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Influence of Soft Magnetic Material type in Fixture Components on the Magnetization of Bonded Neo Magnet and Motor Performance

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Introduction

- Advantages of isotropic bonded neo magnets
  - Higher magnetic properties than ferrite
  - Near net shape magnet production
  - No heavy rare earth elements
  - Feasibility to obtain wide range of magnetization profiles

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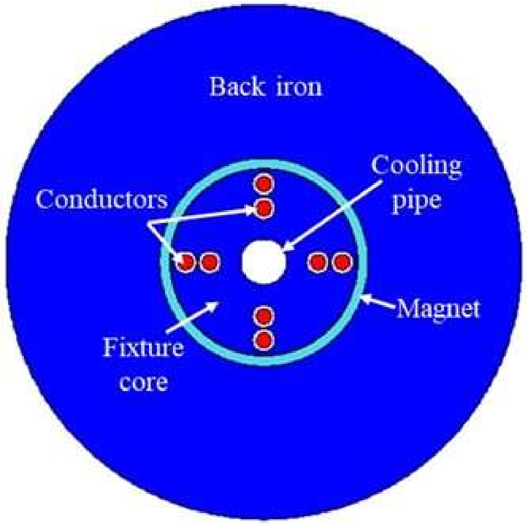
Magnetization Fixture

- A magnetization fixture consists of:
  - Copper coils
  - Soft iron / air core
- To achieve radial magnetization profile
  - Back iron made up of soft magnetic material is used.
    - Back iron reduces the magnetizing energy needed to saturate the magnet.
  - Laminated steel is preferred but solid steel is also used for the fixture components.



Radial magnetization fixture

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Approach

- Using Finite Element analysis (FEA), magnetization of magnet and motor performance is evaluated for the following combinations of soft magnetic materials used in magnetizing fixtures.
    - Laminated steel fixture core + Laminated steel back iron (LCLB)
    - Laminated steel fixture core + Solid steel back iron (LCSB)
    - Solid steel fixture core + Solid steel back iron (SCSB)

- Fixtures are fabricated using both laminated and solid steel components and the FEA based observations are validated on both magnet and motor performance.

Finite Element Analysis (FEA)

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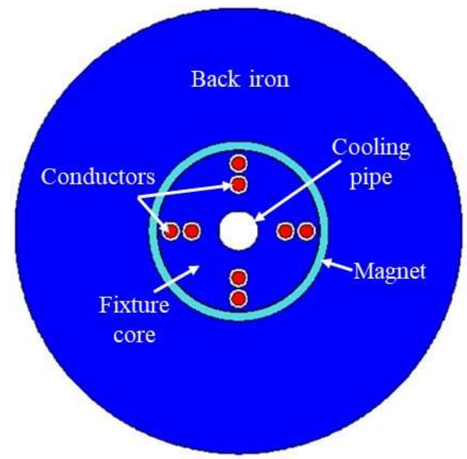
FEA: Designed Magnetization Fixture

Magnet Dimensional Details

Parameter	Value
Inner diameter	24 mm
Outer diameter	27 mm
Height	29 mm
Magnet grade	MQ1™
Number of poles	4
Flux orientation	Radial



Magnetization fixture cross-section

- Fixture is designed to achieve full saturation of the magnet.
  - Minimum 30kG magnetizing field throughout the magnet thickness
- Based on the fixture component materials, following configurations were evaluated
  - Laminated steel fixture core + Laminated steel back iron (LCLB) - Benchmark
  - Laminated steel fixture core + Solid steel back iron (LCSB)
  - Solid steel fixture core + Solid steel back iron (SCSB)

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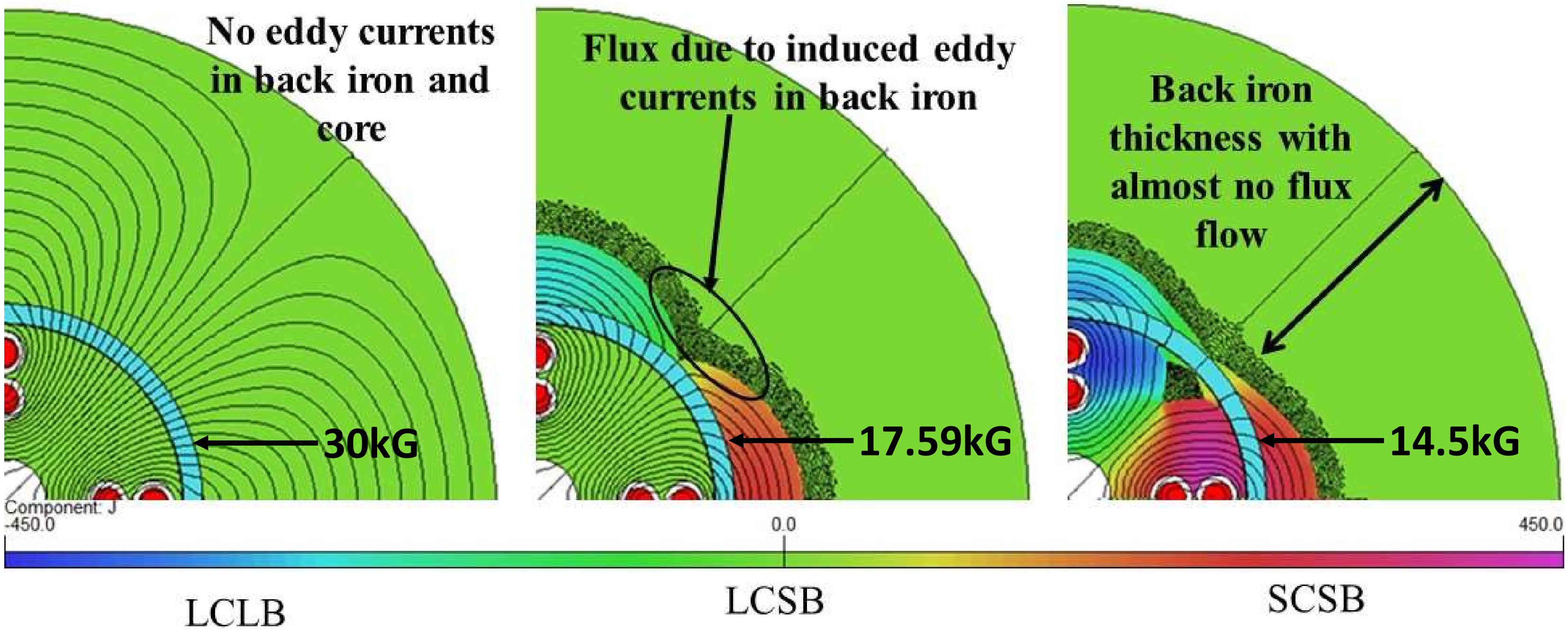
FEA: Magnetization



Magnetization flux and induced eddy currents in the fixture

- Use of solid steel components leads to the generation of eddy currents
  - Reduction in effective thickness of back iron
  - Reduces the resultant magnetization field

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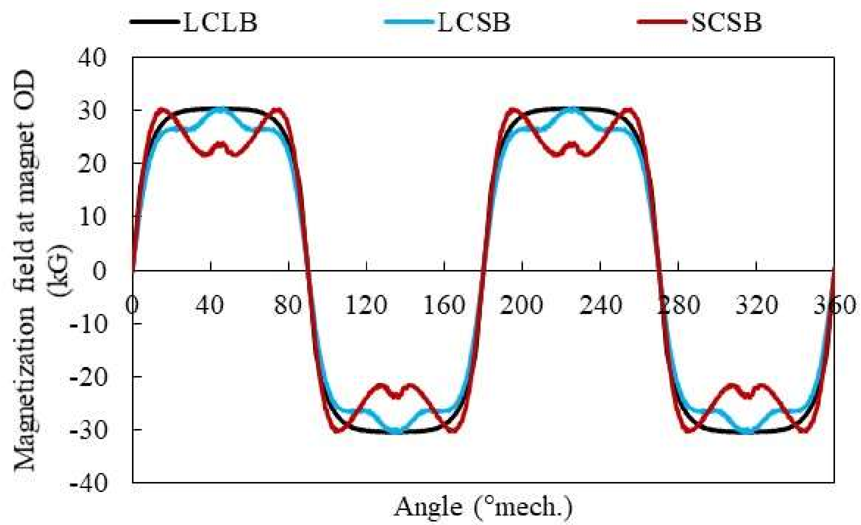
FEA: Magnetization

Simulated energy required for magnet saturation

Fixture type	Energy required to generate 30kG field at magnet OD (kJ)	Current density (kA/mm^2)
LCLB	5.44	7.85
LCSB	34.02	19.64
SCSB	68.28	27.79



Applied magnetization field measured at magnet OD

- The presence of solid steel components ⟹ generation of eddy currents
  - Increase in magnetizing energy and current density in the conductor
    - Reduction of fixture reliability
  - The estimated energy needed to achieve full magnet saturation in LCSB and SCSB combination exceeds the capability of most of the commercially available magnetizers
  - Distorted magnetization flux waveform

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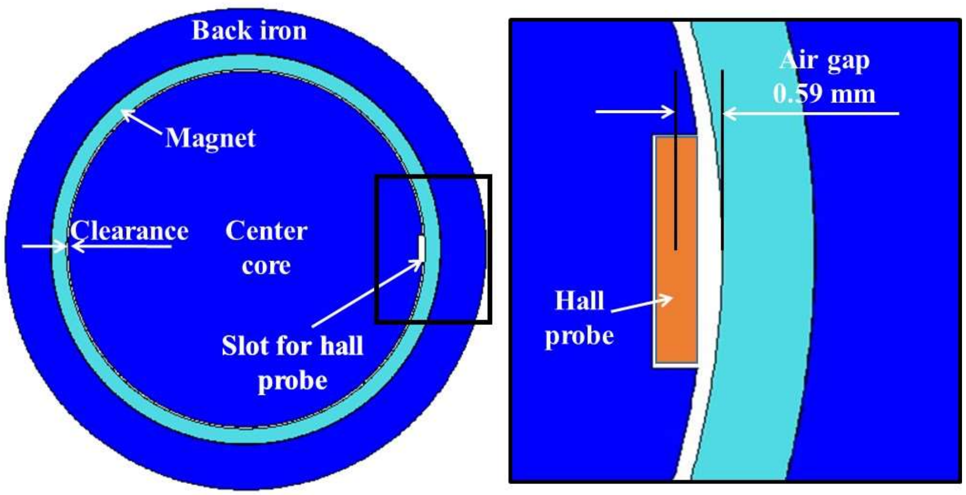
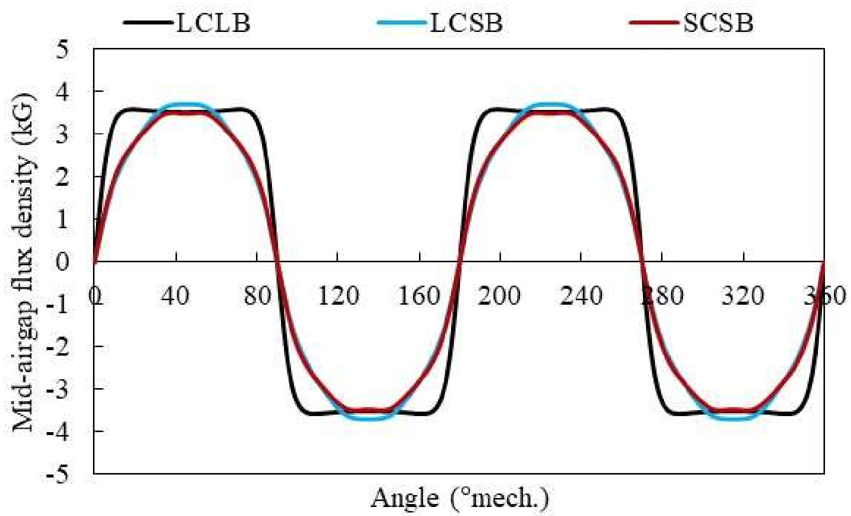
FEA: Closed Circuit Mid Airgap Flux Density

- The magnets are magnetized to full saturation by applying the energy required by each combination.



Closed circuit flux scan set-up



Mid airgap flux density

- Mid-airgap flux density waveform:
  - LCLB ⇒ radial
  - LCSB, SCSB ⇒ near to sinusoidal (Halbach)

FEA: Mid Airgap Flux Density and Motor Performance

Comparison of mid-airgap flux density integral and motor performance

Fixture component combination	Mid-airgap flux density integral per pole (kG-°mech)	Back-emf (V)	Peak-peak Cogging Torque (mN-m)
LCLB	289.5	10.2	47.04
LCSB	241.8	10.0	6.19
SCSB	237.8	9.6	5.15

- The presence of solid steel component (LCSB and SCSB) leads to lower flux integral per pole.
  - This is due to the sinusoidal nature of the flux waveform.
- Reduced flux per pole in LCSB and SCSB combinations leads to
  - Lower cogging torque
  - Lower back-emf

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Experimental Validation

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Experimental Validation: Fabricated Fixture Components

Laminated fixture core

Solid steel fixture core

Laminated back iron

Solid steel back iron

Fabricated fixture components

- Based on the capability of the available magnetizer a maximum of 6 kJ energy is applied during magnetization process.

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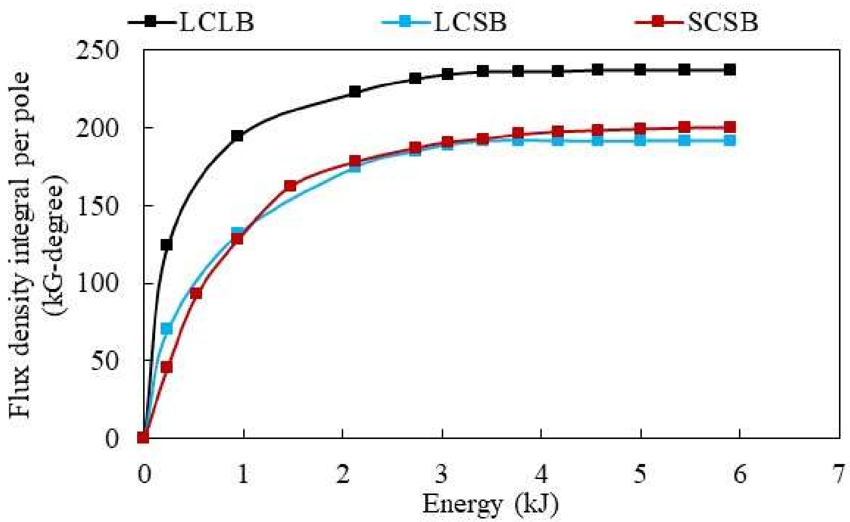
Experimental Validation: Magnetization



Magnetization test results for various combinations

Measured field generated during magnetization

Fixture Component Combination	Field at magnet OD for 6kJ applied energy (kG)
LCLB	29.4
LCSB	15.6
SCSB	13.7

- For LCSB and SCSB combinations,
  - Presence of solid steel components ⟹ Induced eddy current opposing the applied field ⟹ Partially saturated magnet

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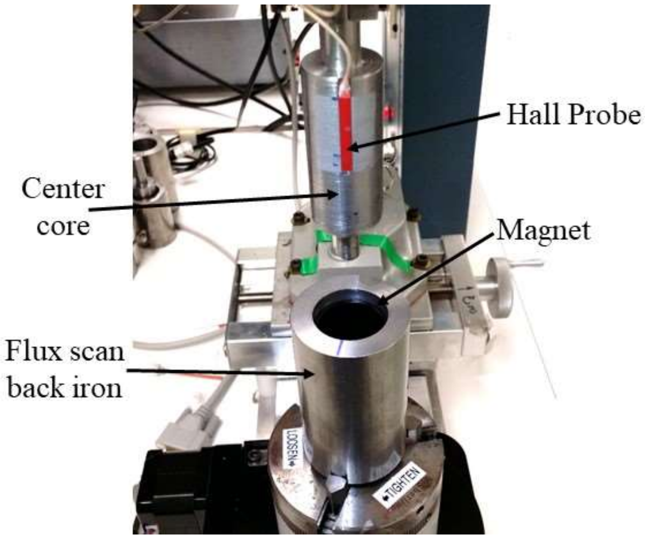
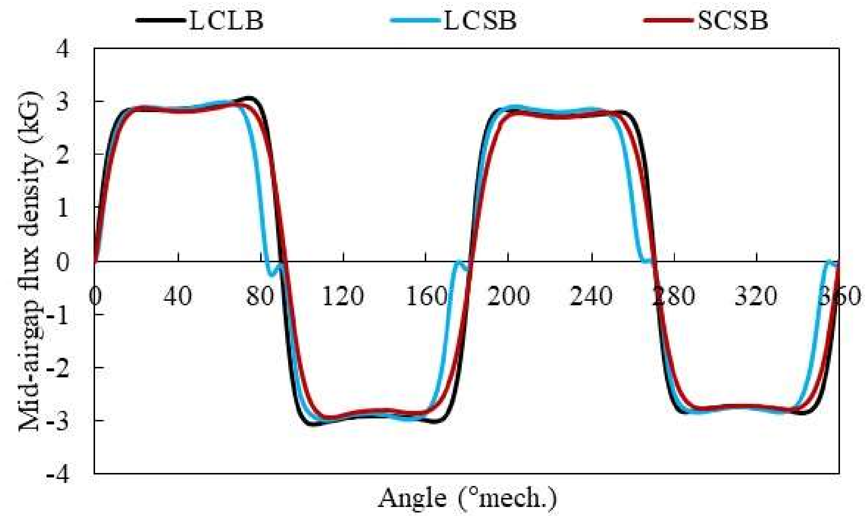
Experimental Validation: Magnet Performance



Closed circuit flux scan measurement set-up



Comparison of mid airgap flux density for various combinations

Comparison of magnet flux integral

Fixture Component Combination	Mid airgap flux density integral per pole (kG-°mech)	Change in integral
LCLB	233.5	-
LCSB	207.6	-11.1%
SCSB	218.1	-6.6%

- Mid airgap flux density profile
  - Eddy currents only in back iron ⇒ small notch near the transition zone in LCSB ⇒ lowest flux density integral (LCSB)

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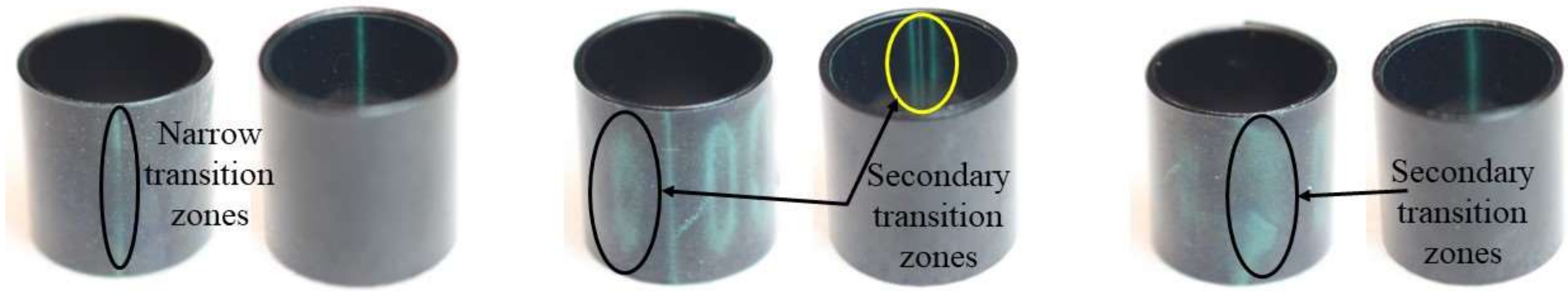
Experimental Validation: Magnet Transition Zone



LCLB LCSB SCSB

Magnet pole transition zone

- The material used for the fixture components influences the transition zone on the magnet surface.
  - The presence of solid steel component leads to the unwanted secondary transition zones.
  - The presence of eddy currents on both fixture core and the back iron in SCSB combination results in a blurred transition zone on the magnet outer surface.

Effect on Motor Performance

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Experimental Validation: Effect on Motor Performance:
Cogging Torque, Motor Back-emf and No-load Performance

Comparison of peak-to-peak cogging torque, motor back-emf and no-load performance

Fixture component combination	Motor Back-emf at 3300 rpm (V)	No-load speed (rpm)	Peak-peak Cogging Torque (mN-m)
LCLB	8.53	5062	69.9
LCSB	7.82	5435	25.2
SCSB	8.20	5220	27.9

- LCLB combination has the highest flux and hence,
  - Highest back-emf
  - Lowest no-load speed
  - Highest cogging torque
- In LCSB and SCSB combinations, the presence of unwanted secondary zone leads to,
  - Measured cogging torque > Simulated cogging torque

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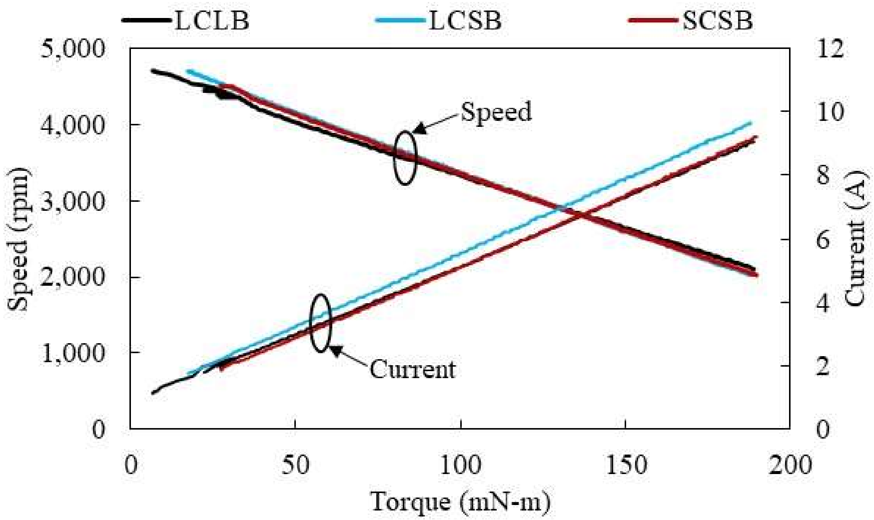
Effect on Motor Performance: Load Performance



Motor performance on load

Estimated stall-condition parameters

Fixture Component Combination	Stall Torque (mN-m)	Difference w.r.t LCLB
LCLB	329	-
LCSB	297	-10%
SCSB	313	-5%

- LCLB combination,
  - Highest flux ⟹ Highest stall torque

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Conclusions

- The magnetization fixtures made with solid steel components results in
  - Increased energy requirement to generate the saturation magnetization field due to eddy current induction.
  - Partially saturated magnets $\Rightarrow$ poor motor performance
  - Secondary transition zones $\Rightarrow$ higher cogging torque
- <u>Use of laminated steel for all soft magnetic components in the magnetization fixture is highly recommended</u>

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Thank You!!!!!

Questions?