Ring Form Factor Film Capacitors for Embedded Motor Controls

Consider an E-Drive Inverter located within the Motor Housing

Presented by:
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Consider E-Drive Inverter located within the Motor Housing

✓ Advantages:

✓ A more ideal Motor Form Factor for many applications

✓ Smaller Volume/Lower Weight System
  • Higher Power Density

✓ Electrical Efficiency Improvement Opportunity

✓ The possibility to Reduce EMI
Consider E-Drive Inverter located within the Motor Housing

✔ Challenges:

✔ Thermal Management
  • More Cooling Capacity Needed

✔ Sourcing Suitable Components

✔ Round PC Boards/Bus Structures are not “the norm”

✔ DC Link Capacitor Assembly

Note: The concept of an embedded inverter is not presented as a unique idea
SBE presents a discussion of DC Link Capacitor-related issues, and a solution to the need for a Round Capacitor.

The SBE Power Ring™ Solution:

- Customized Center Hole and Terminal Configuration
- Highest Capacitance Density
- Lowest Possible Losses and Inductance
  - Higher Ripple Current Rating
Examples of Ring Form Factor Film Capacitors
Trade-Off Between Capacitance and Center Hole Size

- The presence of the Center Hole:
  - Can be very useful
  - Results in minimal reduction in capacitance
    - A 30% diameter hole sacrifices less than 10% of the total available ring capacitance
Trade-Off Between Capacitance and Center Hole Size

Capacitance vs. "Hole to OD" ratio

The Hole Subtracts a small percentage of Capacitance
Other Approaches to a Round DC Link Capacitor Implementation

✓ Others have implemented this concept using discrete capacitor windings
What is the Difference between the Discrete Implementation and the Solid Ring Approach?

CAPACITANCE "PACKING FACTOR"
ID/OD = 0.47 for this example.

POWER RING: 100%

EXTREME PARALLEL DISCRETE SOLUTION:
- 2.77% * 13 = 36%
- 2.29% * 13 = 30%
- 0.58% * 13 = 8%
- 0.22% * 13 = 3%
  TOTAL 77%

MORE PRACTICAL SOLUTION: 66%
Available Capacitance of the Power Ring?

✓ Consider some Capacitor Sizes Relevant to Typical Electric Motors

- 4.5 inch ID/7 inch OD
- 4.5 inch ID/10 inch OD
- 5.5 inch ID/15 inch OD
Available Capacitance of the Power Ring?

- 4.5 inch ID/7 inch OD
- 5.5 inch ID/15 inch OD
- 4.5 inch ID/10 inch OD
Available Capacitance of the Power Ring

Available Capacitance

Typical 600VDC design [3.8u MPP film]

- **5.5" ID/15" OD**
- **4.5" ID/10" OD**
- **4.5" ID/7" OD**
Available Capacitance of the Power Ring

- Graph represents a Nominally Aggressive Capacitor Design
- Increased Dielectric Stress would allow for more capacitance per volume
- But Capacitance change versus thickness will stay the same
The Large Ring Capacitor behaves as a distributed Circuit Element both Thermally and Electrically.
Effects of Increasing Capacitor Thickness

- Increased Electrode Contribution to Total Effective Series Resistance (ESR)
- Increased Series Inductance
- Longer Thermal Path for heat Removal
  - Higher Temperature Rise for a given Dissipation
- Capacitor Hot Spot limits overall System Temperature
Effects of Increasing Capacitor Thickness

ESR vs. Capacitor thickness

Typical 600VDC design [3.8u MPP film]

- 4.5" ID/7" OD
- 4.5" ID/10" OD
- 5.5" ID/15" OD
Trade-Offs for Increased Capacitance

- Reducing Film Thickness will also increase ESR and tend to reduce lifetime.
- Increasing Ring Thickness will result in higher ESR and Thermal Resistance.
- ESR and Thermal Resistance are prime drivers of Ripple Current Ratings.
Ripple Current

✔ It’s a function of Temperature

✔ MPP is usable from -55°C to +105°C, with possible upside (i.e., high crystallinity film)

✔ A “Current Rating” is near meaningless unless the thermal environment is well defined

✔ Traditional Capacitor Current Ratings usually assume “free air convection” (the fine print)
  • An invalid assumption for a Motor Environment
Ripple Current

✔ A Thermally Distributed Model Applies

- The Capacitor will see different temperatures at different places
- Thermal Conductivity is not uniform over the capacitor surface
So, as a Capacitor Manufacturer, how do we Rate the Ripple Current?

- We need to know the maximum temperature at the End Spray Surface
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- We need to know the maximum temperature at the End Spray Surface
Unlike Conventional Capacitors, the Film Electrode Loss for the Ring Structure is so Low that current in the End Spray can be the dominant Loss Contributor.

Capacitor Interface with Bus Structure is Critical to minimize End Spray Losses and therefore will dictate the location of this maximum temperature.

Capacitor Hot Spot will be near the terminals.
Ripple Current Rating affected by Terminal Placement
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Ripple Current - Conclusions

✔ Reducing Current Density in the End Spray results in lower Heat Dissipation and a Higher Ripple Current Rating
  - Multiple Terminals and Optimal Placement Required

✔ Use of a Thin Ring results in a higher Ripple Current Rating
  - Lower Film Electrode Loss
  - Shorter Thermal Path
  - Doubling the Ring Thickness results in halving the Ripple Current Rating

✔ Reducing Capacitor Interconnect Losses will also increase the Ripple Current Rating
Simulation and Experiments have shown that the Capacitor behaves as a Heat Sink for the Bus Structure Losses!

- Only considers the AC case

The DC Bus Losses make the above problem even more pronounced

To Truly Optimize Ripple Current Rating, minimize Overall Bus Structure Losses
Bus Structure Losses

✔ Use the highest voltage that Semiconductor SOA and winding insulation systems will allow
  • Doubling the voltage will reduce bus dissipation by a factor of 4. Will not necessarily change Capacitor size.

✔ Skin Effect Losses can be significant
  • Multiple Connections reduce this effect
  • Be sure to consider the harmonic content of ripple current
The Value of Symmetry

✔ The most efficient performance is optimized by Electrical and Mechanical Symmetry.

✔ For 3 Phase Systems, the Inverter power should be withdrawn from the bus at equally spaced locations (120 degrees apart).

✔ If the DC Input is very close to one of the Inverter outputs, the DC losses can be minimized.
The Value of Symmetry
The Value of Symmetry

✓ 6 areas on the Capacitor surface with essentially no dissipation (zero current)

✓ 6 terminals divide the ripple current, further reducing dissipation

✓ Remove DC power to inverters between interconnects to more uniformly distribute the ripple current

✓ Apply DC input current very close to the inverter AC outputs to minimize DC losses in the Bus Structure
Conclusions

✔ There are great advantages when committed to a round shape of the Capacitor/Inverter

✔ To obtain optimum performance from your E-Drive System, close interaction with the Capacitor Manufacturer is required

✔ The advantages of the Power Ring over a discrete implementation are significant in both space and allowable ripple current
  
  • Ripple current has to be reduced by the “Packing Factor” percentage
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Thank you!
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