aluminum welding

Rotor bar to end ring stir welding

Cross section of stir-weld of rotor bar to end ring from GM patent.

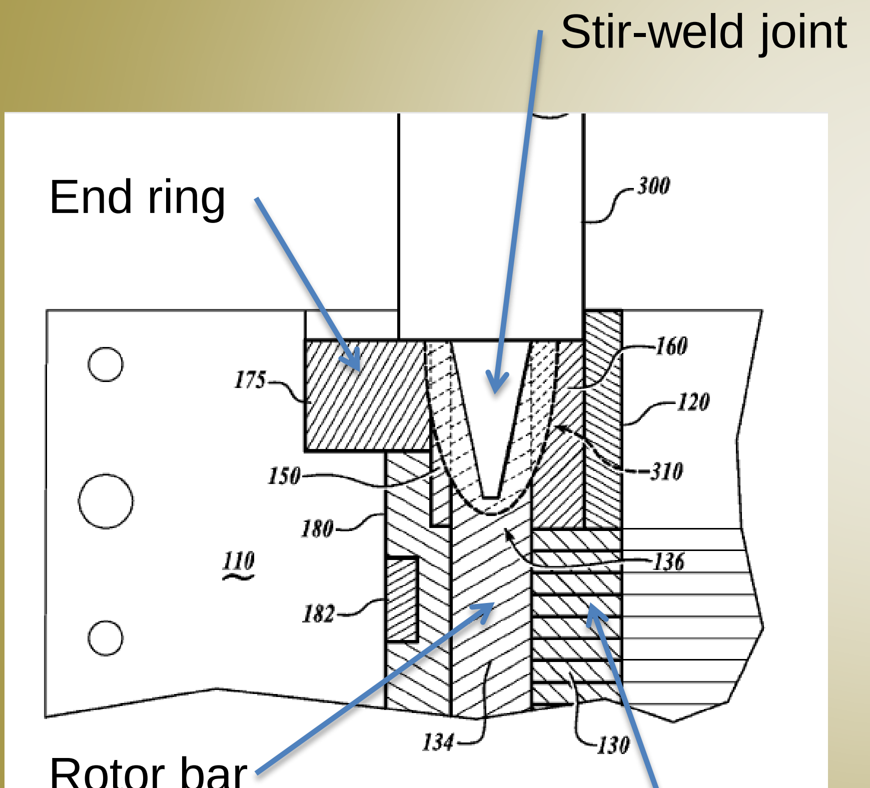
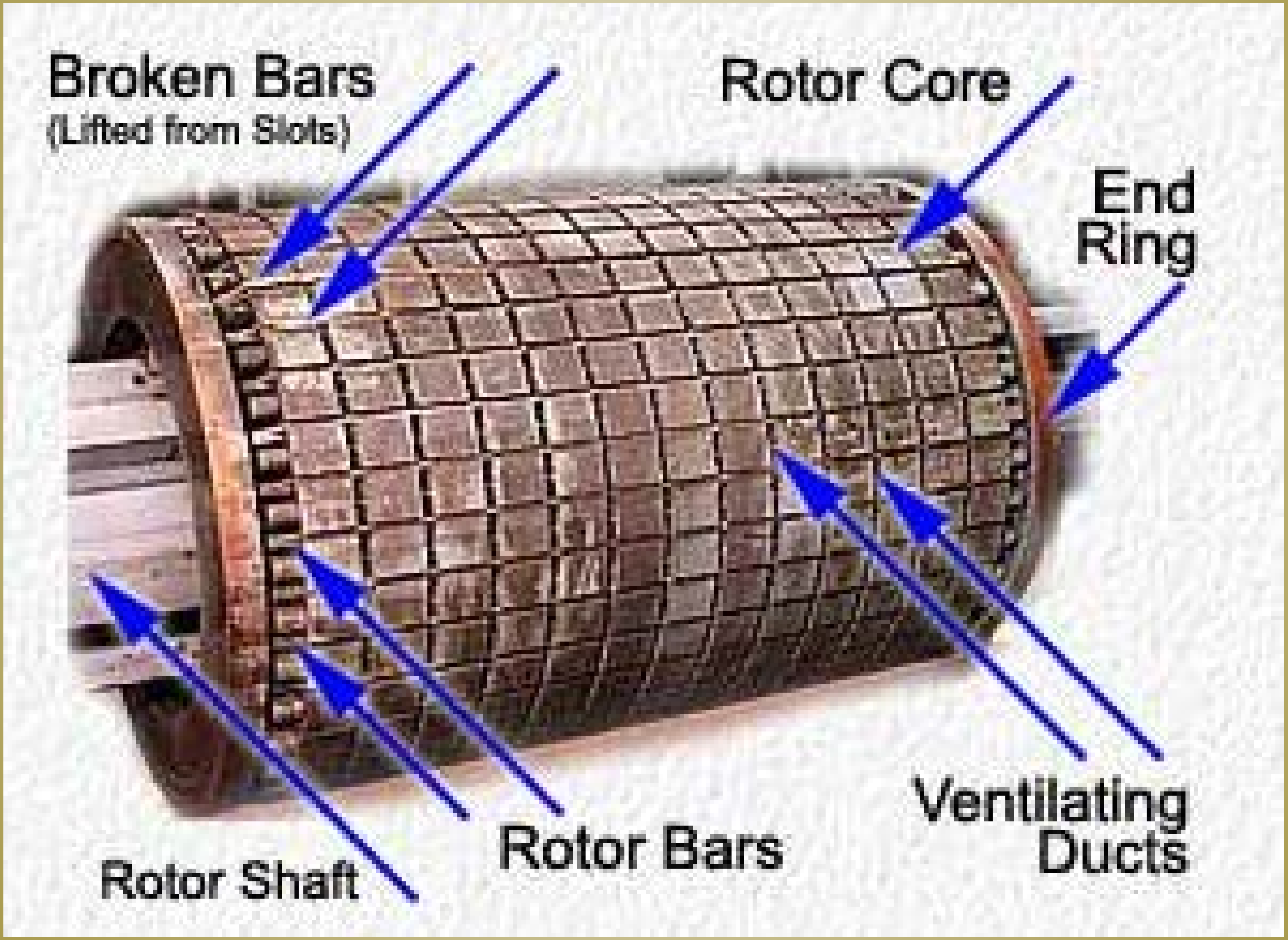


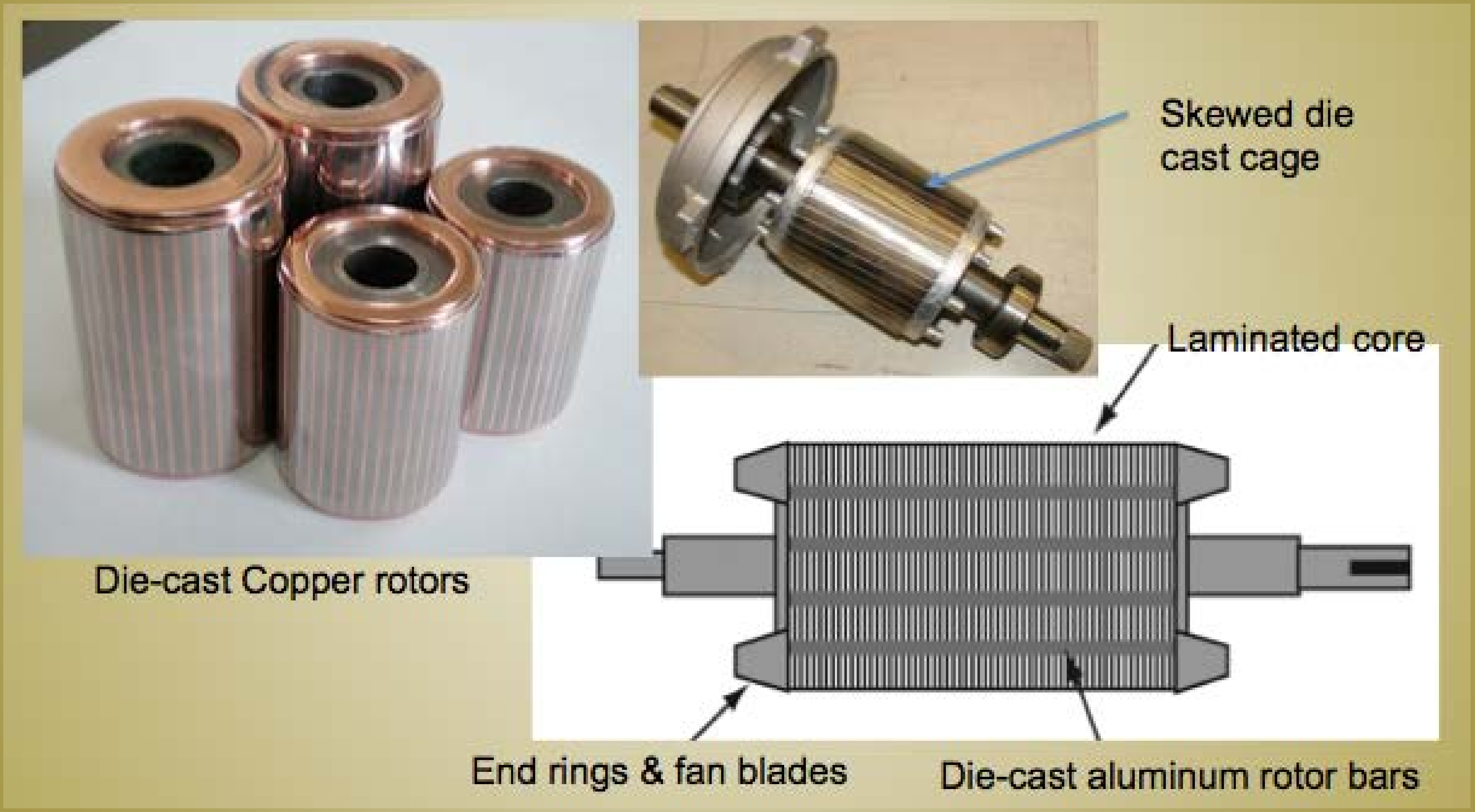
FIG. 7

Various Stir-Weld type joints

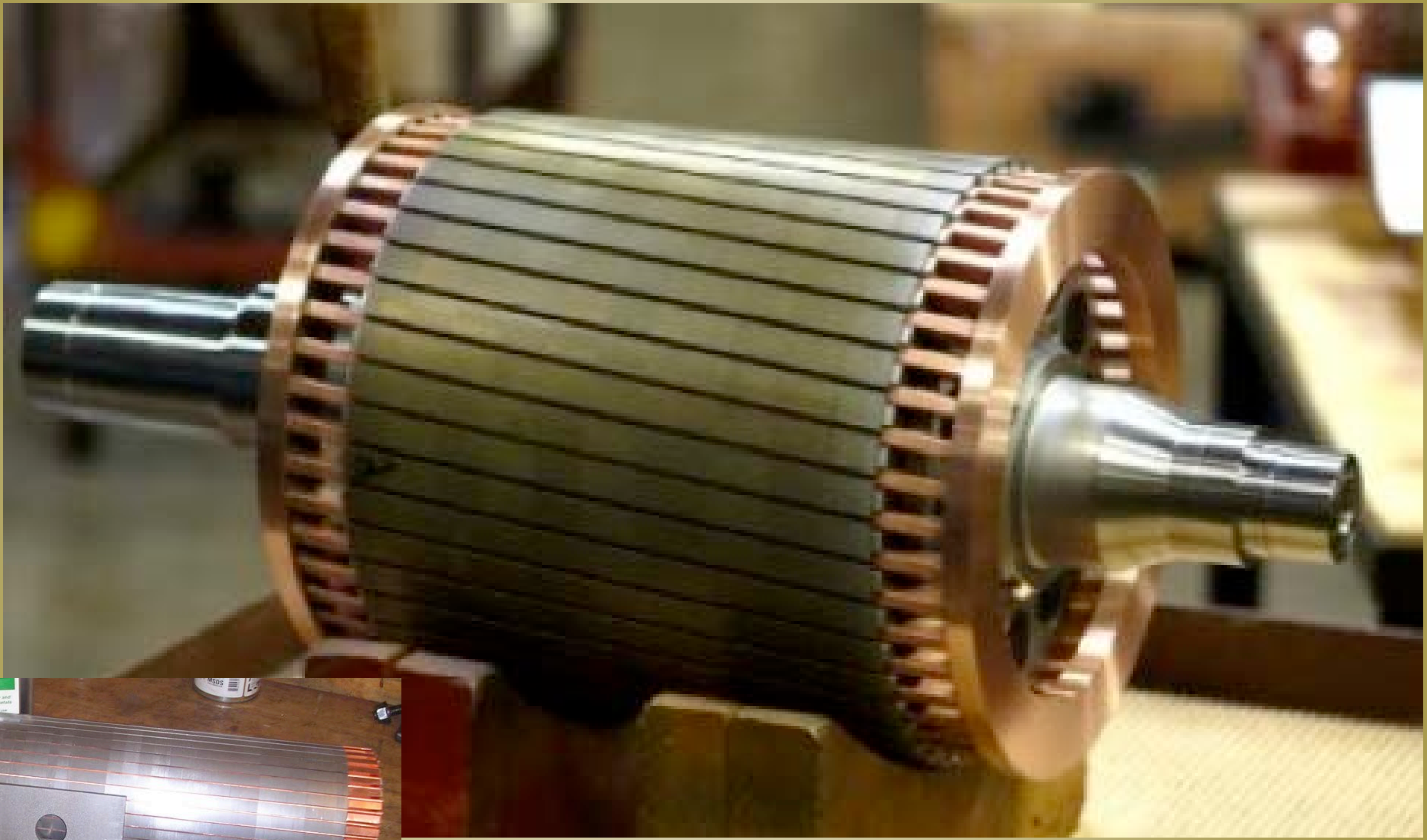
Components of large AC induction motor rotor (usually with copper bars & end rings



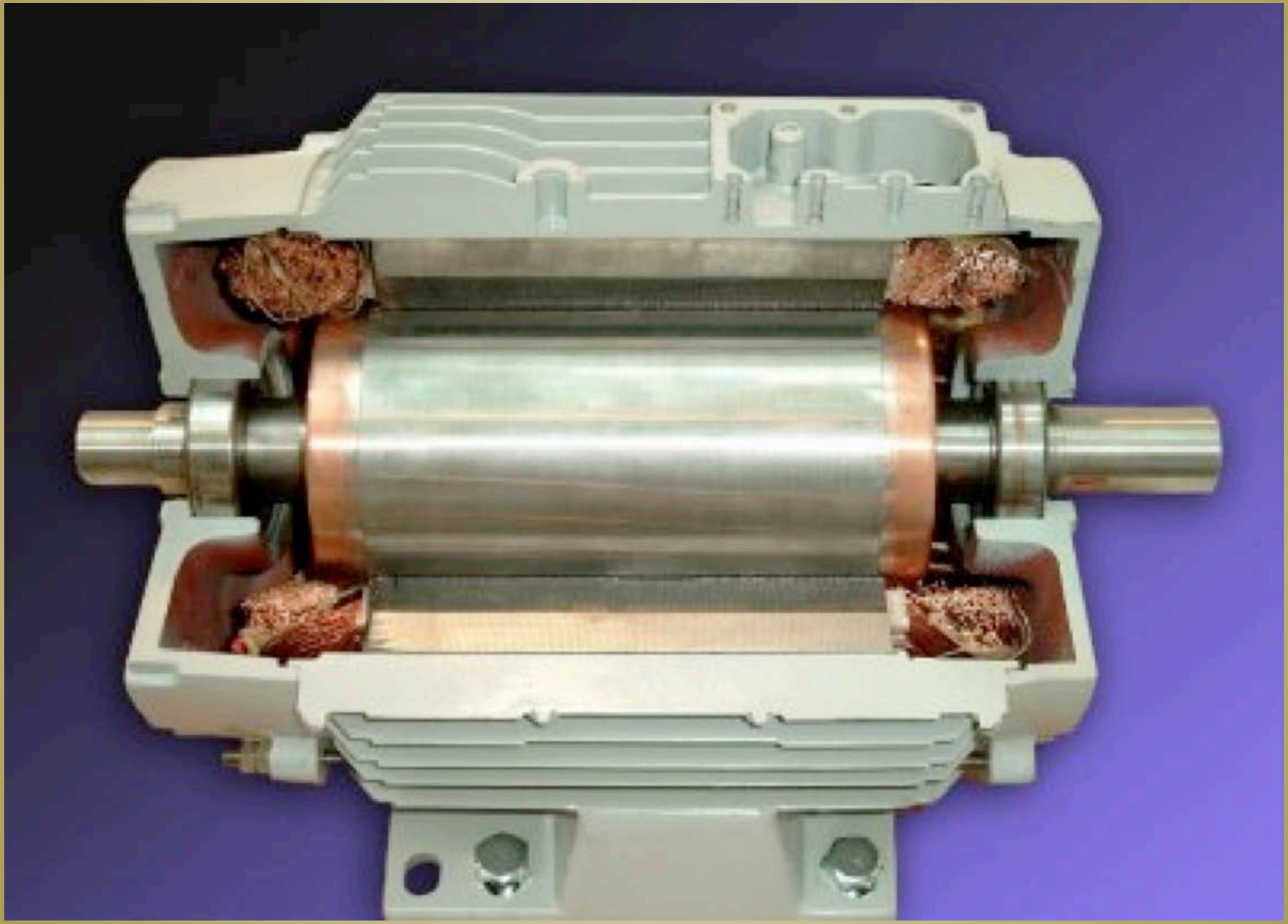
Components of simple AC induction motor rotor (*known as Squirrel Cage*)



Fabricated copper squirrel cage rotor



Die cast copper rotor in an induction motor



Aluminum & Copper rotor bar issues

- Forces on the rotor bar
- Cast Rotors vs Rotor Bars
- Rotor Bar Breakage
- ESA Signatures for Rotor Bar Failures

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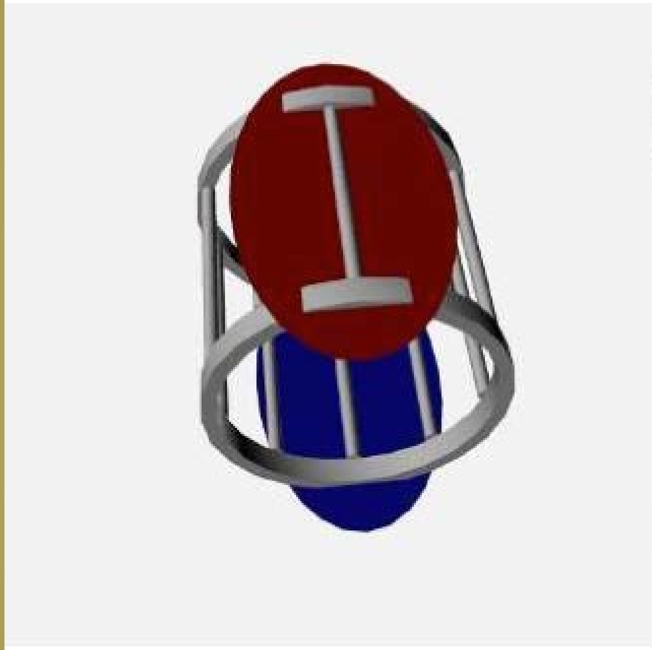
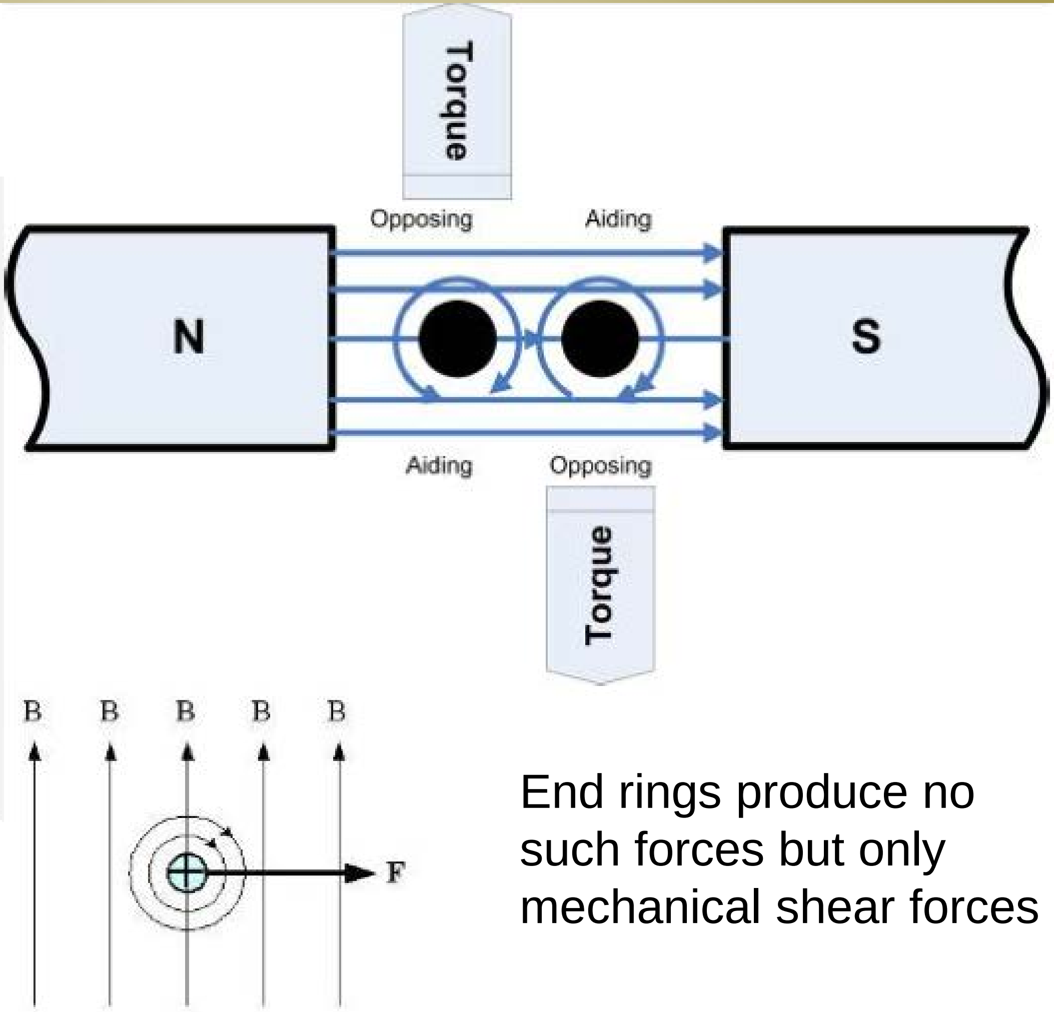
Electro-magnetic tangential forces on rotor bars





End rings produce no such forces but only mechanical shear forces

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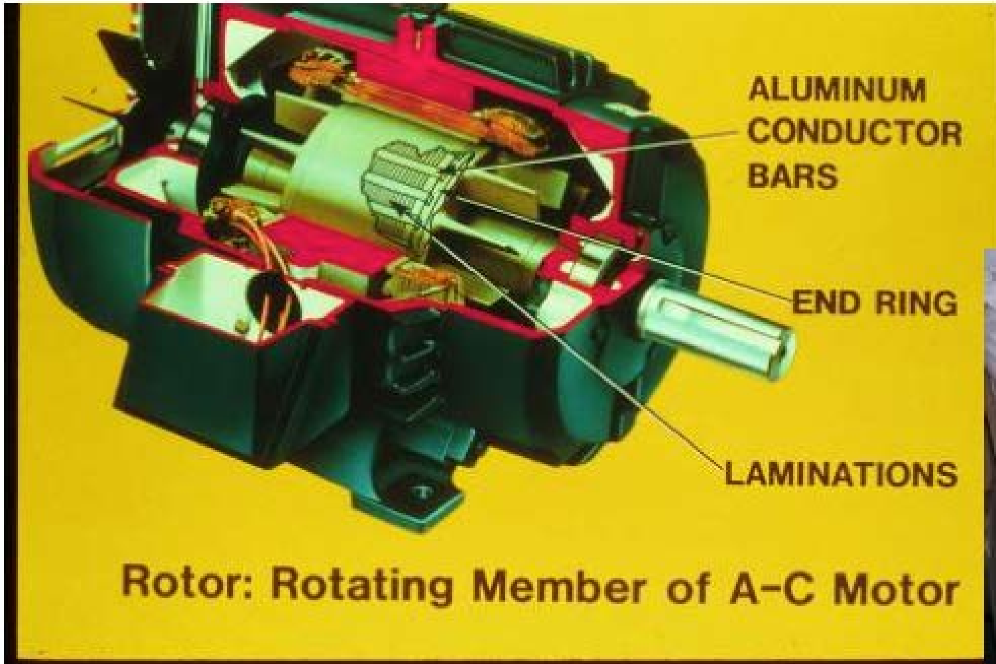
cast vs. fabricated cage inertial forces on bars & end rings



Cast determined as one solid mass.

Rotor bar construction – rotor and end rings calcuated as different inertial forces

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Copper vs. Aluminum Rotor Comparison

Motor Power (HP)	Motor Frequency (Hz)	Design Change‡	Efficiency		Improvement in Efficiency (percentage points)	Percentage Reduction in Rotor Losses	Ref
			Aluminum Rotor	Copper Rotor			
1.5	50	L	75.7%	82.8%	7.1	–	4
2	50	L+ST	78.0%	83.5%	5.5	58%	5
4	50	L	82.0%	84.5%	2.5	46%	6
4	50	L + ST	82.0%	86.5%	4.5	50%	6
4	50	L + ST	81.8%	88.2%	6.4	63%	5
7.4	50	R	84.1%	88.4%	4.3	–	7
7.4	50	R	84.8%	88.1%	3.3	–	4
10	50	L	84.2%	88.1%	3.9	50%	6
10	50	L + ST	84.2%	89.0%	4.8	60%	6
10	50	L + ST	86.1%	90.7%	4.6	59%	5
15	60	F	89.5%	90.7%	1.2	40%	1, 2
20	50	L	90.1%	91.9%	1.8	48%	11
25	60	Slot	90.9%	92.5%	1.6	40%	1, 2

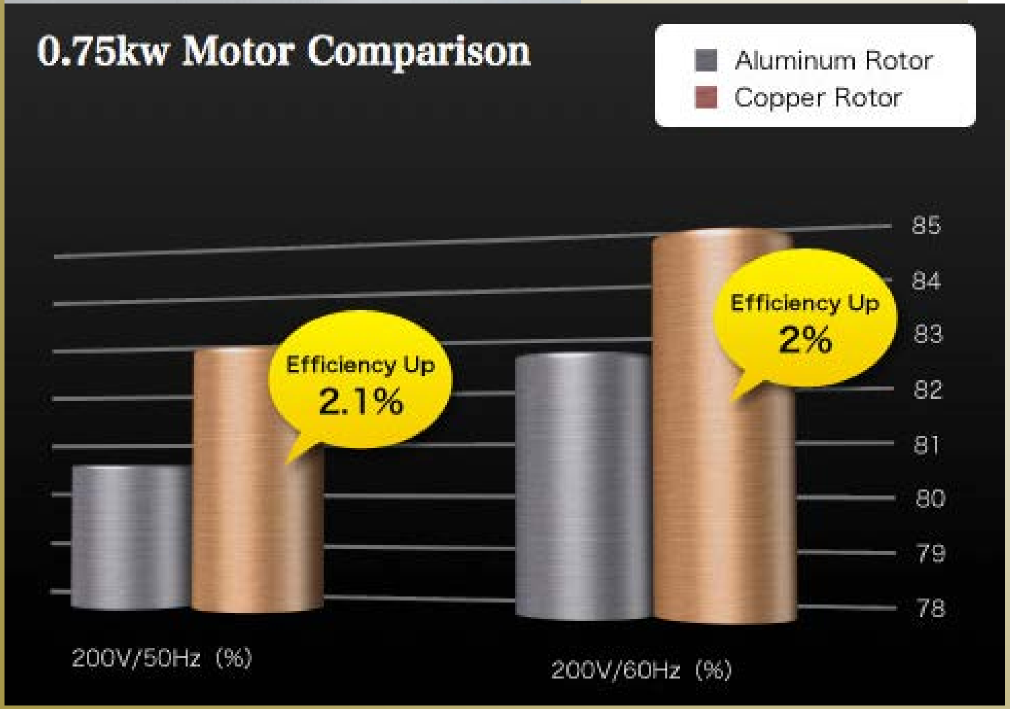
Performance comparison of tested aluminum rotor vs copper rotors.

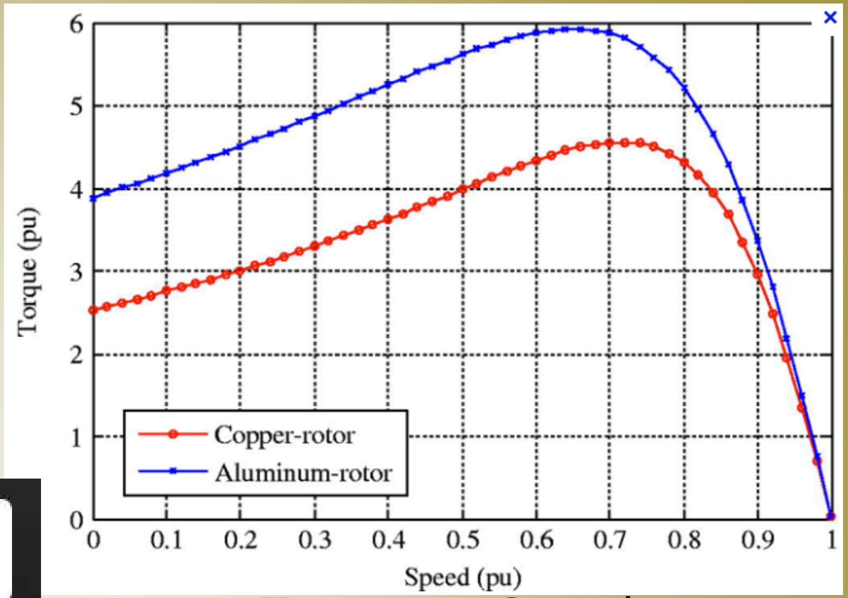
Table 1. Test Data and Performance Characteristics of 1.1, 5.5, 11 & 37 kW Motors – Standard Efficiency Series Aluminum Rotor Models Compared to High Efficiency Copper Rotor Designs. 400 V, 50 Hz.

Rotor Conductor **Rated Power, kW**	**Al** **1.1**	**Cu** **1.1**	**Al** **5.5**	**Cu** **5.5**	**Al** **11**	**Cu** **11**	**Al** **37**	**Cu** **37**
Rated Current, A	2.68	2.45	11	10.9	21.8	21.9	67.1	67.5
Power Factor	0.77	0.79	0.83	0.83	0.83	0.81	0.87	0.85
Speed, rev./min	1418	1459.5	1424	1455.7	1437	1460	1468	1485
Rated Torque, Nm	7.4	7.21	36.9	36.15	73	71.9	240	237.7
Slip, %	5.50	2.70	5.10	2.95	4.20	2.67	2.10	1.00
Power Consumed, W	1435	1334	6485	6276	12590	12330	40700	39900
Stator Copper Losses, W	192.6	115.1	427.4	372.4	629	521	1044	975
Iron Losses, W	63.6	51	140.8	101	227	189	749	520
Stray Load Losses, W	9.5	6.7	100.3	31.4	163	171	699	200
Rotor Losses, W	64.1	31.4	299.2	170.4	483	311	837	451
Windage & Friction, W	15.9	25	17.5	36	63	56.5	304	203
Efficiency, %	**75.9**	**82.8**	**84.8**	**88.12**	**87.6**	**89.9**	**91.1**	**93.2**
Temperature Rise, K°	61.1	27.8	80.0	61.3	75	62.1	77.0	70.4

Energy Efficiency in Motor Driven Systems
5 –8 Sept. 2005 EEMODS 2005Heidelberg

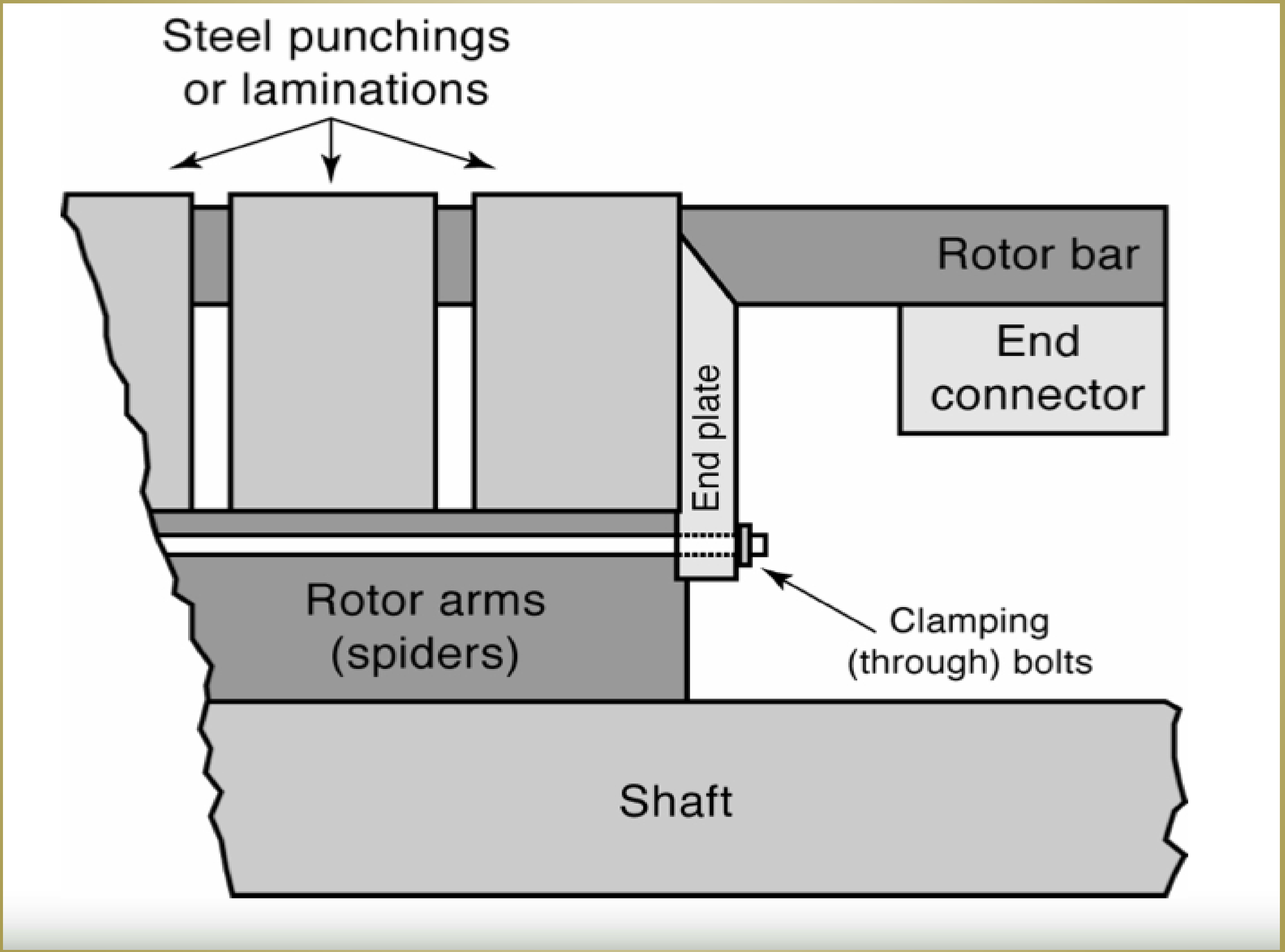
Copper IM rotors



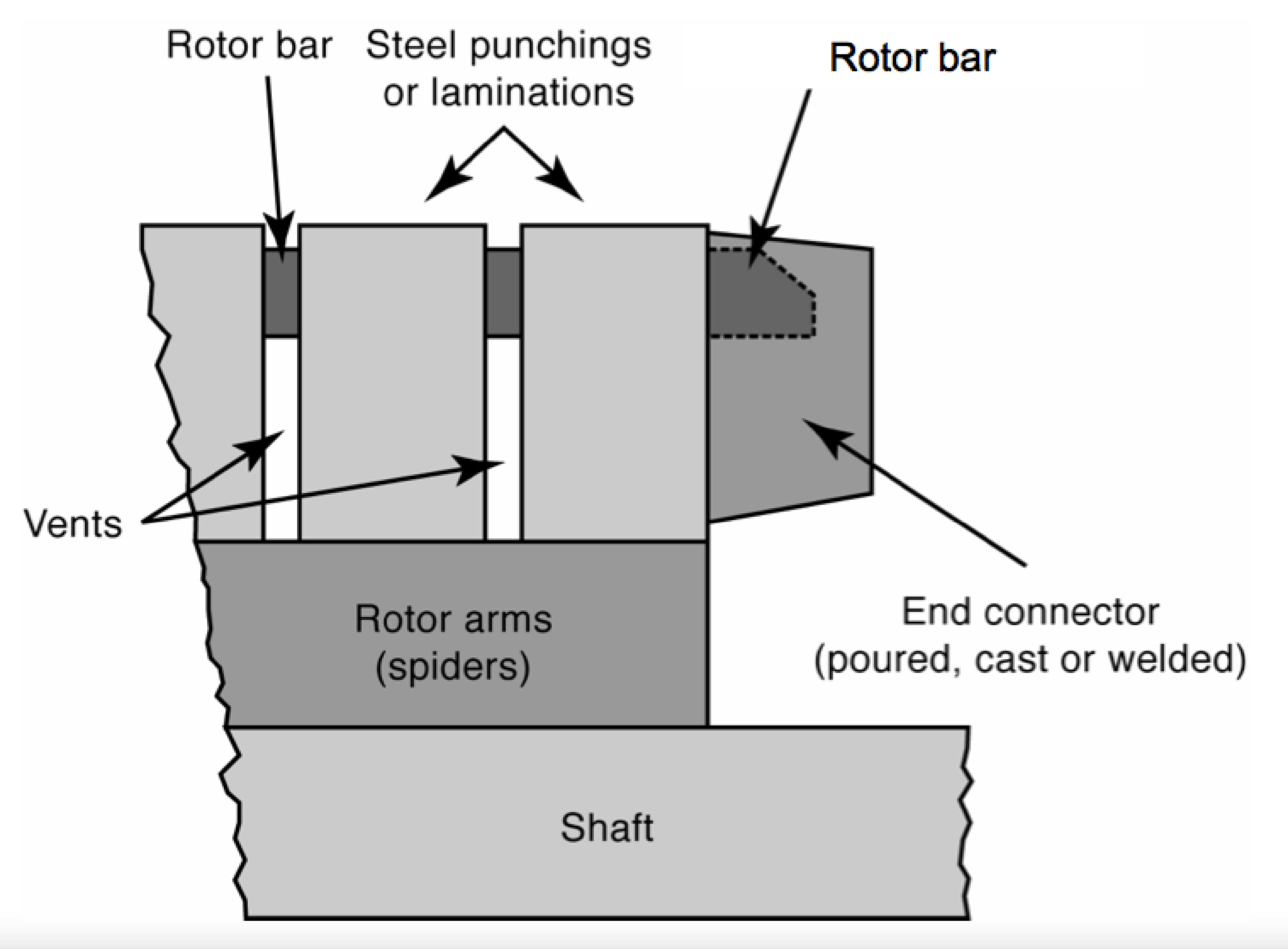


Torque vs. Speed
Aluminum vs copper rotor

Large Copper IM rotor construction



Large aluminum IM rotor construction



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