Investigation into the Design of Navy High-Power Plug-In Shipboard Electrical Connectors

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MIT ESRDC Mini-Symposium
MIT Sea Grant Design Laboratory
May 12, 2022

Agenda

- Motivation
- Plug-in connector Design Process
- State Of The Art: Make And Break Electrical Contacts
- Development of Contact Figure of Merit
- Contact Electrical Insulation
- Concept Design
- Conclusions

Motivation

- High power: both high current and high voltage simultaneously
- Classical connections: bolted or welded
- A quick-connect/quick-disconnect high-power electrical connector: facilitates installation of pre-built electric power corridor units into ships, reduce installation time of loads, and enables rapid reconfigurations
- Traditional high power “make and break” connectors: designed for the commercial land-based utility industry. Not constrained by size or weight.
- No commercially available connectors suitable to the task. No existing design guidelines to build such connectors for the Navy application.

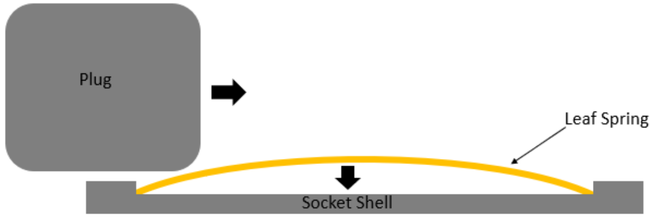
https://bertholdelectric.com/wp-content/uploads/2018/01/BE_PrtGenBrch.pdf

Plug-in Connector Design Process

- Design constraints:
  - Limits set by physics-based rules
  - Conformation to established regulations and standards
  - Enable successful function and safe operation in the Navy ship environment
- Two key topics for all high-power connectors:
  - Metallic contacts required to handle the currents carried by the connector
  - Electrical insulation to safely support the high voltages on the conductor parts
- Evaluated existing contact designs
  - Collected and organized their data to establish performance metrics for parameters such as size, power loss, and current capacity
  - Analyzed for insulation capability in regard to tolerance to ambient conditions as quantified by insulation creepage path length
- Reviewed applicable standards and guidance concerning ambient conditions that strongly impact the insulation design structure.

Brand	Connector
Amphenol	Radlok
Amphenol	Radsok
AZZ	HM Contact System (HM-38)
AZZ	HM Contact System (HM-95)
Deutsch	DTHD
Eaton	Roughneck
Eaton	Rough-lok
Eaton	Cam-lok
Harting	Han S
Harwin	Kona
Hirose	PS3C Series
Hirose	EM30MSD Series
Hirose	EV1
Hubbell	Load Break
Hubbell	PowerEX
ITT Cannon	Powerlock
ITT Cannon	Snaplock
ITT Veam	VSC
JAE	DW Series
JAE	JK06 Series
JAE	KW04 Series
Molex	Brad Quick-Change Connectors
Molex	EXTreme PowerMass High-Current Connectors
Molex	EXTreme Guardian System
ODU	Springtac
ODU	Lamtac
ODU	Turntac
Phase 3	Powersafe
Phase 3	Showsafe
Smiths Interconnect	HBB Series
Smiths Interconnect	Transformer Series
Smiths Interconnect	LSH Series
Smiths Interconnect	Hyperboloid Technology
Smiths Interconnect	Tortac Technology
Staubli	Single-pole round connector 16BL
Staubli	Single-pole round connector 21BV
Staubli	Robifix
Staubli	Multilam Plugs
Staubli	Performore
Staubli	Multilam Flexo
Staubli	Multilam Technology
ZZDQ	Ceeform

State Of The Art: Make And Break Electrical Contacts



- Single pole contacts above 150 Ampere
- Louver mechanism: employed multiple individual spring-loaded contact points to achieve electrical connection between the bulk plug and bulk socket contacts

Radsok

Louvers per inch (LPI): 13.5
Current Rating: 60-1000 A

Han S

LPI: 26
Current Rating: 200 A

LSH

LPI: 26.6
Current Rating: 200 A

HBB

LPI: 23.48
Current Rating: 500 A

Radlok

LPI: 13.5
Current Rating: 400 A

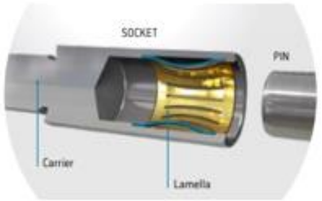
Powersafe

LPI: 13.03
Current Rating: 500 A

EV1

LPI: 13.15
Current Rating: 120 A

Lamtac

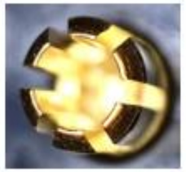


LPI: ~36
Current Rating: 49-1790 A

Springtac

LPI: ~65
Current Rating: 43-1330 A

Kona



LPI: 10.5
Current Rating: 60 A

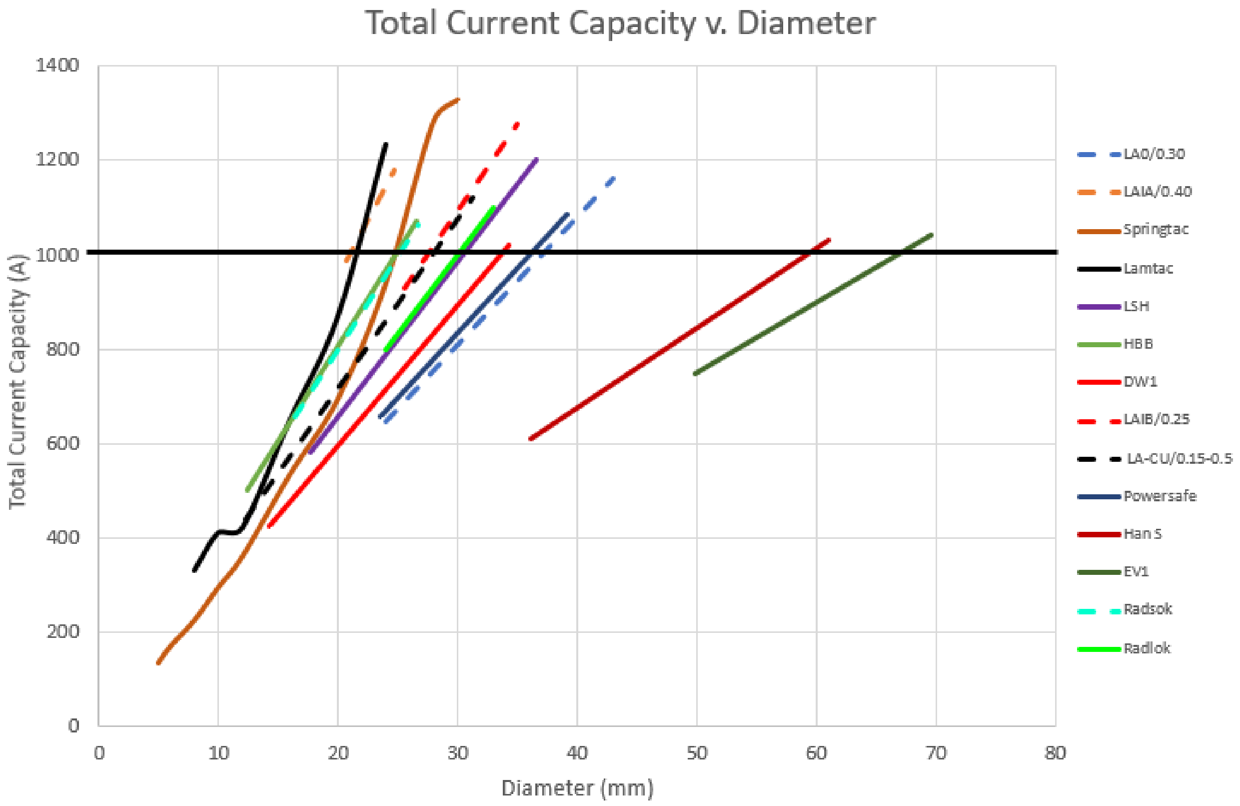
DW1

LPI: 12.5
Current Rating: 500 A

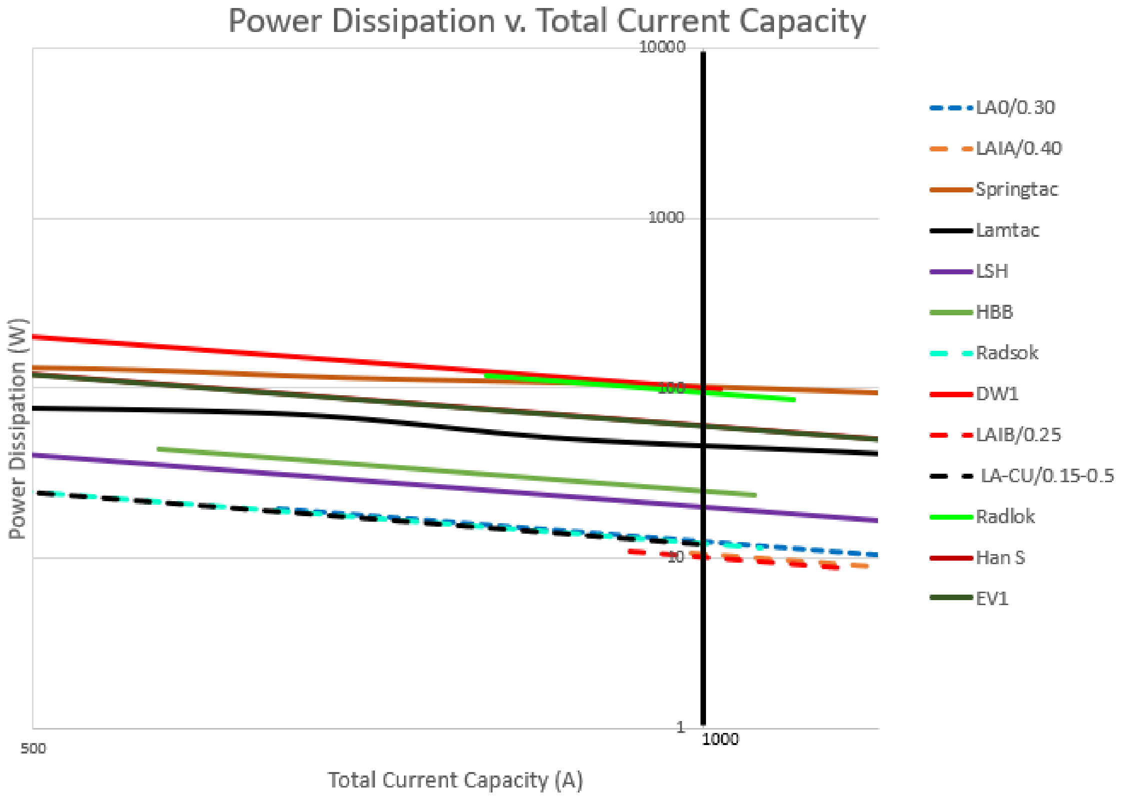
Turntac

LPI: 3.24
Current Rating: 39-125 A

State Of The Art: Make And Break Electrical Contacts



Louver Contacts Total Current Capacity v. Diameter design graph, 1000 A black horizontal design line



Louver Contacts Power Dissipation v. Total Current Capacity design graph, 1000 A black horizontal design line

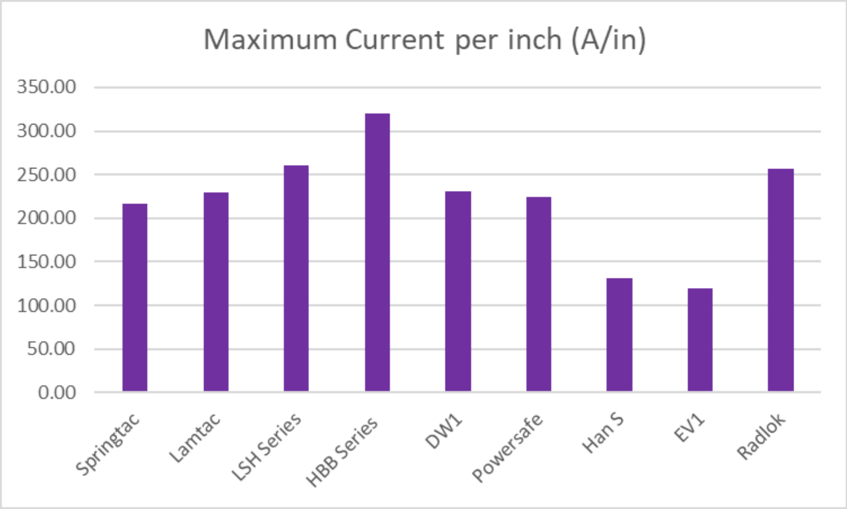
Development of Contact Figure of Merit

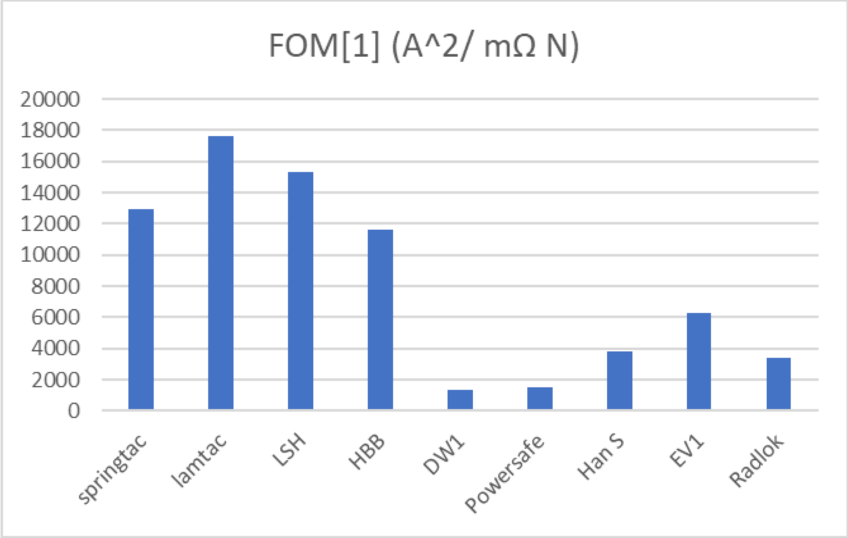
$$FOM1 = \frac{I_{in}^{2}}{R_{in} * F_{in}}$$ (A²/ mΩ N) Current

$$FOM2 = \frac{I_{in}^{\frac{3}{2}}}{R_{in} * \sqrt{F_{in}}}$$ ($A^{3/2}$/ mΩ $N^{1/2}$) Power Loss

$$FOM3 = \frac{I_{in}^{\frac{3}{2}}}{F_{in} * \sqrt{R_{in}}}$$ ($A^{3/2}$/ $m\Omega^{1/2}$ N) Force

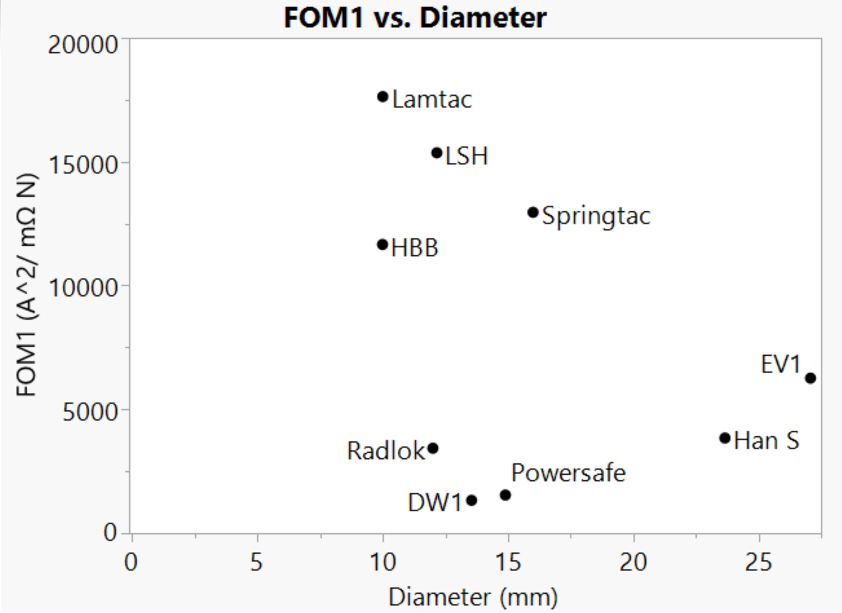
FOM4 = average of the above normalized FOMs All-around



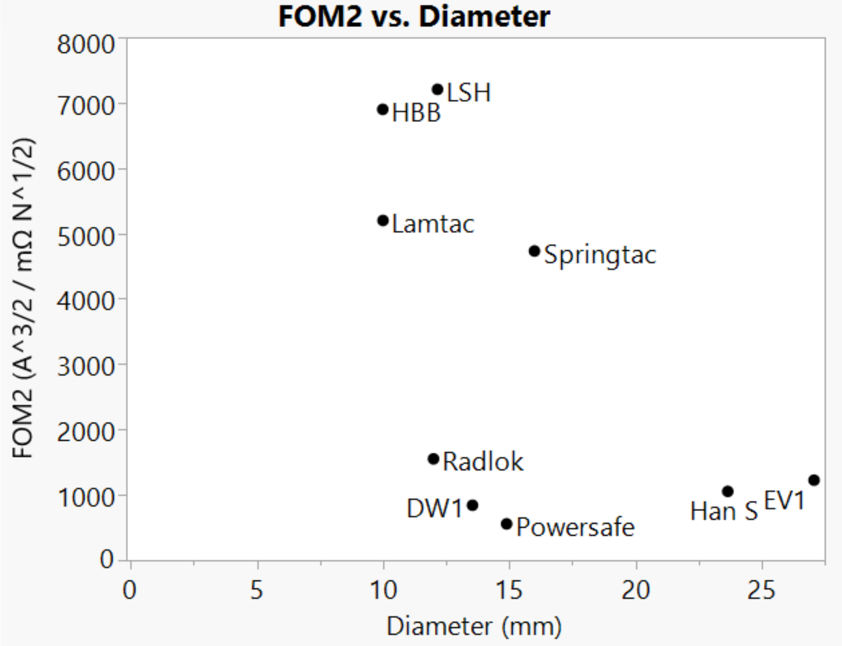


400 A Figure of Merit Contact Comparison

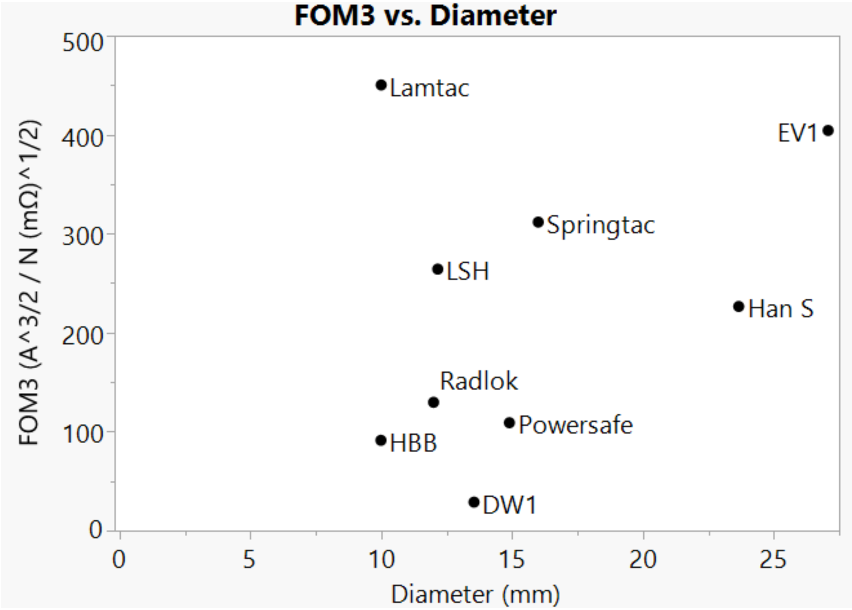
Current



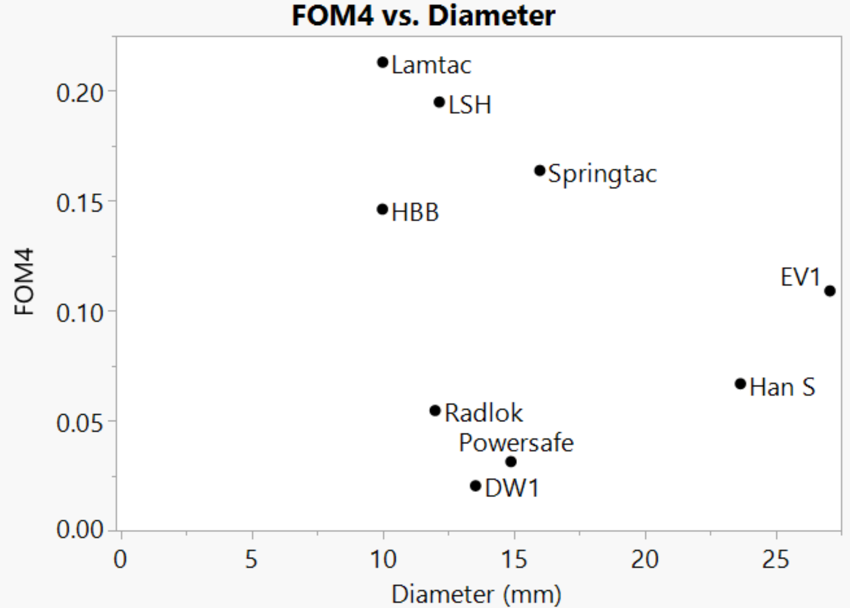
Power Loss



Force

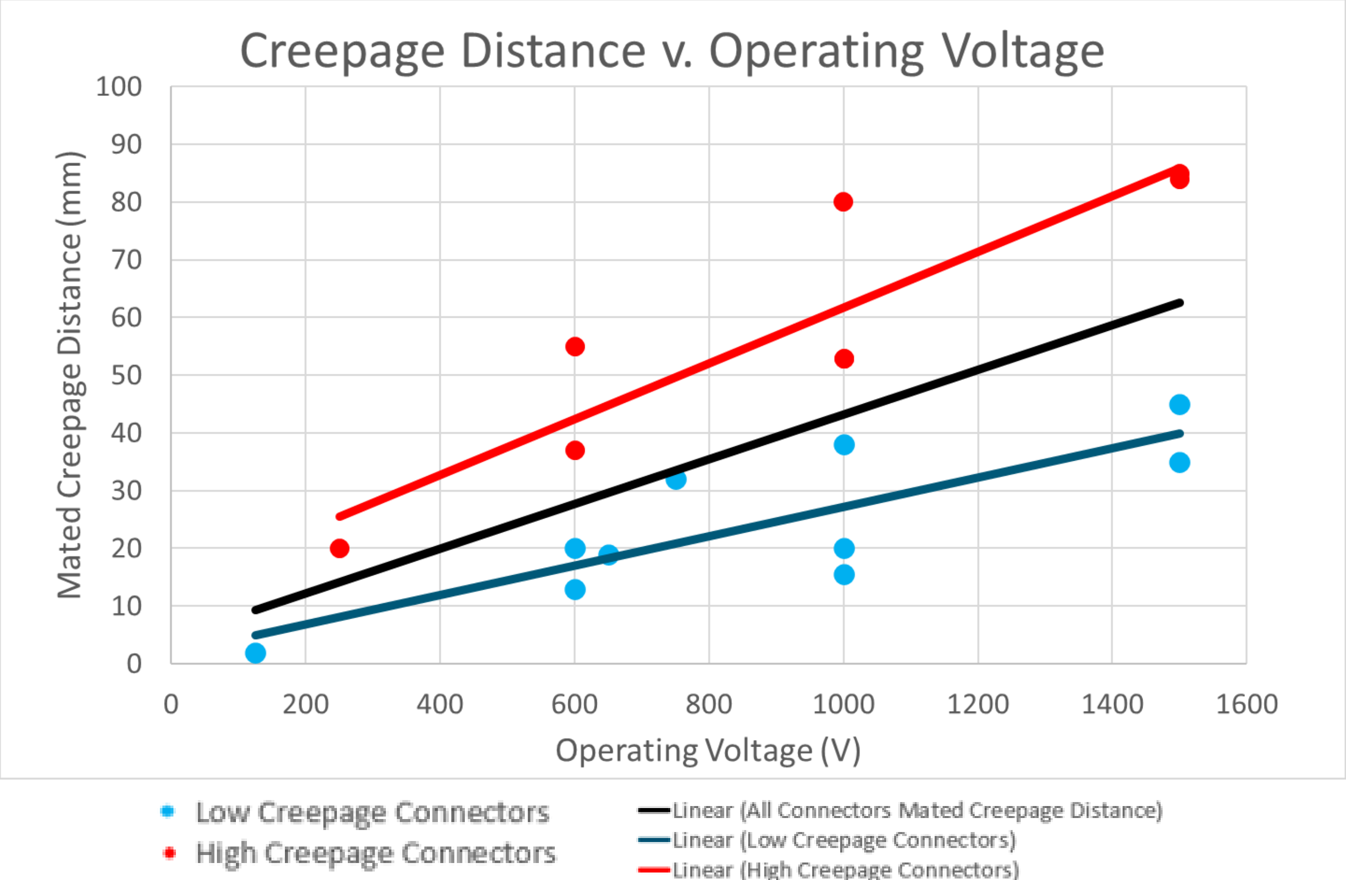


All-around



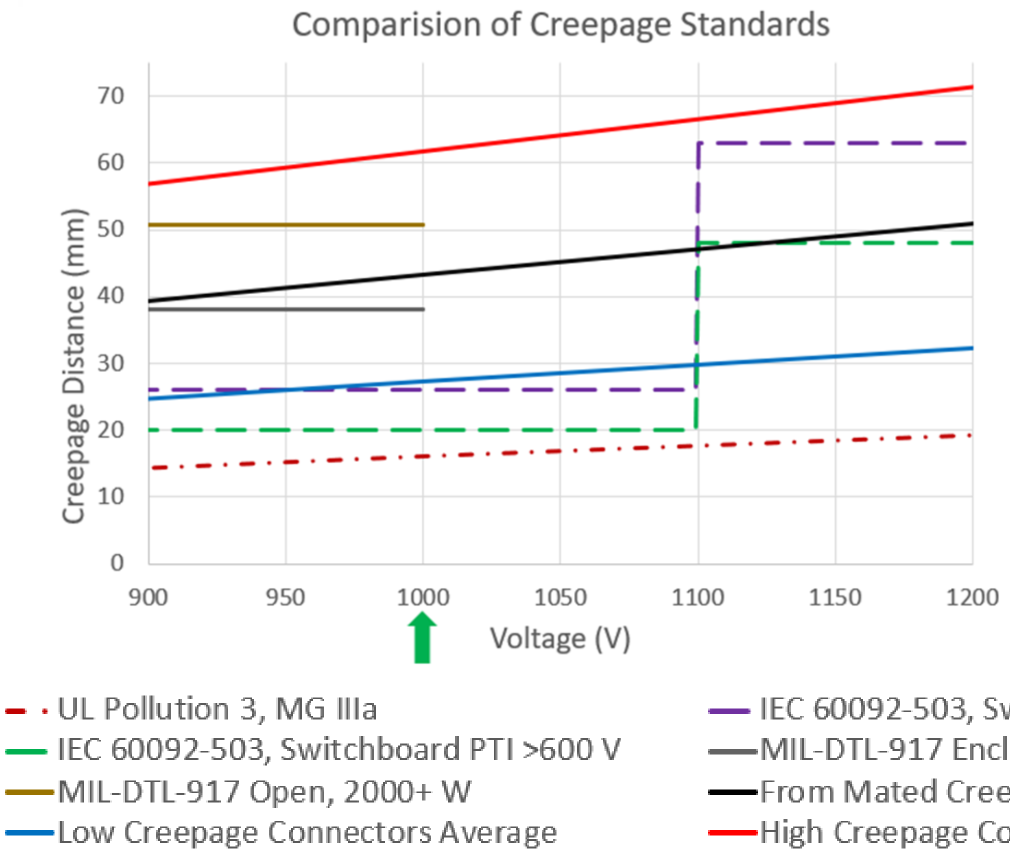
Contact Electrical Insulation

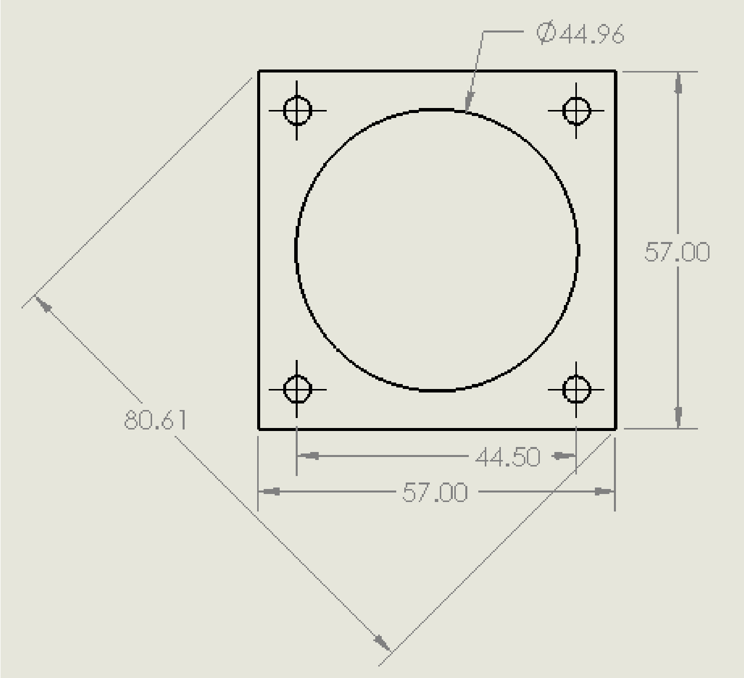
- Creepage distance: chosen to prevent surface tracking on an insulator
- Applicable Standards
  - MIL-DTL-917: Military applications ≤ 1000 V DC
  - IEC 60092: Military application > 1000 V
  - UL 840: Commercial
- Existing Connector Creepage Distances
  - Survey of existing connectors



Concept Design

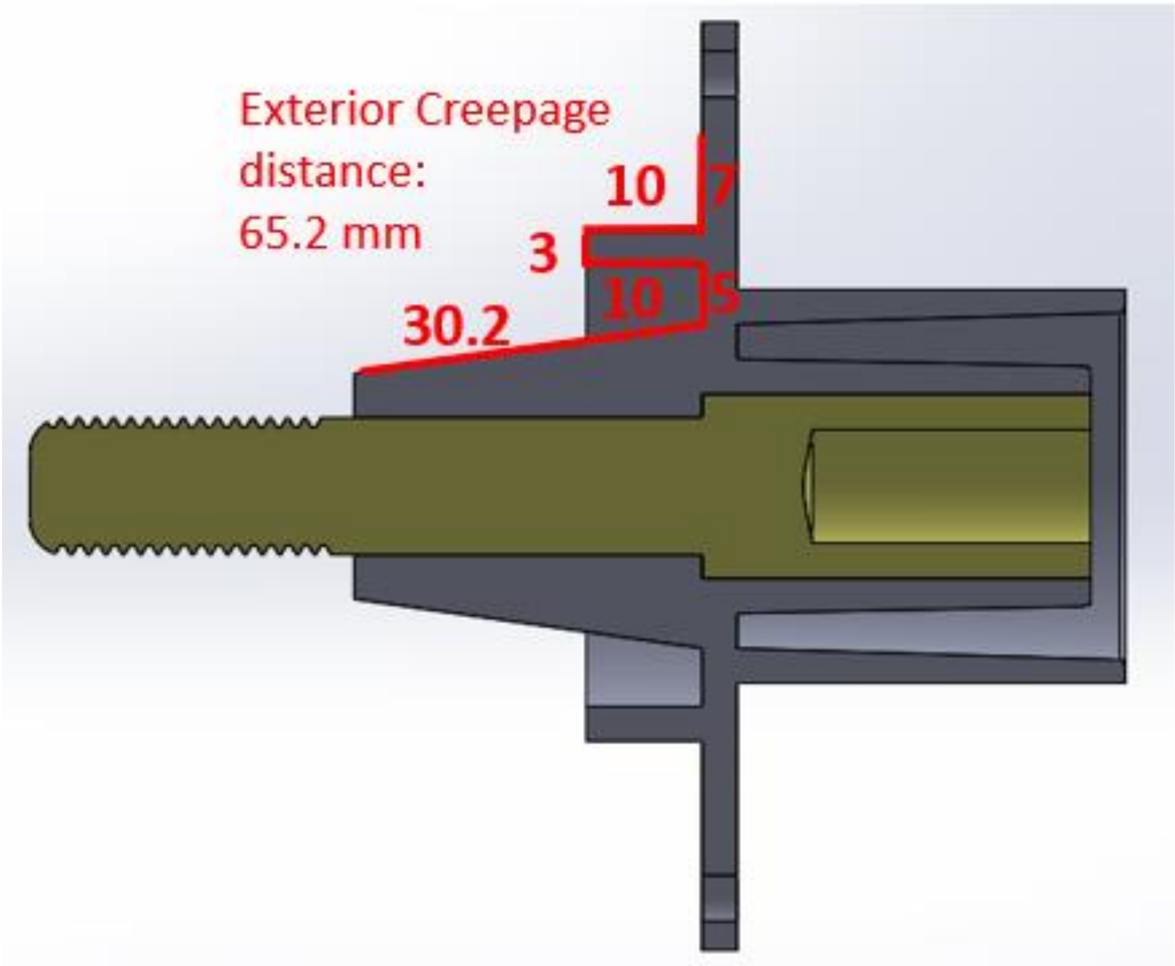
- iPEBB application
- 400 kW (400 A, 1000 V)
- Sizes limitations based on standard military shell size 32
- Mating limitations based on standard military single pole contact size 0
- IP44



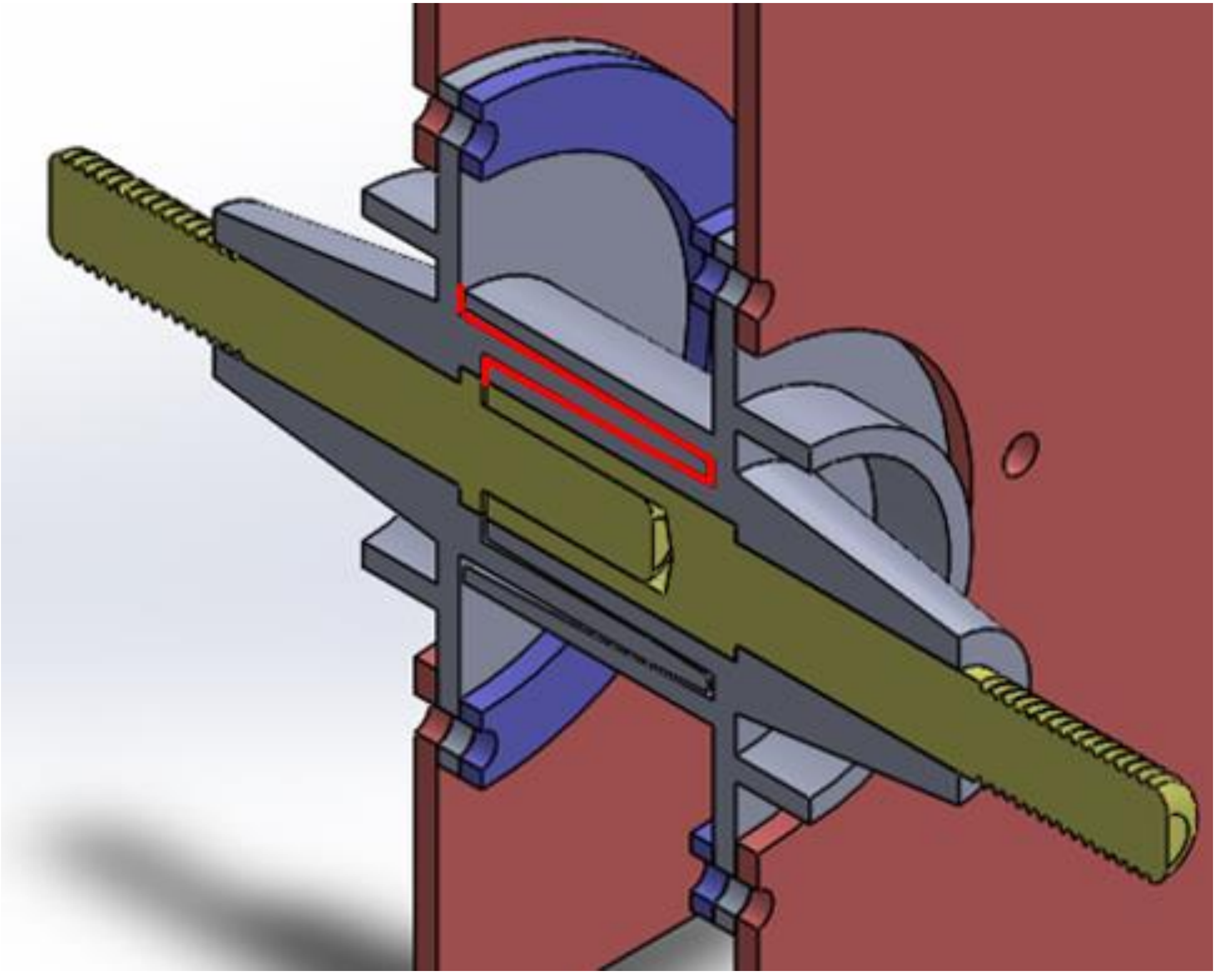


Parameter	Design Condition
Maximum outer diameter (including chassis mating interface)	80.61 mm
Maximum outer diameter of the insulation mating interface	44.96 mm
Maximum contact mating force	89 N
Maximum total mating force	111 N
Minimum Creepage Distance	60 mm

Concept Design

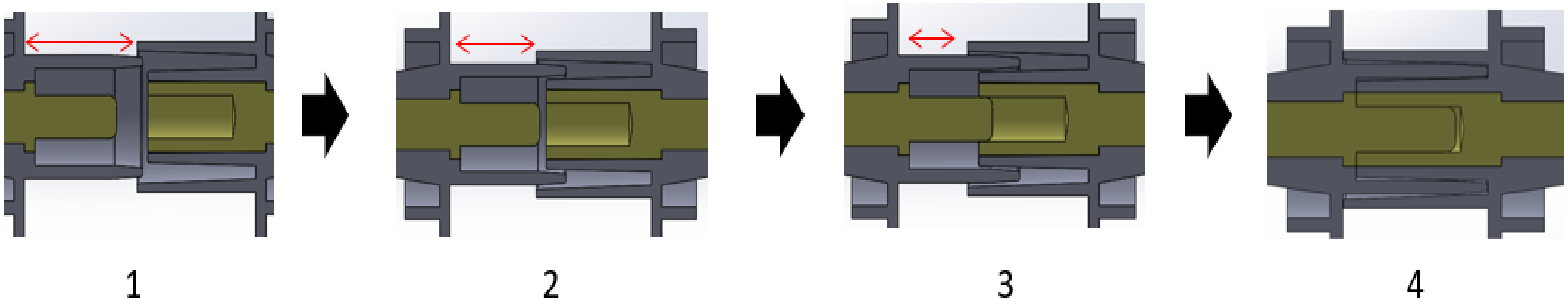


Cross Section of Pin Side Connector

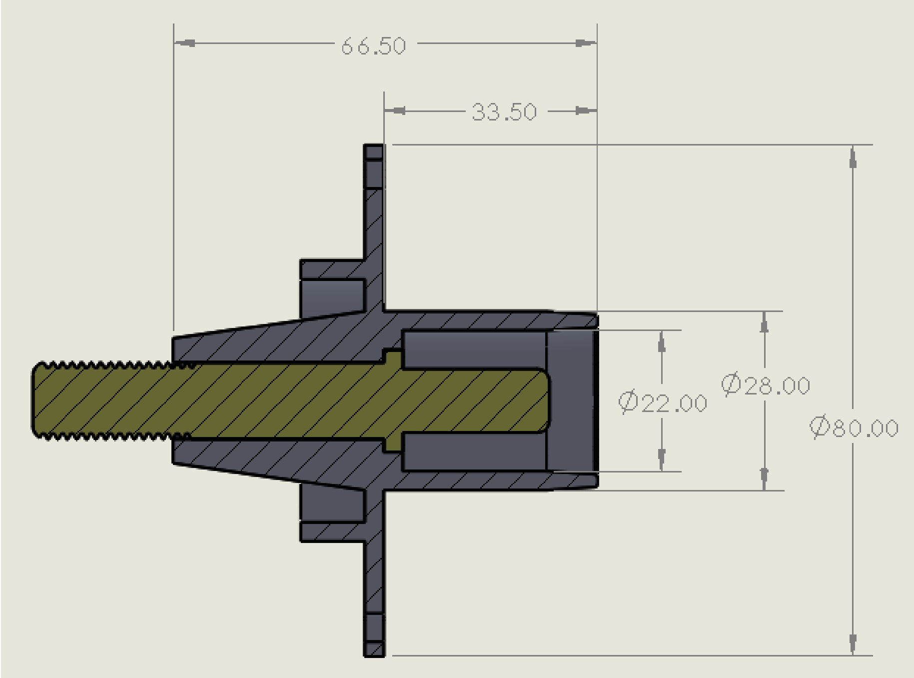


Mated Creepage Distance: 70.5 mm

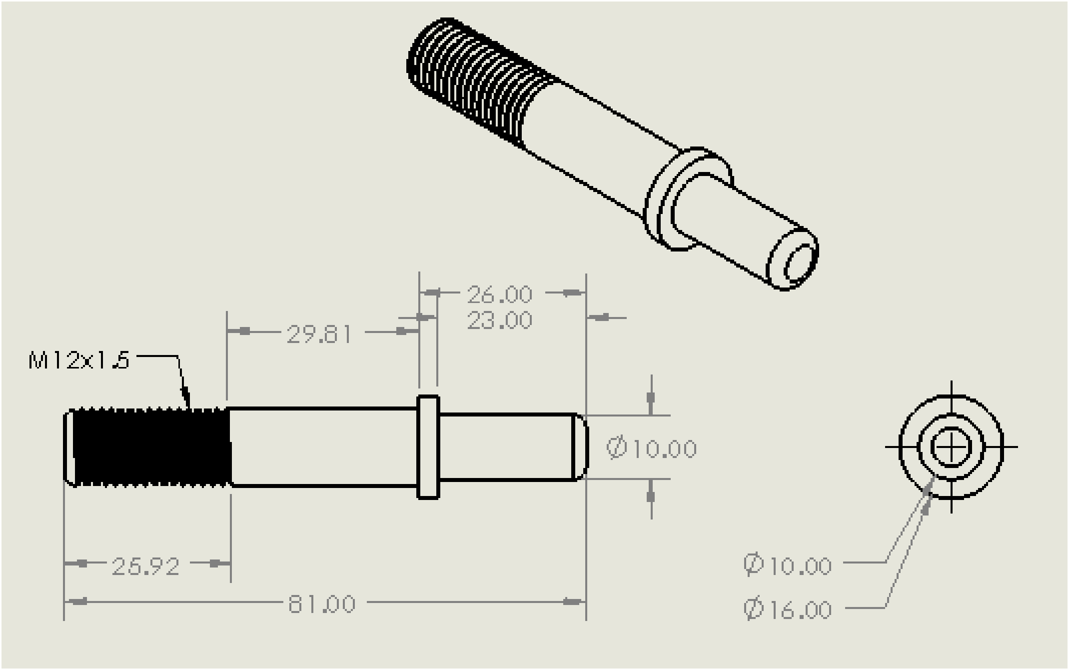
Concept Design



Mating Sequence

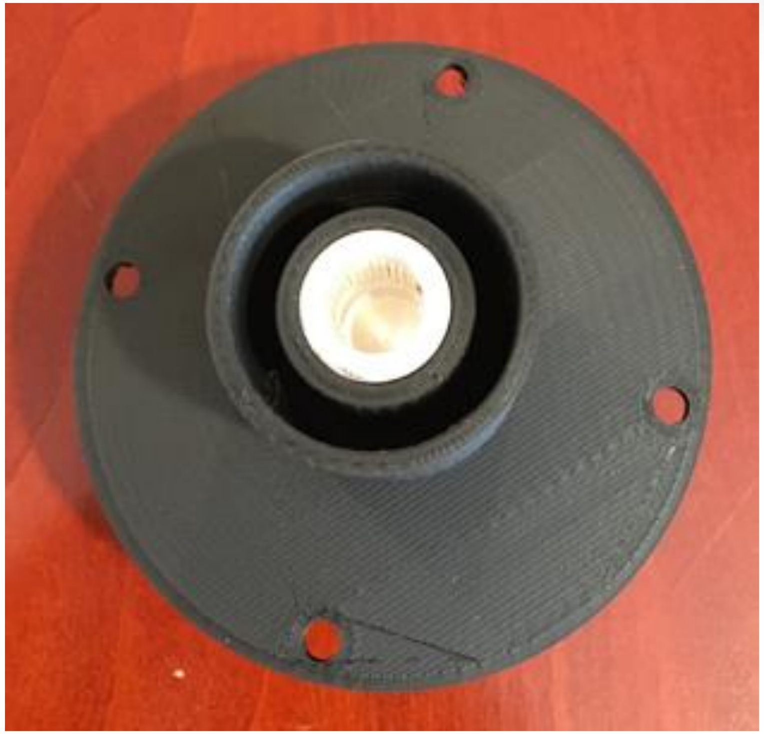


Dimensioned Drawing



Customized Lamtac Design

Conclusions and Future Work



- Conducted an off the shelf electrical connector survey
  - A method to compare dissimilar sized and rated contacts
    - Design graphs
    - Four Figure of Merits
- Identified requirements in order to define constraints for the connector and insulation
- Developed a mock-up design utilizing FOMs for contact selection and following design constraints

- Update the Navy's creepage distance standards
- Improve the FOM processes

Parameter	Design Condition	Concept Design
Maximum outer diameter (including chassis mating interface)	80.61 mm	80 mm
Maximum outer diameter of the insulation mating interface	44.96 mm	34 mm
Maximum contact mating force	89 N	30 N
Maximum total mating force	111 N	31 N
Creepage distance (mated condition)	60 mm	70.5 mm
Creepage distance (chassis side)	60 mm	65.2 mm
IP protection	44	N/A