Impact of Burnout Oven Stripping on Rewound Motor Reliability and Rewinding Considerations

Thursday, August 24th, 2017

Presented by:
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Motor Repair Standards/Specifications

- Designed to ensure reliable repairs
- Standards are created by:
  - National and international organizations
    - IEEE, NEMA, EASA, IEC, etc.
  - Repair shops
  - Motor using companies
  - Motor manufacturers

Motor Repair Standards/Specifications

PROBLEM: A majority of standards/specifications contain little or brief detail on stripping and rewinding of motors.

Dangers of Low Quality Rewind Process

- Failure from Loose Windings/Vibration
- Susceptibility to Contamination
- Poor Heat Transfer
- Imbalanced Current and Temperature
- Insulation Failure
- Physical Deformation of Motor Components
  - Air Gap Change
  - Bearing Misalignment
  - Warping of Motor Frame
  - Soft-Foot

Dangers of Low Quality Rewind Process Cont.

- Core Loss
- Efficiency Loss
- Power Factor Decrease
- Increase Operating Costs
- Phase Imbalance
- Metallurgical Change in Electrical Steel

Stator Winding Types

Random Wound

Form Coil

Winding Components

Winding Ties

Phase Paper

Wedges, Slot Liners, & Insulation

Copper Coils

Lamination/Core Steel

Stator Laminations/Core

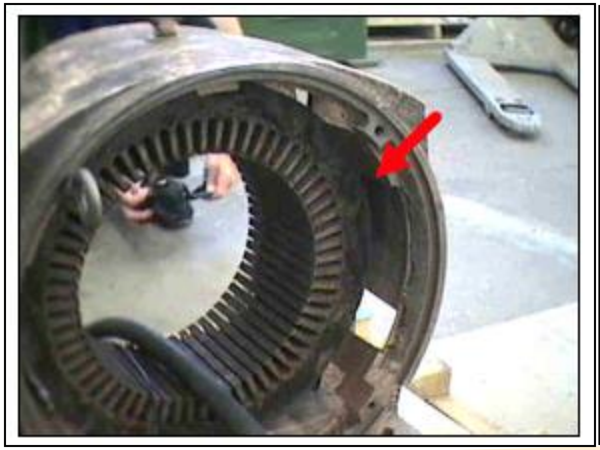
- Laminations are made from electrical steel to channel magnetic fields
- All laminations are individually coated with an insulator to prevent shorting together
- Lamination steels are designed to prevent Eddy Currents and Hysteresis Losses
- Electrical steel manufacturers design laminations for specific electrical characteristics

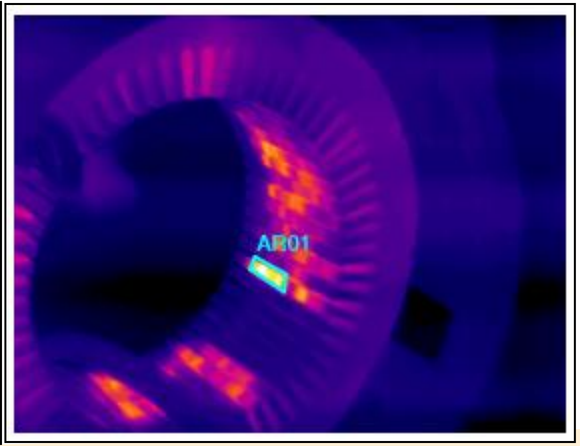
How are Windings Stripped?

- Burnout Oven Incineration:
  - Winding insulations are turned to ash at temperature ranging from 600 °F – 1000 °F
- Flame Thrower/Open Flame Torching:
  - Flame is applied directly to winding slots to incinerate motor insulation
- Chemical Bath
  - Motors are soaked in chemicals that eats away and softens varnish
- High Pressure Water Blasting
  - Coils blasted away with extremely high psi water flow

Core Loss and Hot Spot Testing

- Current is applied thru the stator to measure the loss in Watts/Pound (W/lb.)
- Hot spot test is also performed with machine and infrared camera





Dreisilker Motor Safe Stripping Method

- Gas or Induction Warming with Hydraulic Pulling
  - Stator core is heated with gas or high frequency induction around 400 °F or near the insulation class temperature until copper and varnish softens enough to pull coil groups out hydraulically

Burnout Stripping Method Case Study

- Two motors burnout stripped per EASA recommendations and accreditation auditing checklist

Burnout Stripping Method Case Study

- Recommendations [1] and Accreditation Auditing Checklist [2] for stripping and coil removal:
  - 750 ˚F burnout temperature setting for inorganic laminations
  - Set on feet in burnout oven to avoid warpage
  - Fire suppression system tested before oven cycle started
  - Core loss measured before and after stripping
    - Accreditation Auditing Manual allows 20% change with no baseline of what's an unacceptable value in W's/lb.
  - Burnout oven was calibrated prior to use

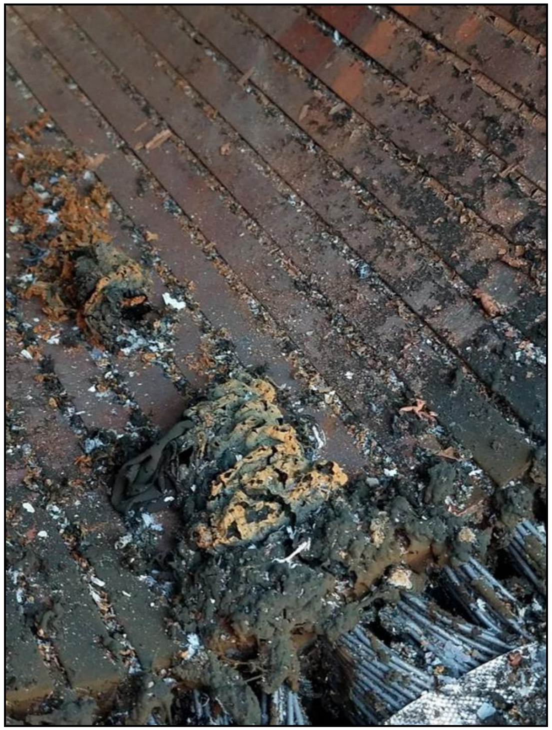
Burnout Stripping Method Case Study
In Oven Before

Burnout Stripping Method Case Study
Burnout Oven Cycle

- Oven started at 8:30am and reached 750 ˚F at 10:30 am.
- Between 1.5 to 2 hours temperature reached over 800 ˚F and fire suppression system activated to quench the fire from the burning winding insulation
- At 7am the next day, the internal oven temperature was at 114 ˚F before opening doors to remove stators

Case Study of Burnout Method
After Oven Cycle

Burnout Stripping Method Case Study
Close Ups After Oven Cycle



Burnout Stripping Method Case Study
Close Ups After Oven Cycle

Top wedge is completely incinerated

Before and After Findings: Core Loss

100 HP	Core Loss (W's/lb.)	Hotspots?
Before	4.678	No
After	10.101	Many

200 HP	Core Loss (W's/lb.)	Hotspots?
Before	2.473	No
After	2.028	No

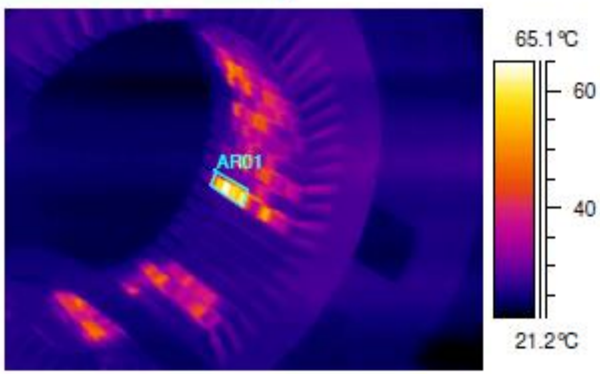
Before and After Findings: Infrared of 100 HP

Identification

Section	Winding Dept
Equipment	Stator
Additional information	Study one (1)
Date	8/8/2017
Time	1:09:05 PM

A Phase	B Phase	C Phase

Fault description



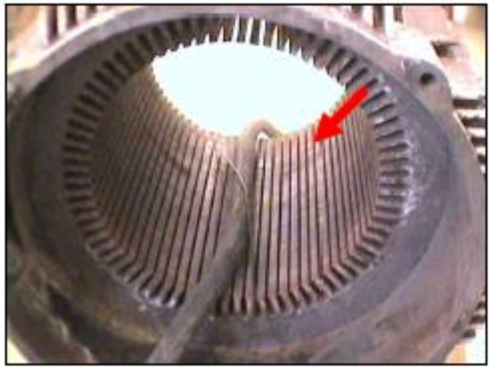
Fault	

Object parameter	**Value**
Emissivity	0.96
Object distance	1.0 ft
Label	**Value**
AR01 : max	67.3°C
AR01 : max-min	41.1°C

153.14 °F
(67.3 °C)

Before and After Findings: Infrared 200 HP

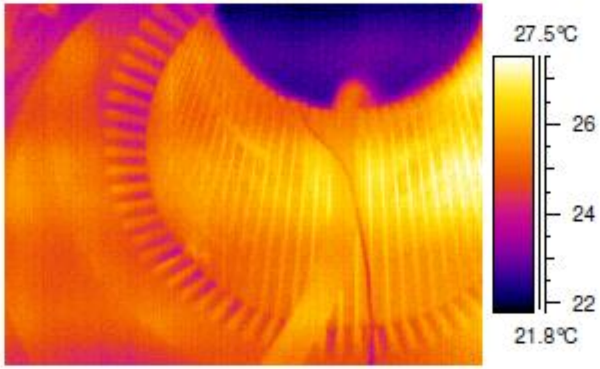
Identification



Section	Winding Dept
Equipment	Longer Stator
Additional information	Study One (1)
Date	8/8/2017
Time	1:41:51 PM

A Phase	B Phase	C Phase

Fault description



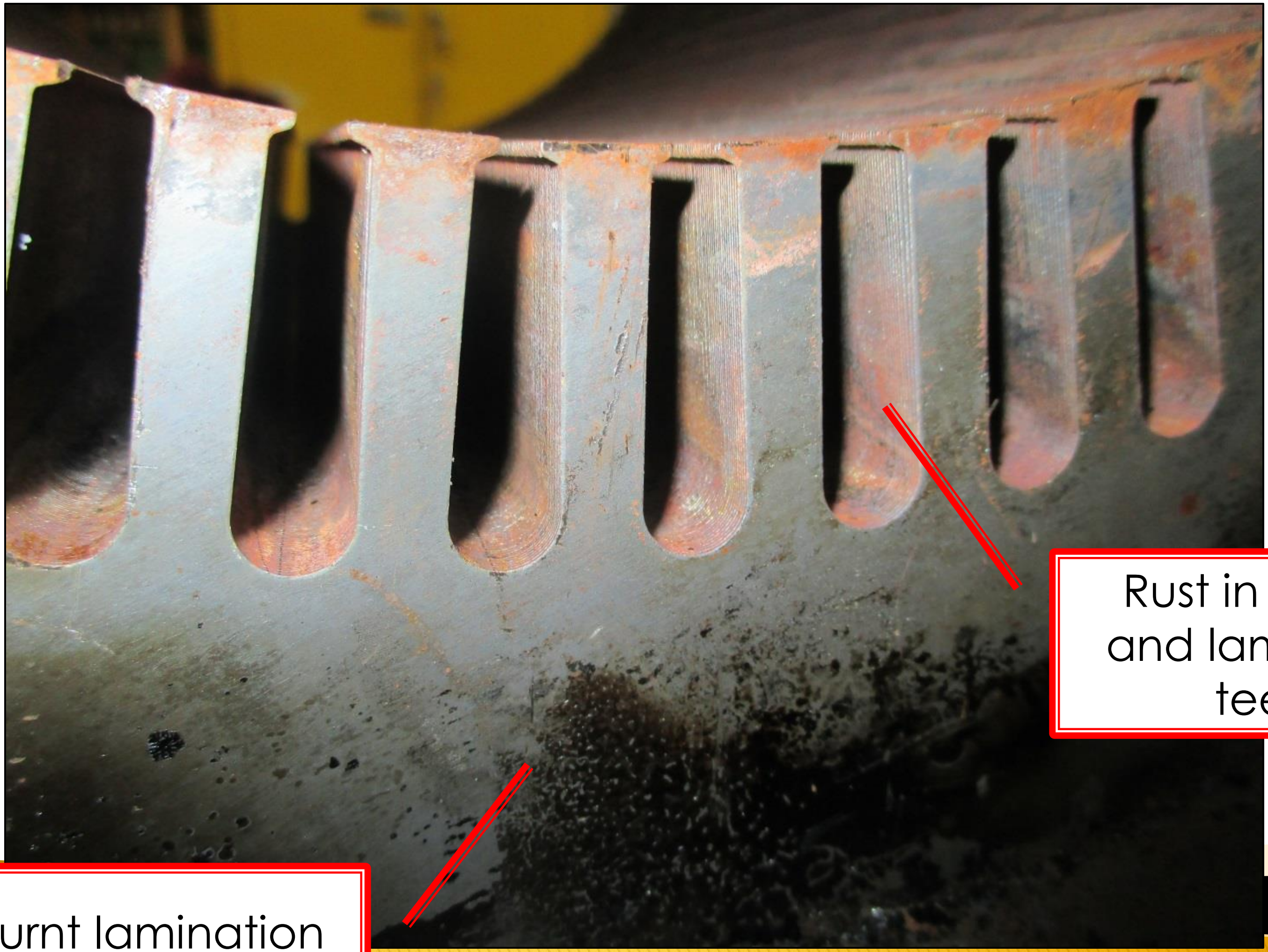
Fault	

Object parameter	**Value**
Emissivity	0.96
Object distance	1.0 ft

Why did Core Loss Decrease for 200 HP?

- Core Loss: 2.473 to 2.028 W's/lb.
- **Why?**
  - Rust developed from fire suppression system sauna effect
  - Rust(Iron-Oxide) is an insulator
  - Rust develops between the motor laminations
  - Five Laminations were removed and presence of rust was found between each

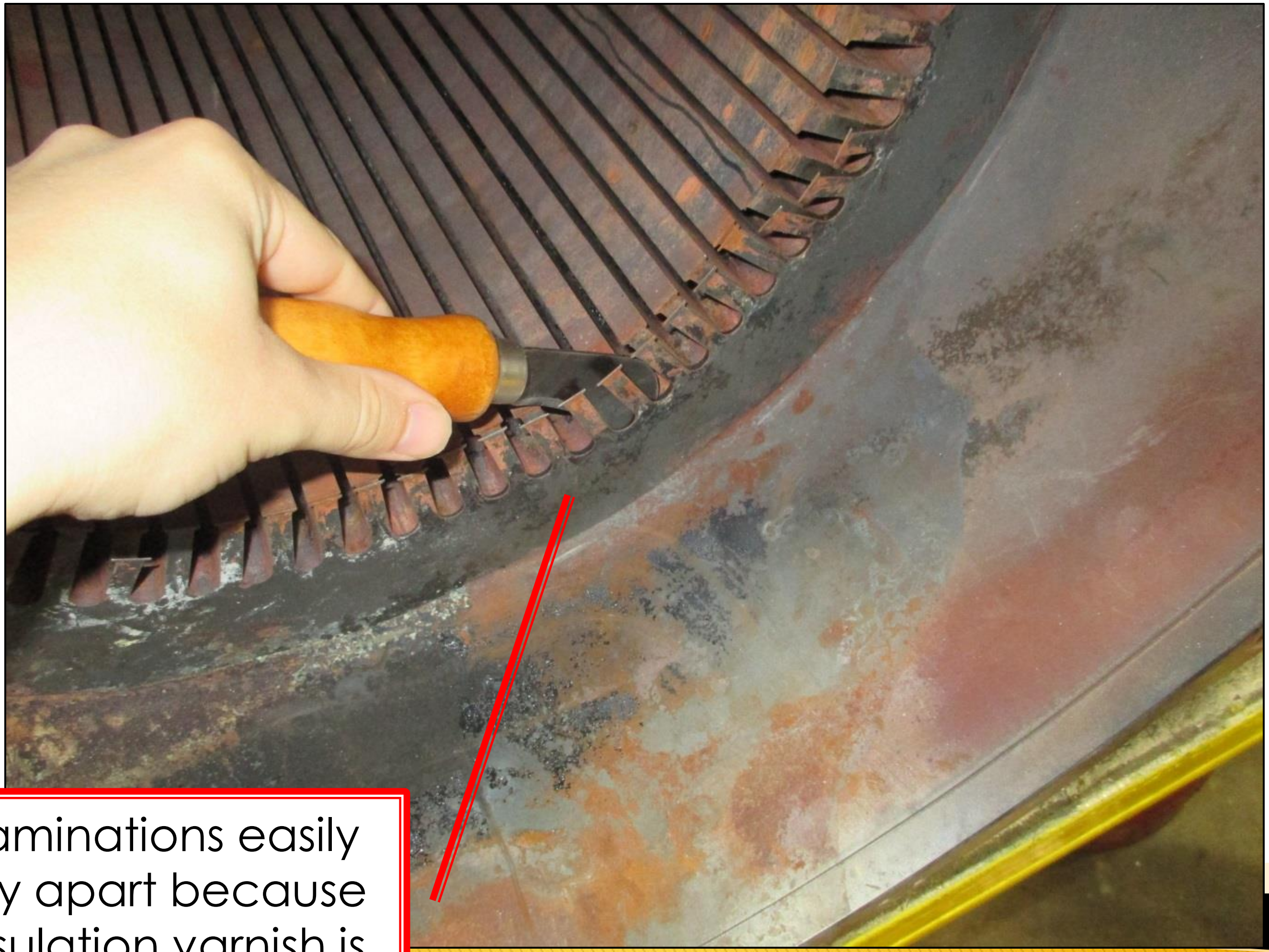
Rusted Burnout Laminations from 200 HP Motor



Rust in all slots and lamination teeth

Burnt lamination varnish

Rusted Burnout Laminations from 200 HP Motor



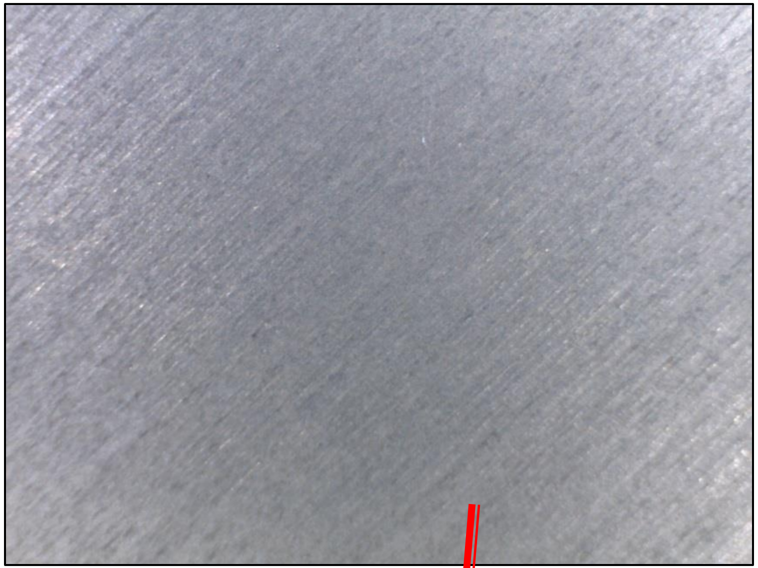
Laminations easily pry apart because insulation varnish is burnt away

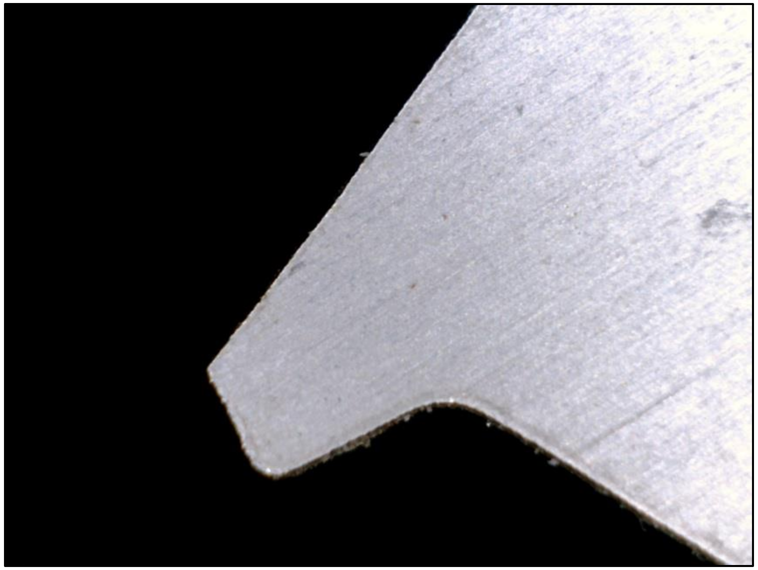
Rusted Burnout Laminations from 100 and 200 HP Motor

Burned out 200 HP Laminations

Burned out 100 HP Laminations

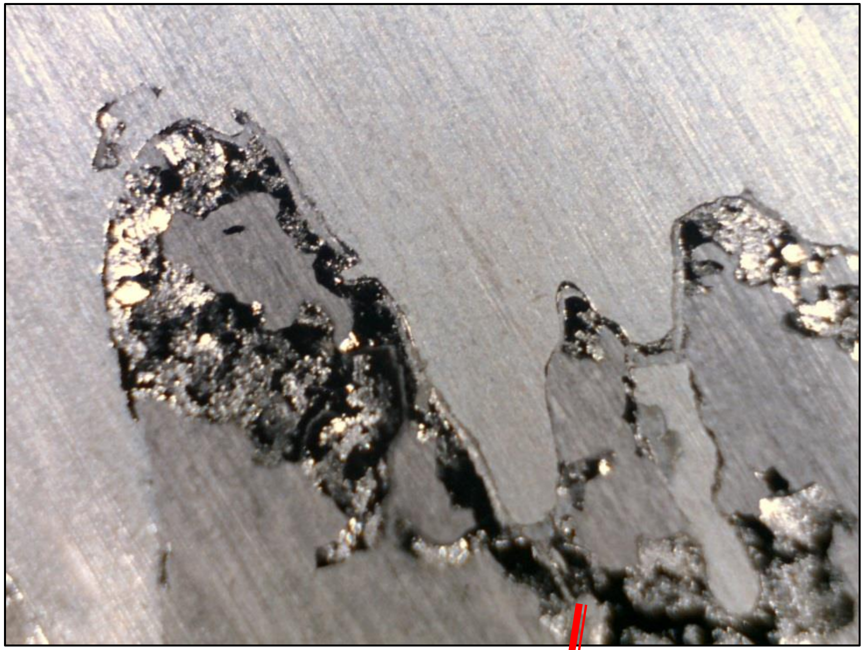
Normal Lamination Coating Microscopic View

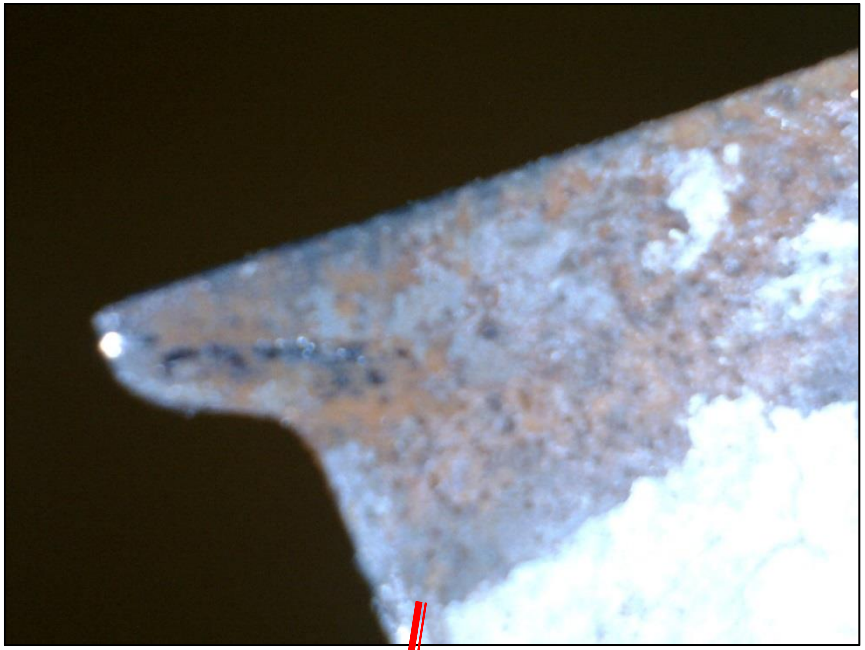




Coating is intact

200 HP Internal Laminations After Burnout Microscopic View

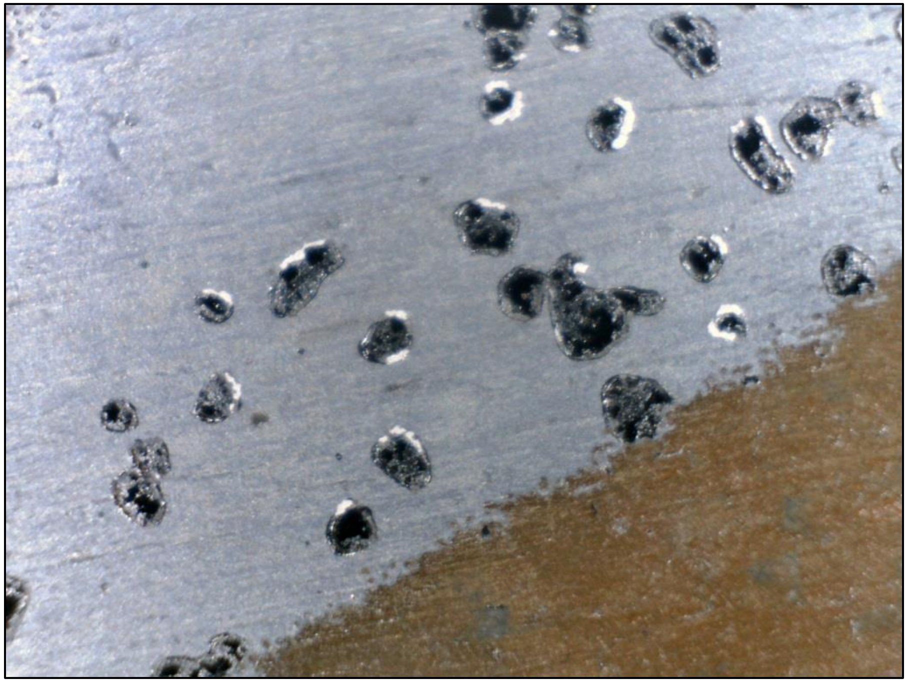


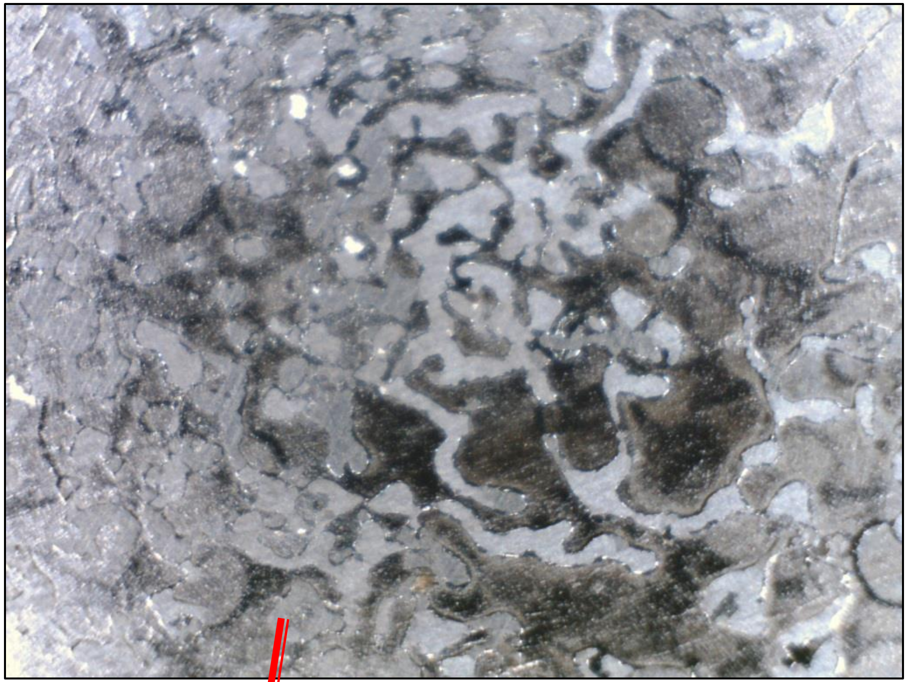


Coating has melted exposing bare steel

Slot teeth has rusted

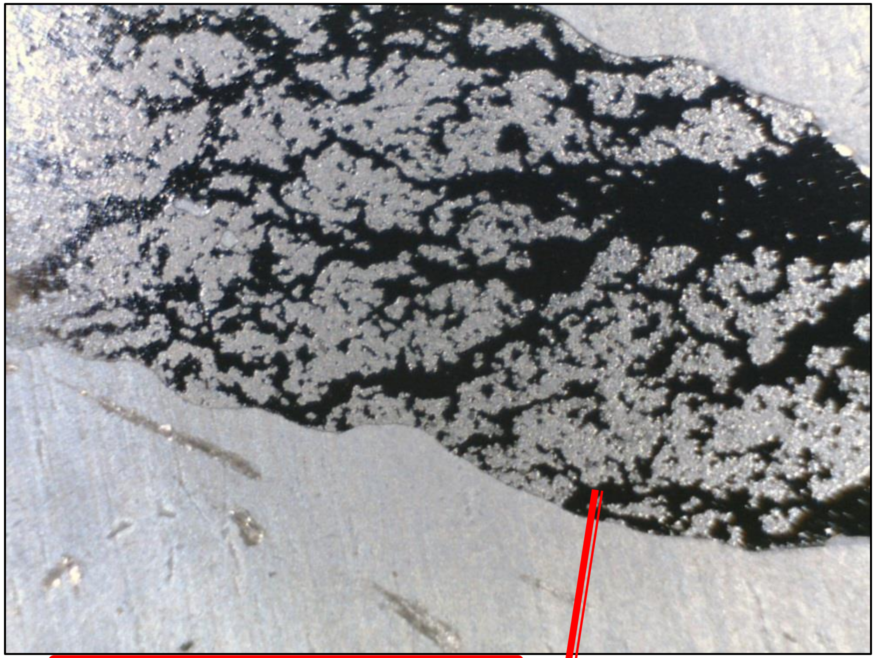
200 HP Internal Laminations After Burnout Microscopic View

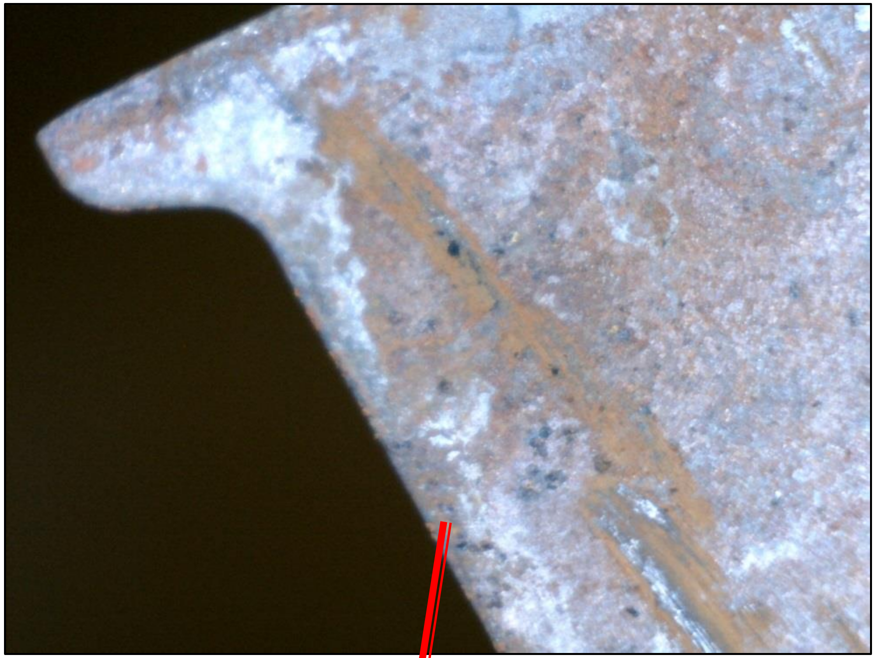




Melted lamination coatings

200 HP Internal Laminations After Burnout Microscopic View

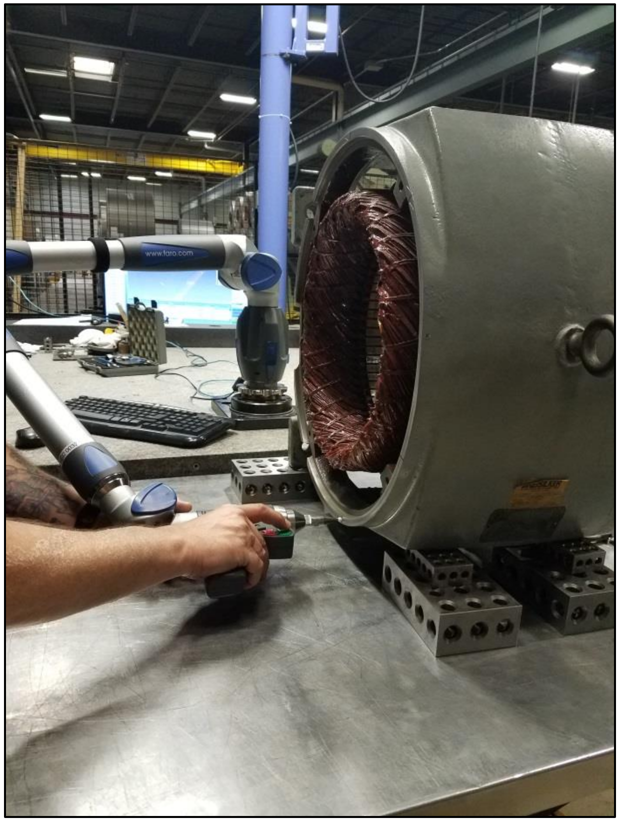




Coating has melted exposing bare steel

Slot teeth has rusted

Physical Measurements of Stator Frame and Cores Before and After Burnout Process

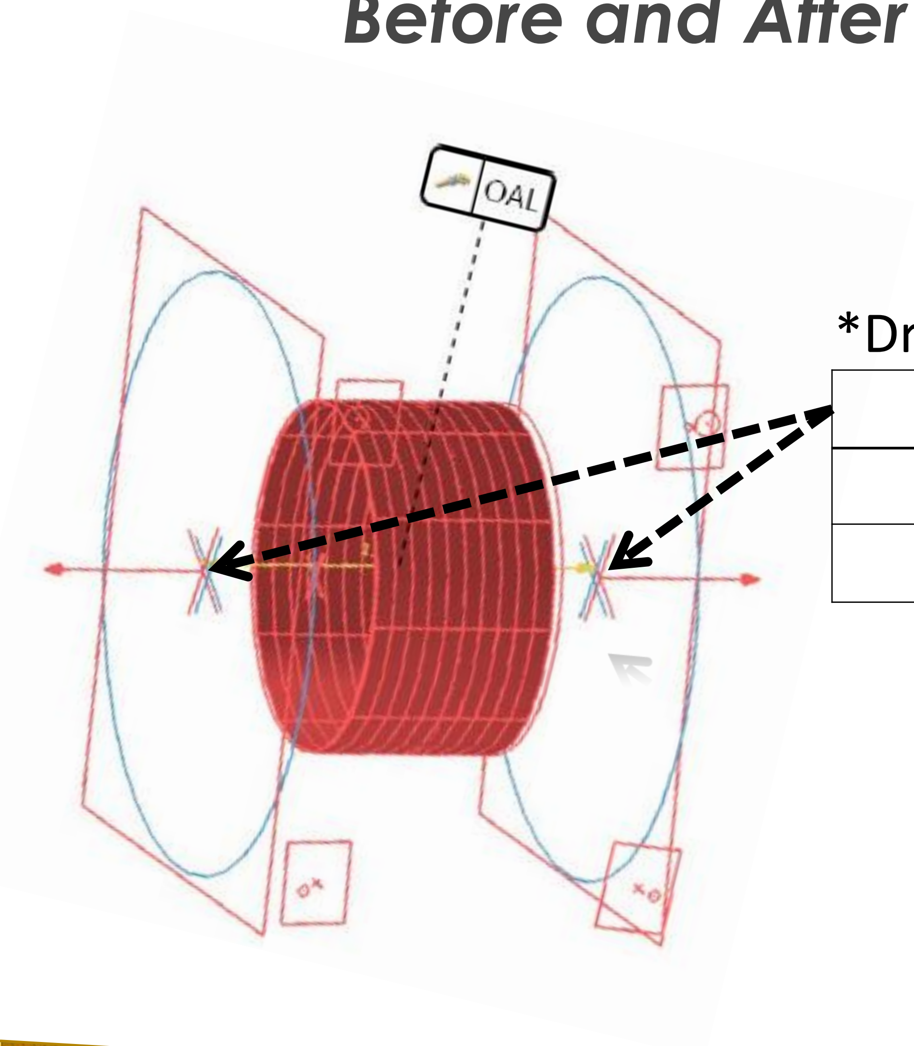


Physical Measurements of Stator Frame and Cores Before and After Burnout Process

Physical Measurements of Stator Frame and Cores Before and After Burnout Process

- Measured Items:
  - Cylindricity of Lamination Bore
  - Foot Flatness
  - Parallelism of Feet
  - Rabbet to Rabbet Axial Offsets Center to Center

Before and After 100 HP Measurements

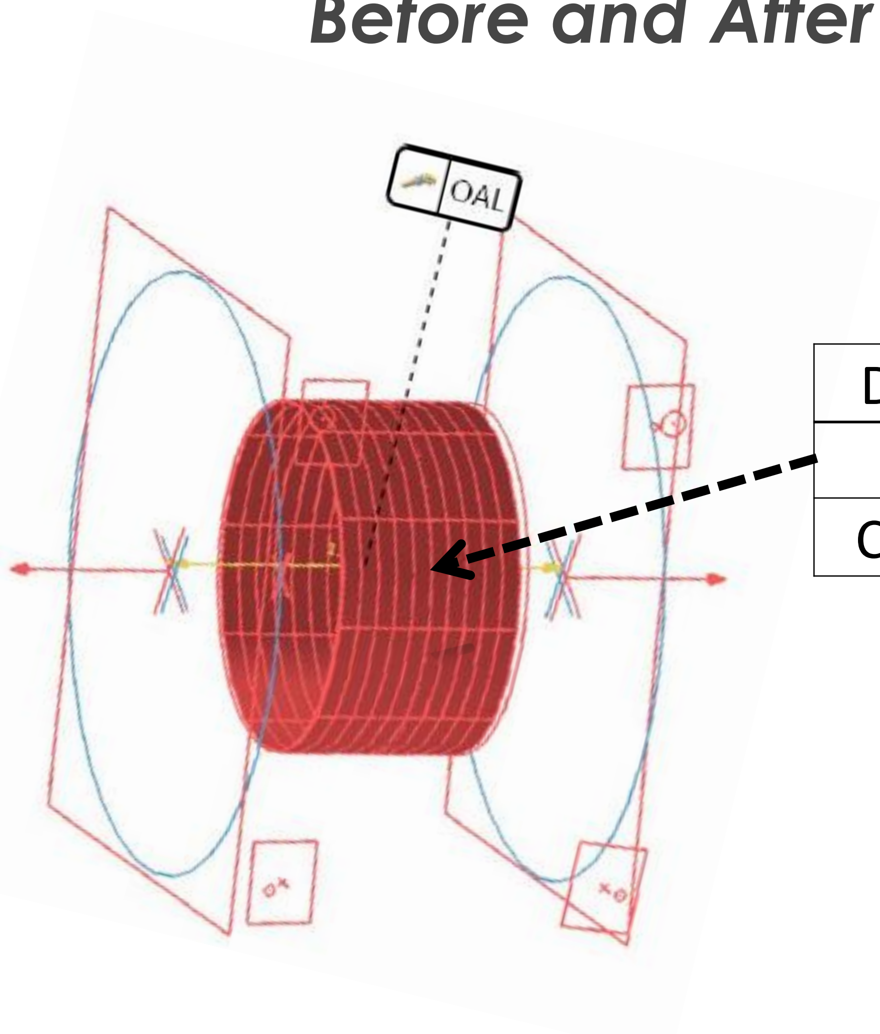


Opposite Drive side Offsets

*Drive Side Set as Zero Point Reference

Offset	Before	After	Change
X	-0.018	-0.004	0.014
Y	-0.019	0.0059	0.025

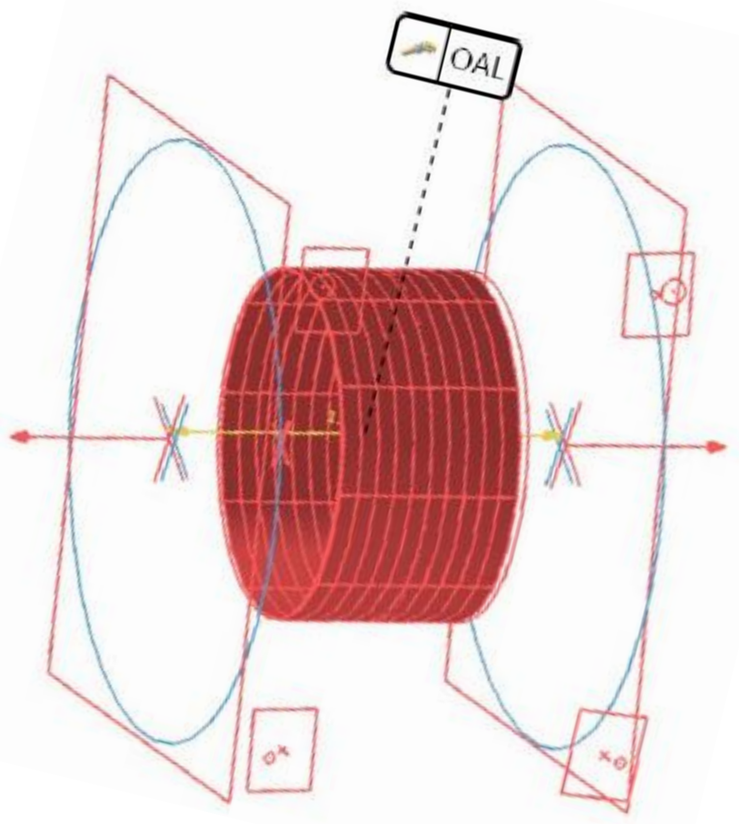
Before and After 100 HP Measurements



Lamination Bore

Dimension	Before	After	Change
Diameter	11.498	11.499	0.001
Cylindricity	0.005	0.010	0.005

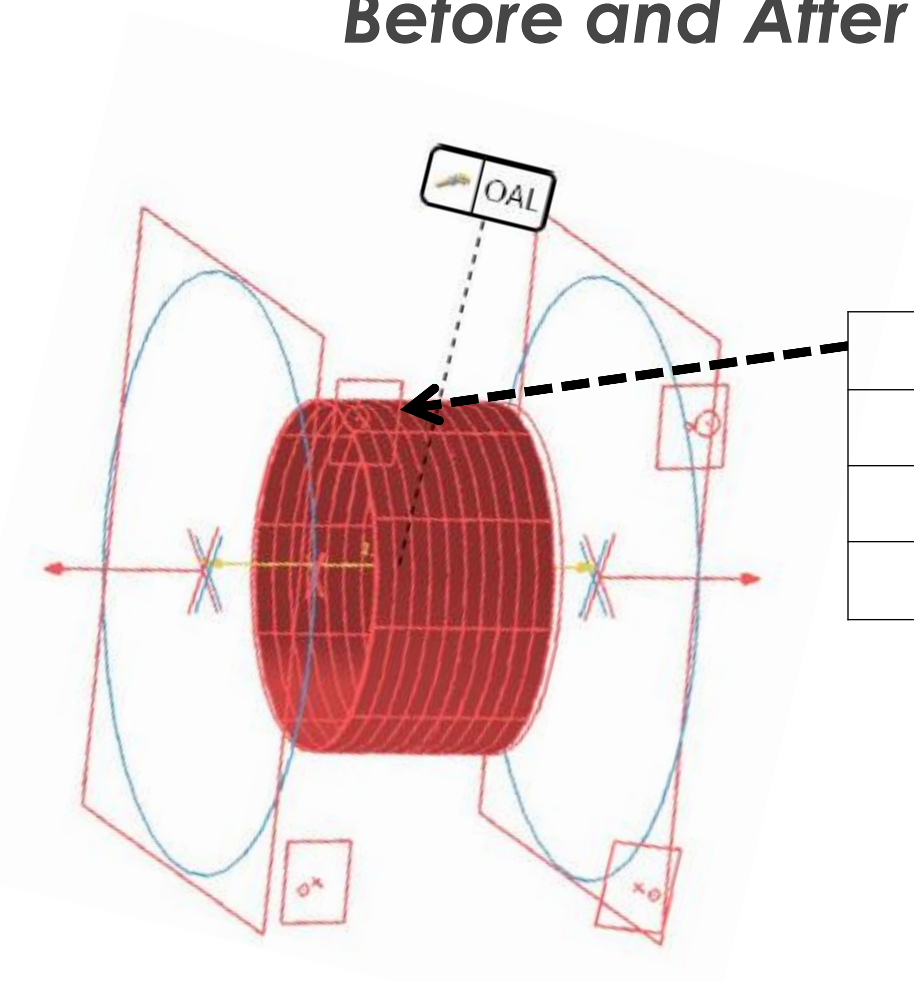
Before and After 100 HP Measurements



Foot Flatness

Foot	Before	After	Change
1	0.000	0.000	0.000
2	0.000	0.000	0.000
3	0.001	0.000	-0.001
4	0.002	0.002	0.000

Before and After 100 HP Measurements

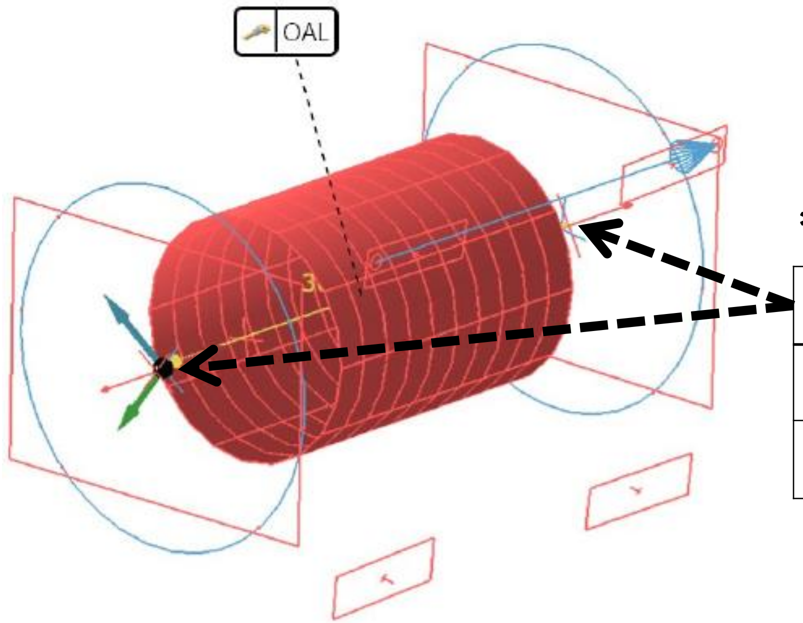


Foot Parallelism to Foot 1

Foot	Before	After	Change
2	0.000	0.003	0.003
3	0.000	0.009	0.009
4	0.000	0.005	0.005

*IEEE 1068-2015 specifies coplanar tolerance of 0.005 in

Before and After 200 HP Measurements

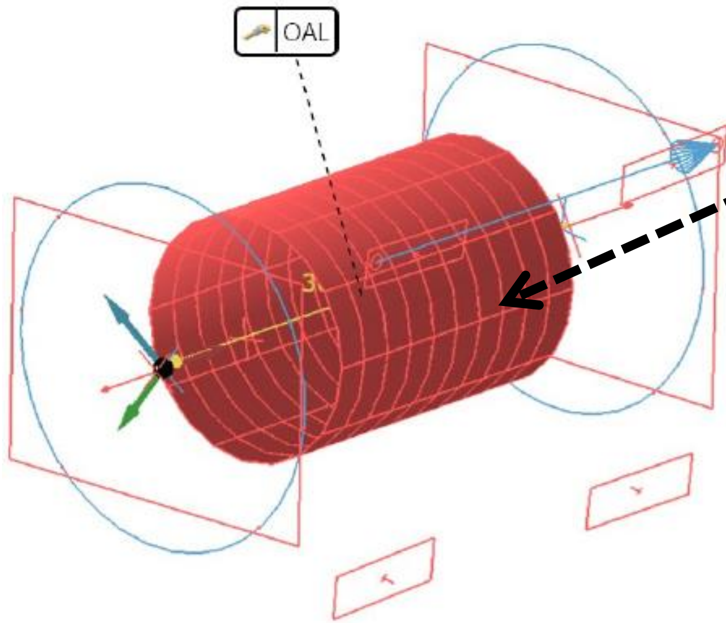


Opposite Drive side Offsets

*Drive Side Set as Zero Point Reference

Offset	Before	After	Change
X	0.005	0.002	-0.003
Y	-0.003	-0.007	-0.004

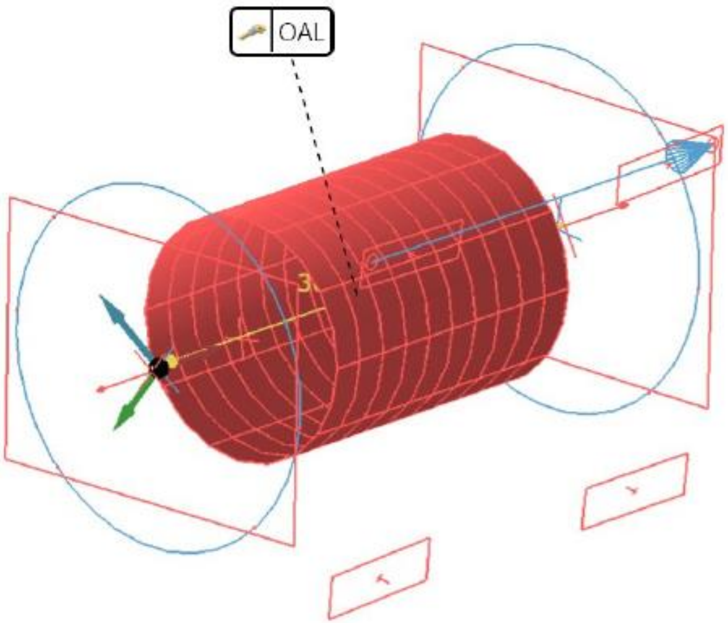
Before and After 200 HP Measurements



Lamination Bore

Dimension	Before	After	Change
Diameter	12.611	12.601	-0.010
Cylindricity	0.010	0.014	0.004

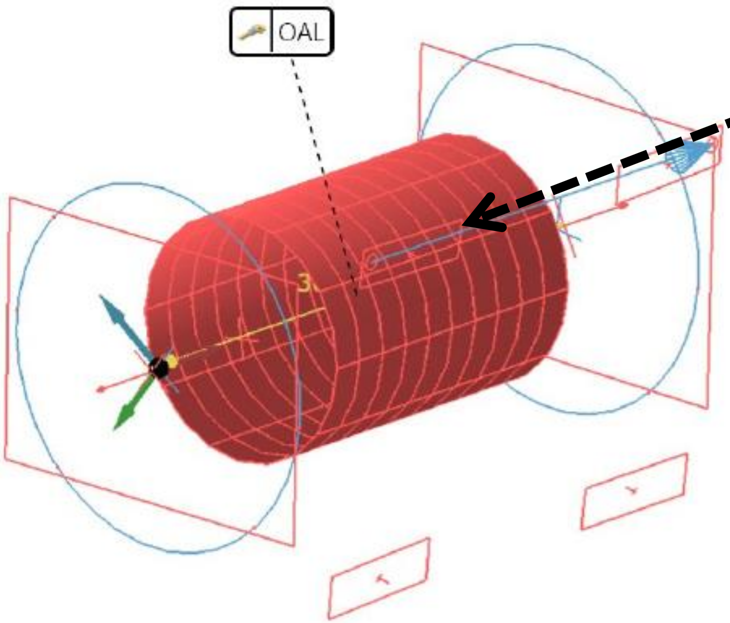
Before and After 200 HP Measurements



Foot Flatness

Foot	Before	After	Change
1	0.003	0.003	0.000
2	0.002	0.001	-0.001
3	0.003	0.002	-0.001
4	0.001	0.002	0.001

Before and After 200 HP Measurements



Foot Parallelism to Foot 1

Foot	Before	After	Change
2	0.005	0.003	-0.002
3	0.010	0.012	0.002
4	0.010	0.010	0.000

*IEEE 1068-2015 specifies coplanar tolerance of 0.005 in

EASA Core Loss Standards

- EASA Standard AR100-2015 Recommended Practice [1]
  - *"Core temperature should be controlled to avoid degradation of the interlaminar insulation and distortion of any parts. The temperature should not exceed 700 °F(370 °C) for organic and 750 °F (400 °C) for inorganic coreplate. If a burnoff oven is used, the oven should have a water suppression system. Parts should be oriented and supported in the oven so as to avoid distortion of the parts."*

EASA Core Loss Standards

- **Accreditation Audit Checklist** [2]
  - Mandatory Major Criteria: "*If core test losses increase more than 20% between the before and after winding removal tests, the core is repaired or replaced.*"
- **Examples:**
  - 2.0 W's/lb., 20% = 2.4
  - 6.0 W's/lb., 20% = 7.2
  - 10.0 W's/lb., 20% = 12 W's/lb.

Core Loss Ratings per Lexseco Core Loss Testing Machine

Frame Designation	Marginal Core Loss (W's/lb.)	Maximum Core Loss (W's/lb.)
NEMA	6.0	8.0
U-Frame	6.5	9.0
U-Frame High Efficiency	5.5	8.0
T-Frame	6.5	9.0
T-Frame High Efficiency	4.5	6.5
IEC	6.5	9.0
Compressor	5.0	6.0

EASA Core Loss Standards

- **The Effect of Repair/Rewinding on Motor Efficiency [3].**
  - *"The EASA/AEMT study confirmed, however, that testing the core with the loop test or a commercial tester before and after winding removal can detect increased losses caused by burning out and cleaning the core."*

EASA Core Loss Document

- **The importance of stator core loss testing before and after burn-off process** [4]:
- *"We also started to see a pattern of motors the were manufactured beginning in the late 1990s that could not be rewound more than once or twice before core losses increased well beyond acceptable limits. In some cases, we found hotspots due to blown copper deposits; grinding and separating them only caused the hot spot to worsen, and expand in area. In other cases the core was unacceptably hot overall. Or motors were failing within weeks of being rewound if they had not been culled out by core loss testing."*
- *"These scenarios left us in the unenviable position of having to explain to a customer that their critical motor was not repairable after only one rewind…"*

EASA Core Loss Document

- **Consider this aluminum frame motor burnout method** [5]: *"The size of the pan of sand is critical to the dimensions of the stator frame to be burned out."*

Figure 1. Aluminum frame and stator in pan of sand.

Additional Lamination Hardness Test

- A burnout lamination and original lamination were sent out for hardness testing on three spots using Rockwell B Hardness scale:

35.3 HRB

80 HRB

Discussion with Motor Manufacturer Metallurgist

- **Summary:** If you over anneal laminations with a furnace atmosphere that is humid, then you can develop subsurface oxides. The most common complaint of over-annealing is the subsurface oxides lower the magnetic permeability of the steel.
- **Problem:** Lowering the permeability of the lamination steel directly lowers the magnetic flux density and creates unknown changes to the steels saturation curve

Additional Lamination Hardness Test

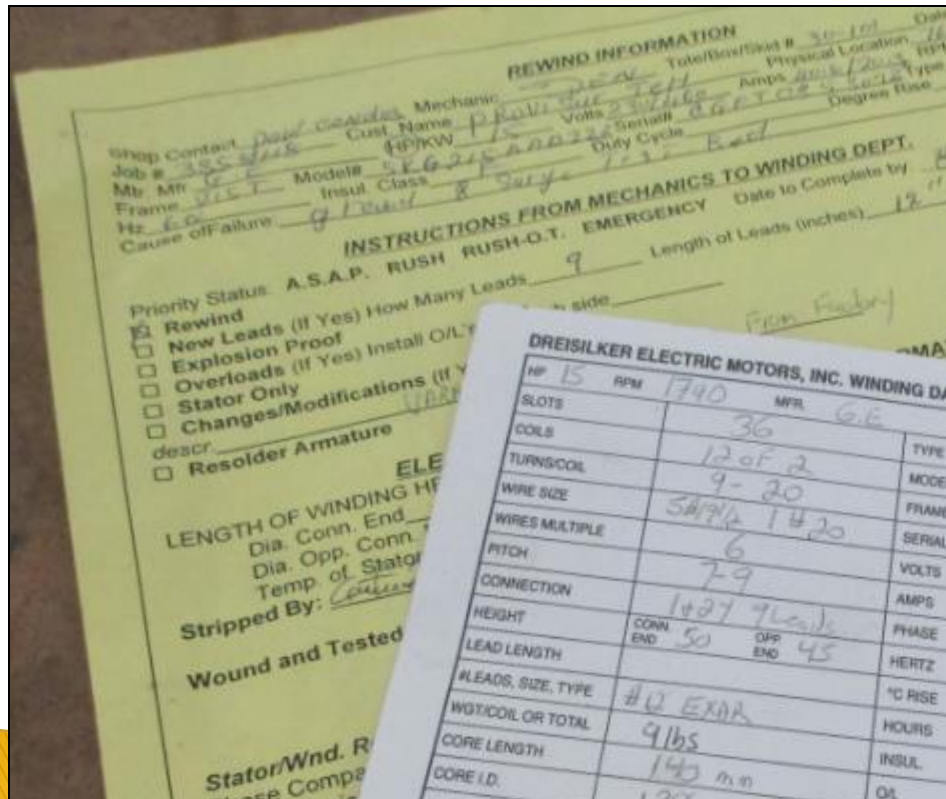
- Typical hardness levels from AK Steel [6]:

AK Steel Grade Designation	Density gm/cm³	Electrical Resistivity Microhm-cm	Ultimate Tensile Strength psi (MPa)	Yield Strength psi (MPa)	Elongation % in 2" (50 mm)	Hardness Rockwell B	Modulus of
TRAN-COR H-0 and H-1	7.65	50	52,000 (359)	50,000 (345)	11	83	
Oriented M-2 to M-6	7.65	51	51,000 (352)	48,000 (331)	9	81	
DI-MAX M-15 FP	7.65	50	71,000 (490)	52,000 (358)	23	72	
Di-MAX M-36 FP	7.70	43	63,000 (434)	42,000 (290)	30	64	
DI-MAX M-47 FP	7.75	37	62,000 (427)	39,000 (269)	34	61	
DI-MAX M-43 SP	7.70	43	70,000 (483)	50,000 (345)	32	64	
DI-MAX M-47 SP	7.75	37	67,000 (462)	48,000 (331)	33	62	

Hardness Rockwell B
83
81
72
64
61
64
62

Motor Safe Stripping Method

- Physical measurements are documented prior to taking connection and coil data.

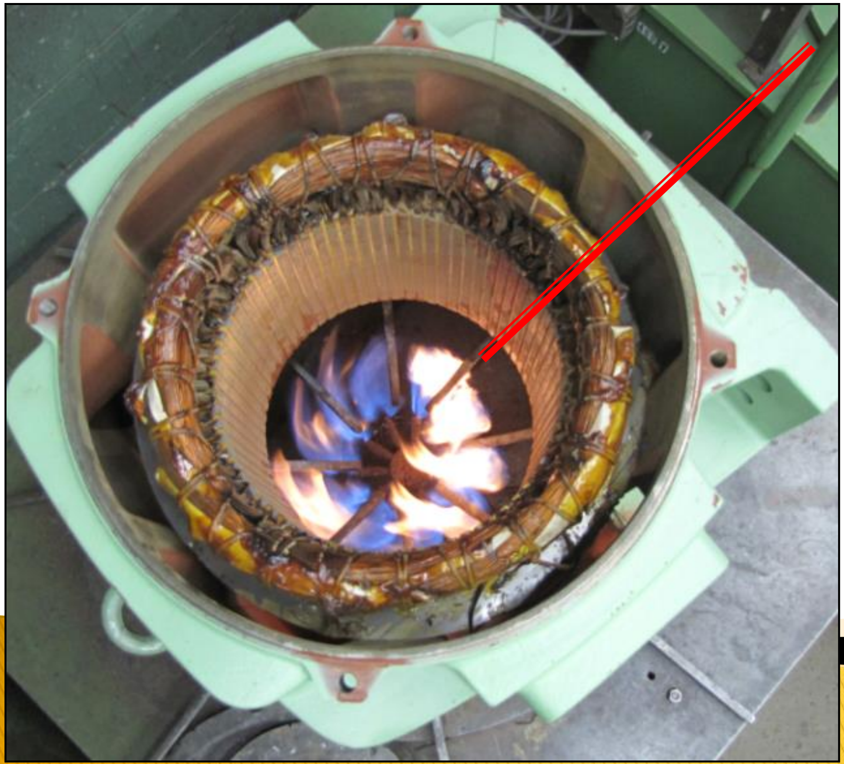


Motor Safe Stripping Method

- Winding connection head is cut off from the lead side to preserve connection data for documentation.

Motor Safe Stripping Method

- The outer diameter is heated to just above insulation class rating using gas heat or high frequency induction.



Heat source does <u>not</u> contact bottom lamination!

Motor Safe Stripping Method

- Coils are removed hydraulically (often with intact insulation paper) from the stator. Coil groups are saved for data

Motor Safe Stripping Method

- After coil removal, stator slots are cleaned with hand tools to remove all remaining insulation and debris.

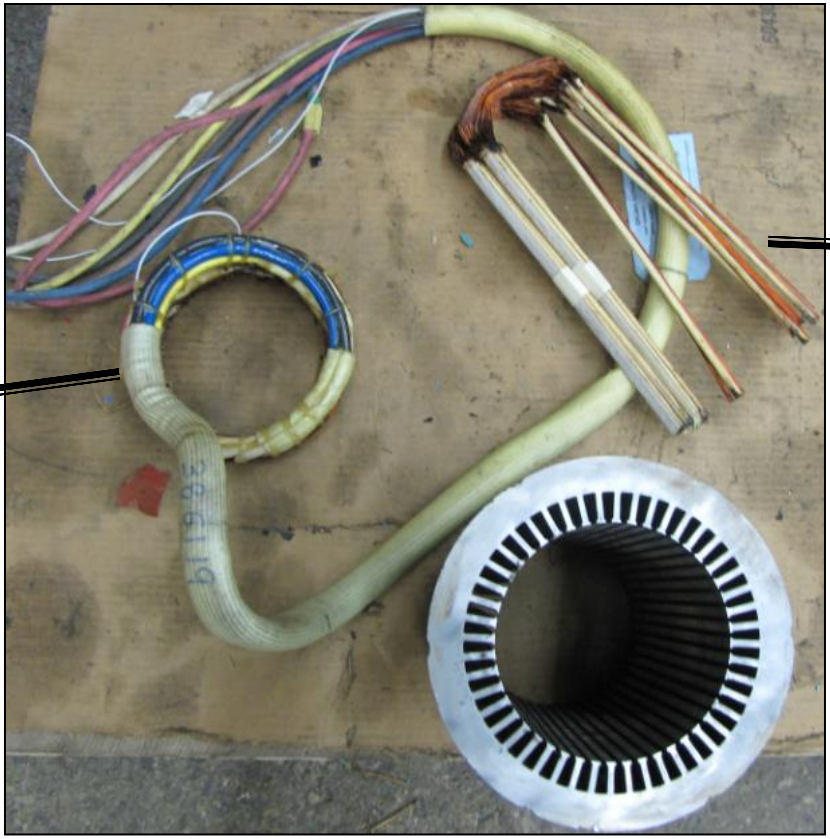
No discoloration of original manufacturers paint coating from heat

Motor Safe Stripping Method

- The 200 HP motor with 72 slots was stripped of windings in less than 5 hours (compared to 22.5 hours of burnout case study).
- Core Loss Before Stripping: 2.190 W's/lb.
- Core Loss After Stripping: 2.134 W's/lb.

Motor Safe Stripping Method

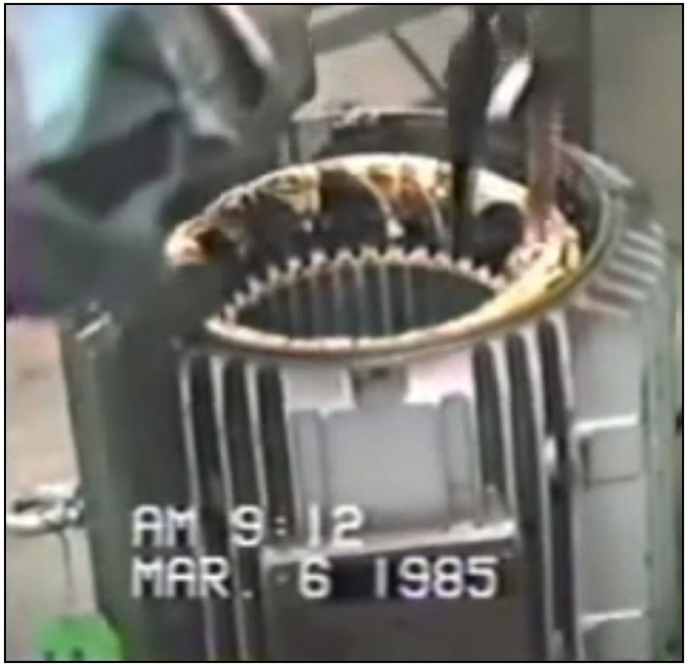
Connection head is preserved for data



Coil groups are saved, measured, and counted for data

Motor Safe Stripping Method

- This process has been in use since 1967 and does not damage the core or mechanical dimensions



Core Loss Before and After Using Motor Safe Stripping Method

Motor Description	Before (W's/lb.)	After (W's/lb.)	Percent Change
350 HP, 4160 Volt, Reliance	8.369	6.762	- 24 %
10,000 RPM Yaskawa Spindle	1.601	1.378	- 16 %
6.3 kW Siemens Servo	6.462	6.277	- 2.9%
800 kW, 4160 Volt, C.A.T. Generator	4.980	5.059	+ 2.6 %
200 HP, 460 Volt, Baldor	2.917	2.788	- 4.6%

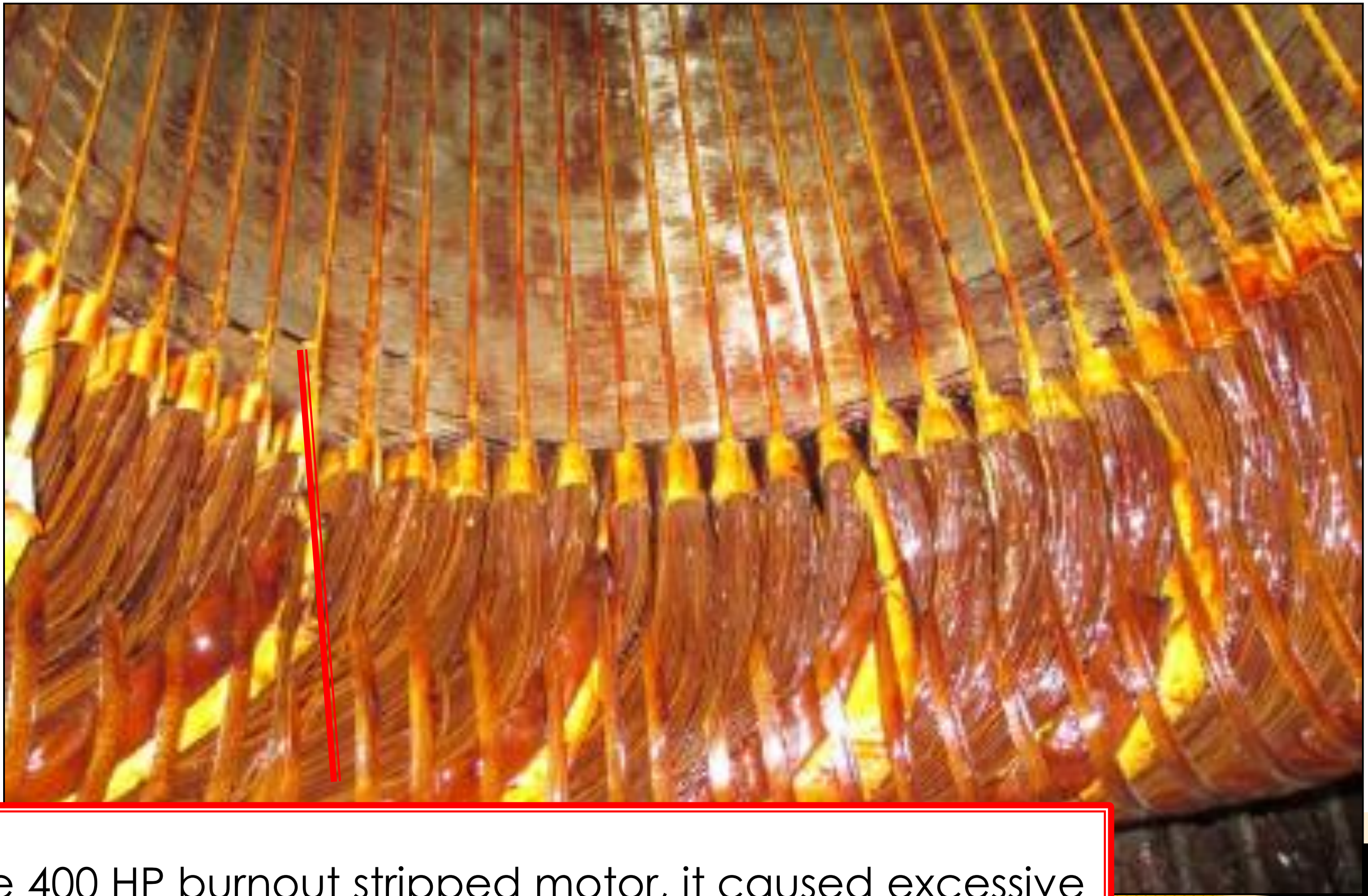
Other Burnout Destroyed Motors

This motors lamination steel was grinded away and repaired with epoxy. If this motor was stripped with a burnout oven, the epoxy would have been destroyed and not found.

Other Burnout Destroyed Motors

This a 400 HP motor that was repaired with burnout oven stripping and failing every 2 months.

Other Burnout Destroyed Motors



On the 400 HP burnout stripped motor, it caused excessive splaying causing air gaps between laminations..

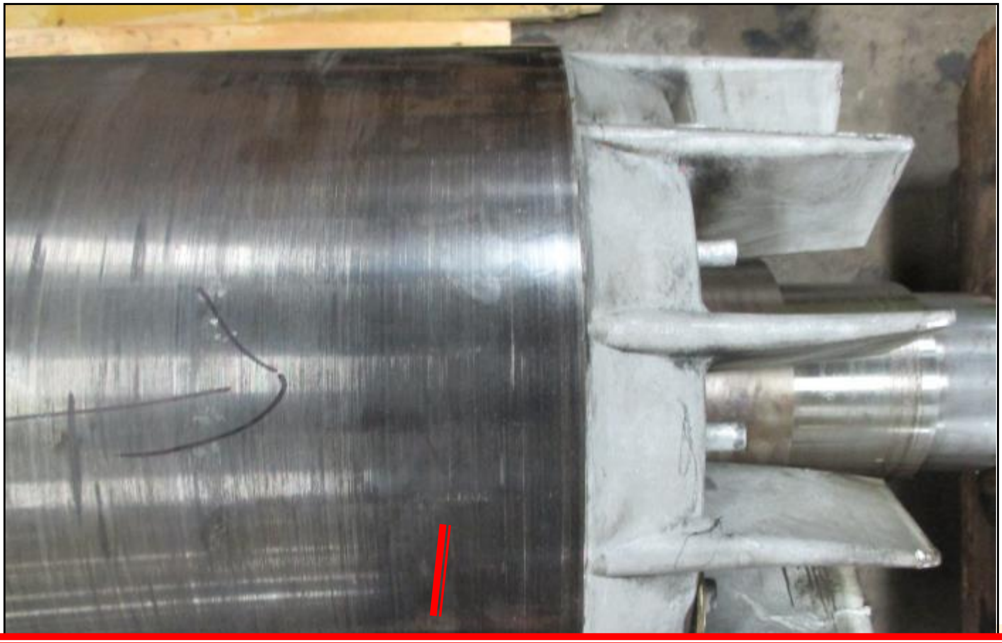
Other Burnout Destroyed Motors

Entire lamination stacked was dropped and warped during stripping.

On the 400 HP burnout stripped motor, the entire lamination core dropped in the frame causing the winding and rotor to be off center as well as the laminations to be warped.

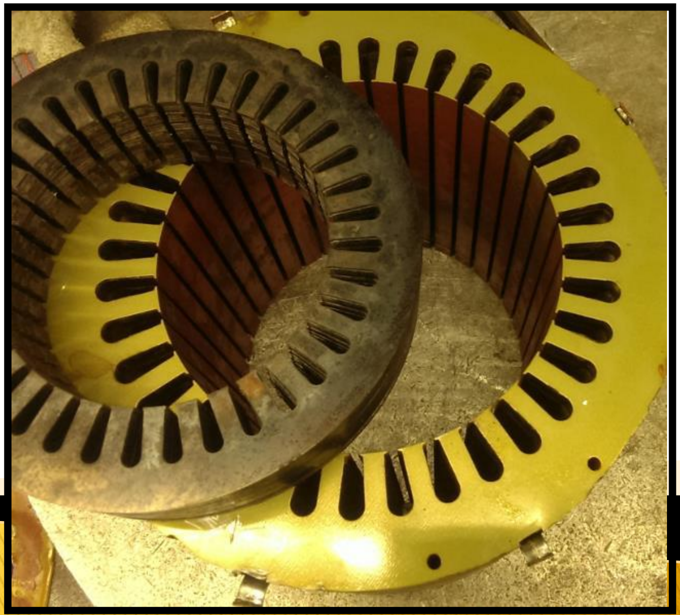
Other Burnout Destroyed Motors

The stator was off center to the rotor by one inch. Bearings were failing in six months.



On the 400 HP burnout stripped motor because the core was not in the correct location, the rotor stuck out one inch and caused a magnetic pull on the rotor putting a high axial thrust load on the bearings which cause premature failure.

Burnout and Motor Safe Stripped Motors



Managing Your Motor Repair Decisions

- Do you have repair specifications?
- Does your repair shop know and follow your specifications?
- Have you visited your repair shops?
- Are you receiving documentation, data, and repair reports?
- Who in your organization is your motor repair decision maker? (Purchasing, Engineering, Maintenance, Reliability Manager?)
- If you have a standard, does it detail core loss acceptance testing?
- Is your company managing your new motors and motor repair as a low cost commodity?

Conclusions

- Multiple industry organizations and manufacturers knowingly accept :
  - Core loss increase is an expected result from burnout oven stripping
  - Frames are distorted and warped
- Hotspots cause uneven amperage draw, increased motor operating temperature, and lower efficiency and power factor
- Rust accumulates between laminations as a result of insulation degradation during burnout process
- Rusty laminations will falsify core loss test results
- Potential exists for continuous degradation of the core while the motor is in service

Conclusions Cont.

- Operating costs increase
- Motor life and reliability decreases
- Motor rewinding ability decreases with core loss increase during burnout stripping process

Bibliography

- [1] ANSI/EASA Standard AR100-2015: Recommended Practice for the Repair of Rotating Electrical Apparatus: easa .com/sites/files/resource_library_public/ EASA_AR100-2015_0815_0.pdf
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» Thank you

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