Redesign of a spark gap switch assembly towards ease of assembly and reduction of volume and weight

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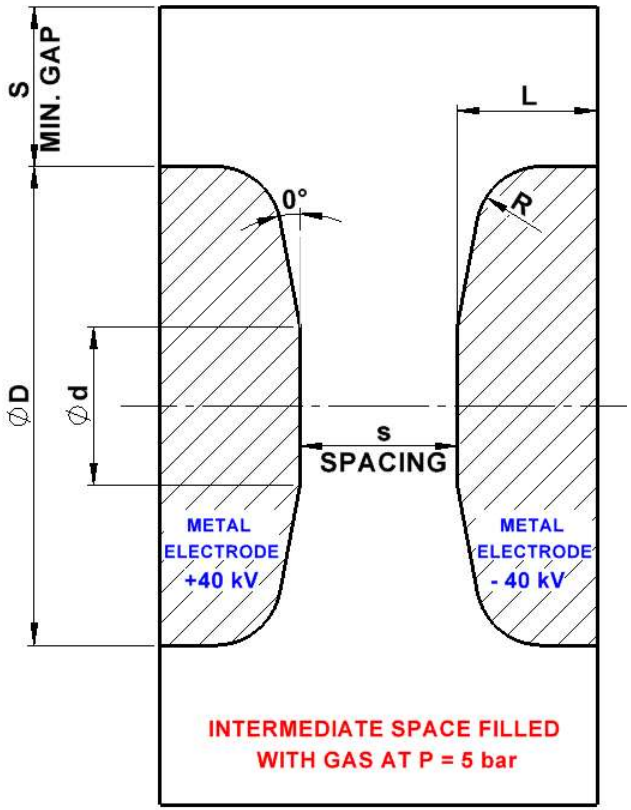
Requirements for the switch assembly

- **Switch important constituent for high voltage impulse generators**
- **Switch should discharge at 80 kV**
- **Assembly pressurised to 5 bar with N_2 gas**
  - **Gas pressure variation – flexibility to vary voltage of discharge**
- **Spacing between electrode - 12 to 14 mm – based on electrical design**
- **Switch internal volume – 0.3 litre minimum – for adequacy of N_2 gas**
- **Provision for electrical connections**

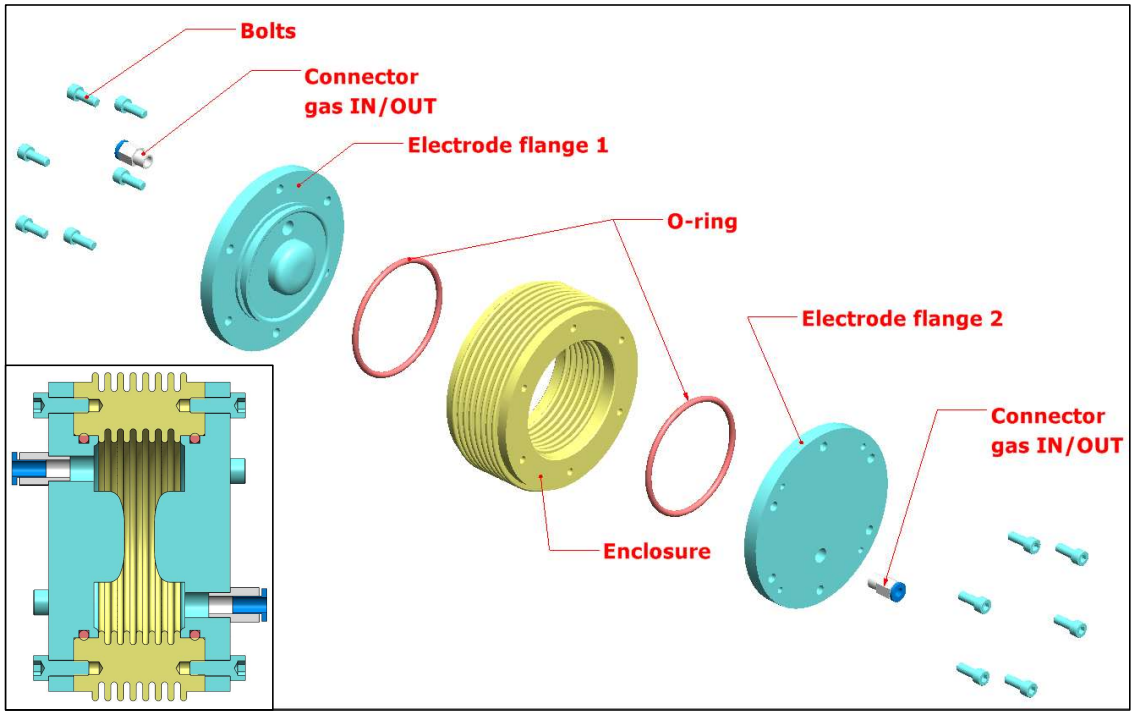
Parameters	Values
High voltage(kV)	75-80
Volume (m^3)	$3x10^{-4}$ (0.3 litre)
Electrode spacing (mm)	12 to 14
Pressure (bar)	5 (7.5)



Existing switch assembly

- **Electrodes of stainless steel integral with flanges**
- **Nylon enclosure at the centre**
- **Flanges fastened to enclosure by M6 bolts x 16 mm long - 6 Nos. on each side**
- **IN/OUT connectors for gas in both the flanges – to vary inside pressure**
- **O-rings on either side to prevent gas leakage**
- **Corrugations on enclosure to avoid insulator breakdown (creepage of high voltage)**

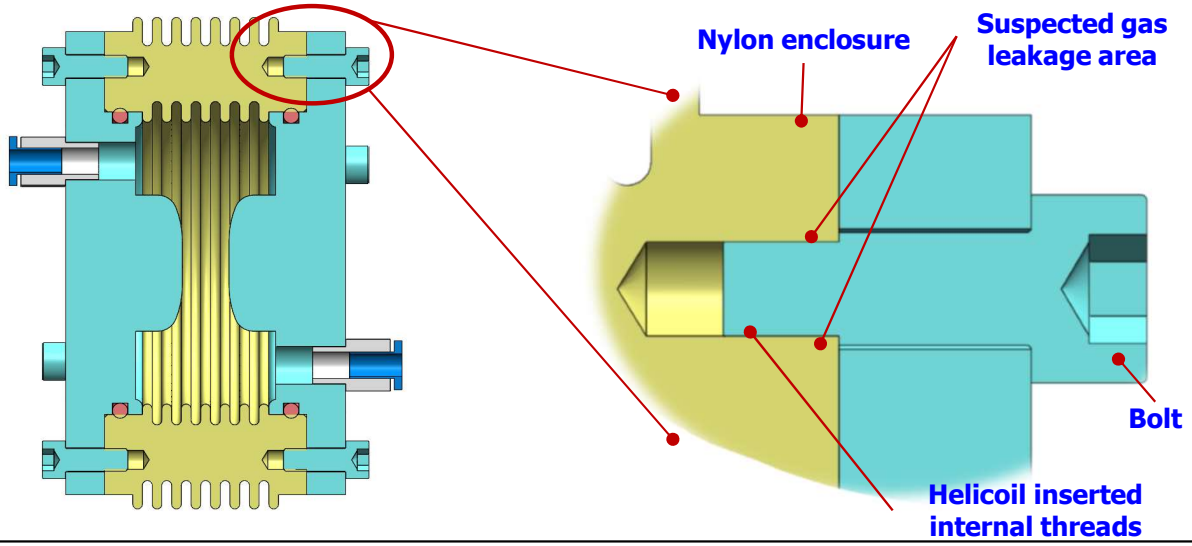
Part	Material	Quantity	Weight (g)
Bolt - M6 x 16 mm long	Stainless steel	12	196.8
Electrodes integral with flanges	Stainless steel	2	2622
Enclosure	Nylon 6-6	1	496
Total			**3314.8**



Exploded view of the existing switch assembly

Need for redesign

- **Leakage after repetitive usage**
  - **Probable reason – Degradation of threads in nylon enclosure**
- **Lack of provision for fastening the assembly in the final impulse generator**
  - **Needed for the mobile fieldable system**
- **Time of assembly, weight and volume to be reduced**
  - **8 assemblies to be used in one impulse generator – hence 8 times the benefits**
- **Minimize the high voltage breakdown paths**
  - **Possible short path between the bolts fastening the flanges**



Though the internal threads have helicoil/recoil inserts.

The helicoil is suspected to loosen from the nylon material after prolonged usage.

Material selection

- **Alternate material for Nylon enclosure explored**
  - **Nylon retained due to better Yield strength, Hardness, Dielectric strength apart from machinability**
- **Ceramics not considered as the assembly design is evolving – Only machinable material considered**
  - **Needed for the mobile fieldable system**
- **Stainless steel was replaced by aluminium for the flanges to make the assembly lighter**
  - **Electrodes – stainless steel (higher melting point) retained to avoid erosion during sparking**

Material		Density (kg/m³)	Young's Modulus E (MPa)	Poisson's ratio - ν	Yield Strength (MPa)	Hardness (Rockwell)	Dielectric Strength (MV/m)
Non metal	Polyamide (Nylon 6-6)	1150	1850	0.4	110-120	115-120	25
	Delrin	1410	3100	0.35	75	120	17.3
	Polycarbonate	1200	2400	0.36	39.7	114-126	16-335
	Perspex	1180	2855	0.35-0.4	70	90	20
Metal	Stainless steel	8000	193000	0.33	205	88	NA
	Al 6061 T6	2700	68900	0.33	276	95	NA

Analytical design

ν = *Poisson's ratio of the cylinder material*

σ = *Permissible tensile stress for the cylinder material*

σ_{tb} = *Permissible tensile stress for the bolt material*

p = Pressure in the cylinder

P = Load on the cylinder cover = $\frac{\pi}{4}(D_i{}^2)p$

t = Thickness of the cylinder

t_1 = *Thickness of the cylinder cover plate*

t_2 = *Thickness of the cylinder flange*

D_i = *Cylinder inner diameter*

D_o = *End cover outer diameter*

D_p = *Pitch circle diameter for the bolts*

d_1 = *Bolt hole diameter*

d_c = *Core diameter of the bolts*

M = Bending moment = $0.053P(D_p)$

w = Width of the cover plate = $D_o - 2d_i$

e = Eccentricity in flange = $\frac{D_p}{2} - \left(\frac{d_1}{2} + t\right)$

Z = Section modulus of the plate = $\frac{1}{6}\,w\,(t_1^2)$

n = Number of bolts

d/t < 15 thick cylinder – nylon enclosure

$$t = \frac{D_i}{2}\left(\sqrt{\frac{\sigma+(1-2\vartheta)*p}{\sigma-(1+\vartheta)*p}} - 1\right);$$ *t = 0.7 mm with FOS of 3* *10 mm chosen*

Number of bolts – M6 bolts considered

$$\frac{\pi}{4}(D_i{}^2)p = \frac{\pi}{4}(d_c^2) * \sigma_{tb} * n;$$ *n = 1* *n = 4 chosen*

Outer diameter of the cover and flange

$$D_o = D + 2t + 6d_1;$$ *D_o = 136 mm* *125 mm chosen*

Thickness of the cover

$\sigma t_1 = M / Z;$ *t_1 = 2.0 mm* *13 mm chosen for threads*

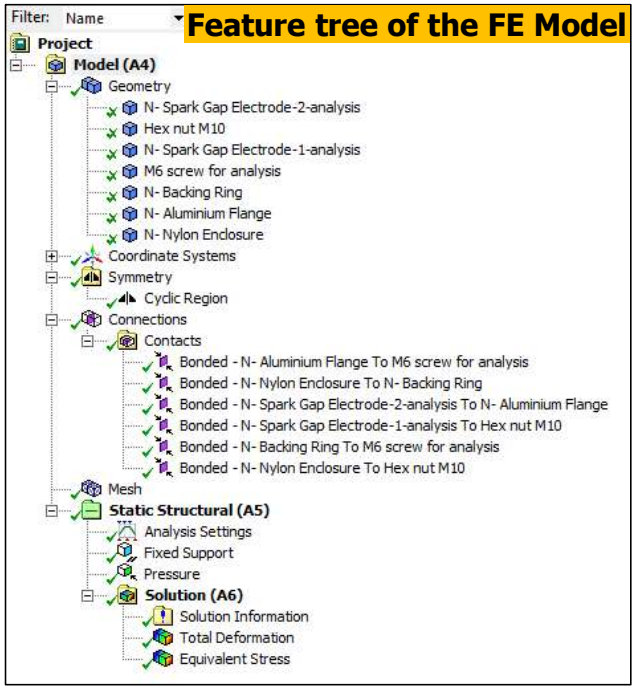
Thickness of the flange

$M = \frac{P}{n} * e$; $w = \frac{2\pi R}{n}$; $R = (D/2)+t$

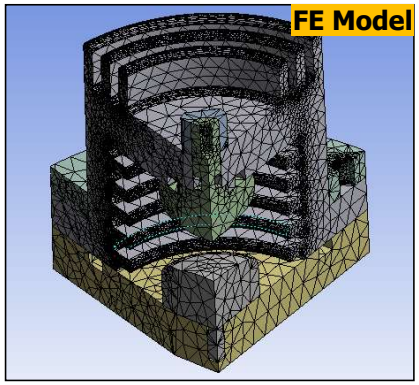
$\sigma t_2 = M / Z;$ *t_2 = 3.3 mm* *10 mm chosen for threads*

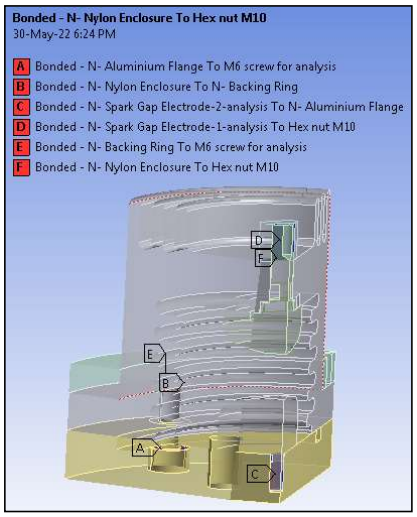
Formulae from Machine Design Hand book

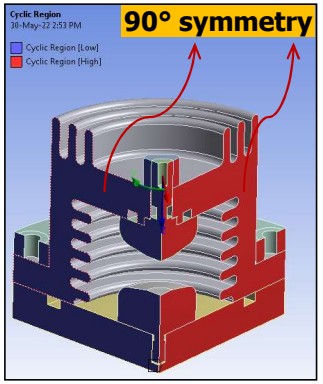
Finite Element Analysis – Model

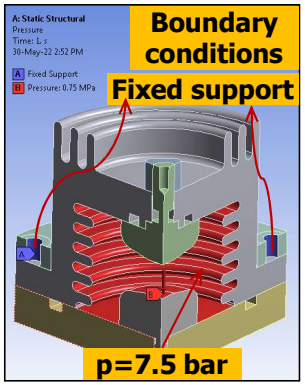


Mesh sensitivity of the FE model









Analysis type – Static structural

Element type – Solid 187 mid-side nodes included

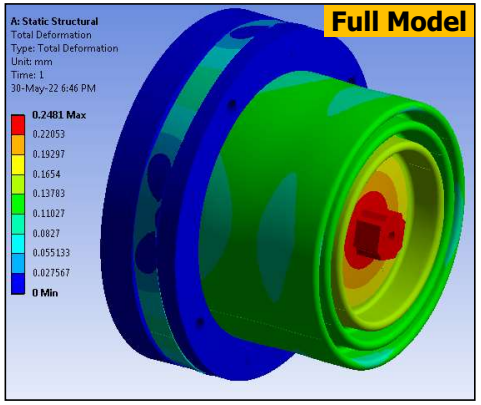
90° symmetry model considered for analysis

Bonded contact pairs – simulate the bolted joints

Boundary conditions

- **– Pressure at internal walls**
- **– Fixed support**

Finite Element Analysis – Results



Maximum deflection

0.25 mm at centre of the enclosure

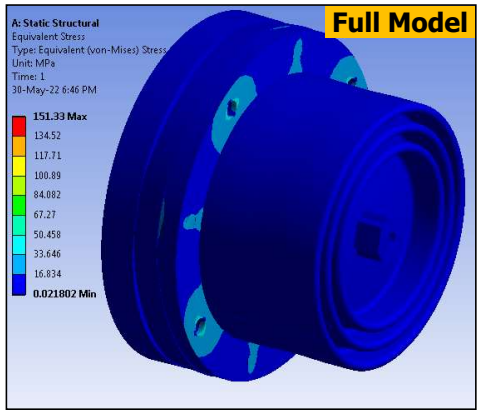
Between cover plate and nylon enclosure < 0.08 mm

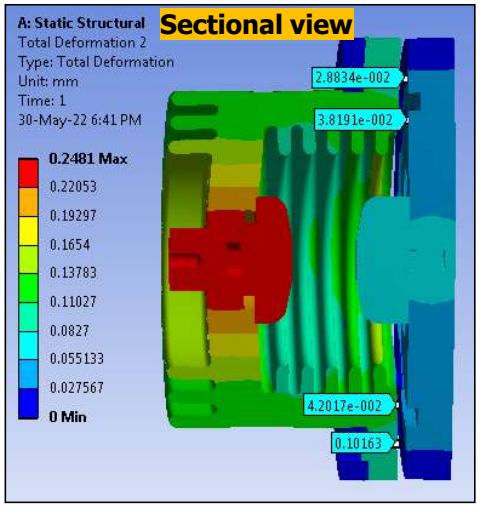
– O-ring compression nearly 0.5 mm

Maximum equivalent stress

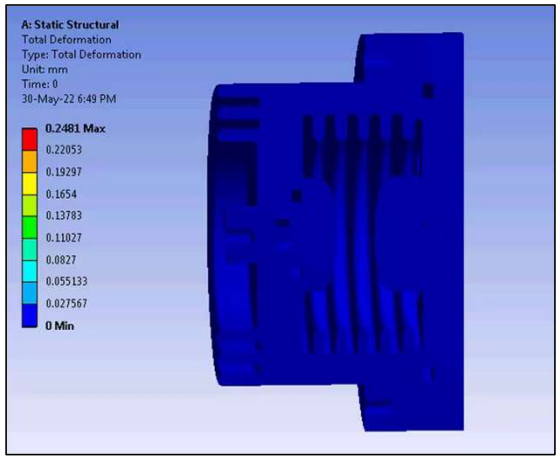
151 MPa at the bolted joint at backing ring

– lesser than yield strength of Al. alloy

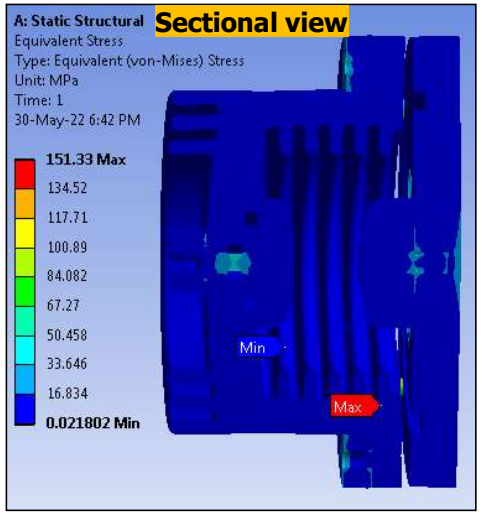




Deflection plot



Deformation animation

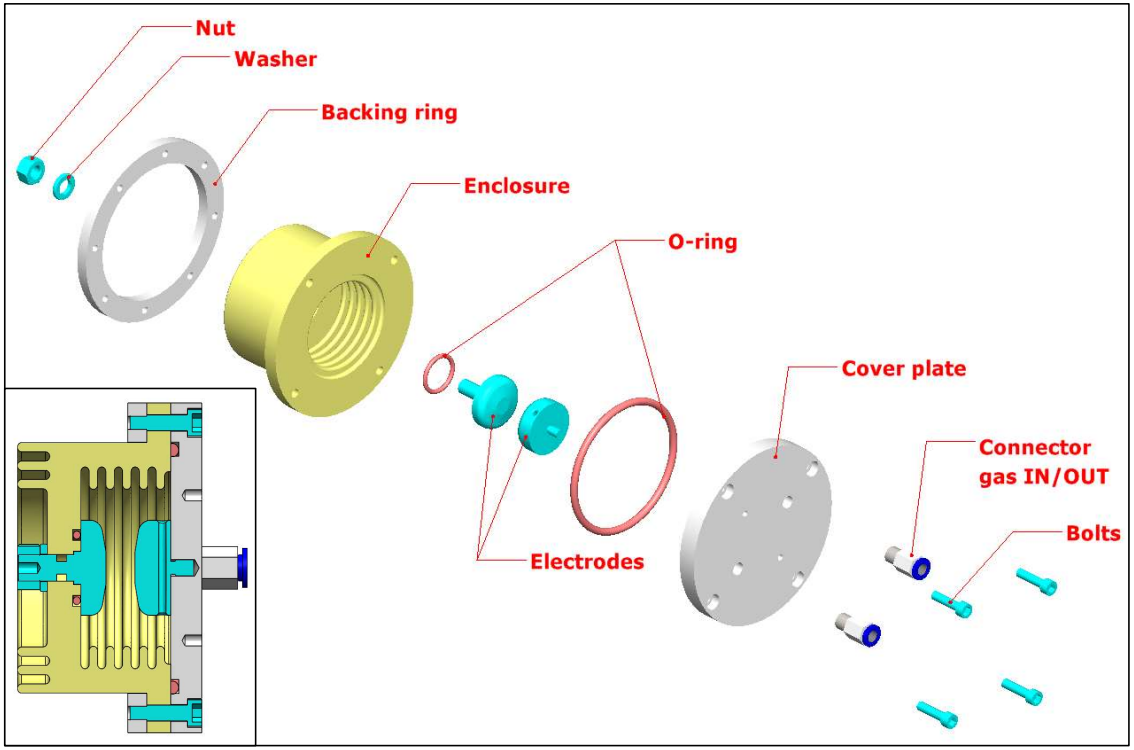


Von-mises stress plot

Proposed switch assembly

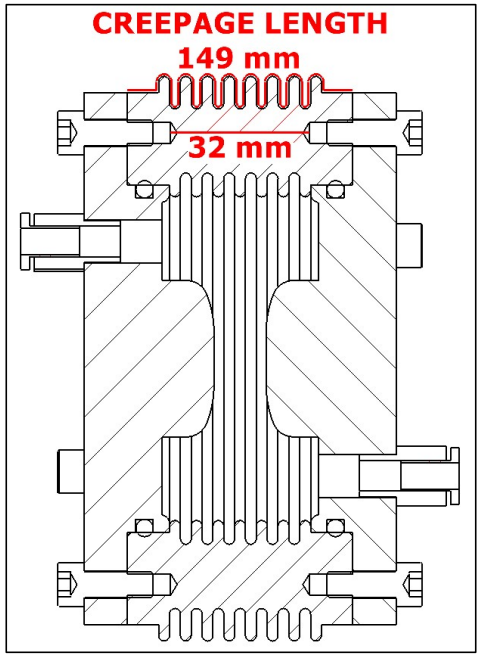
- **Electrode of stainless steel threaded on to the Al. alloy flange/cover plate on one end**
- **Enclosure redesigned to have stainless steel electrode at other end – one SS flange reduced**
- **Backing ring of Al. alloy provided to avoid threads in non-metallic enclosure**
- **IN/OUT gas connectors gas located on the same side**
- **No. of bolts reduced to 4 from 12 Nos.**
- **Weight reduced to 1.2 kg from 3.3 kg**

Part	Material	Quantity	Weight (g)
Bolt - M6 x 16 mm long	Stainless steel	4	65.6
Nut - M10	Stainless steel	1	12.5
Electrode 1	Stainless steel	1	89
Electrode 2	Stainless steel	1	110
Cover plate	Al. alloy	1	403
Backing ring	Al. alloy	1	109
Enclosure	Nylon 6-6	1	426
Total			**1215.1**



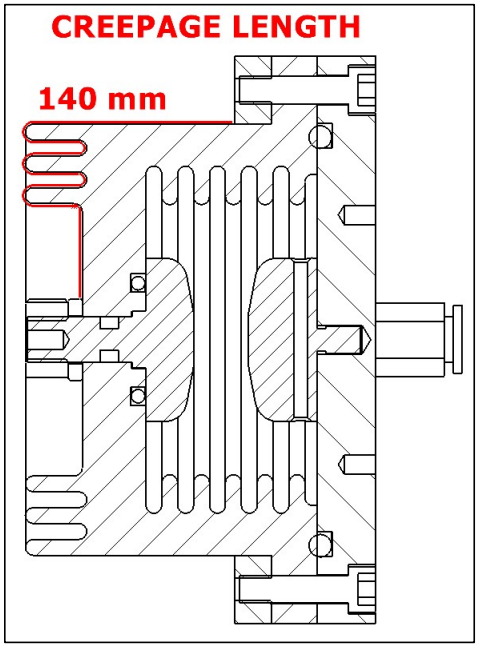
Exploded view of the proposed switch assembly

Conclusions



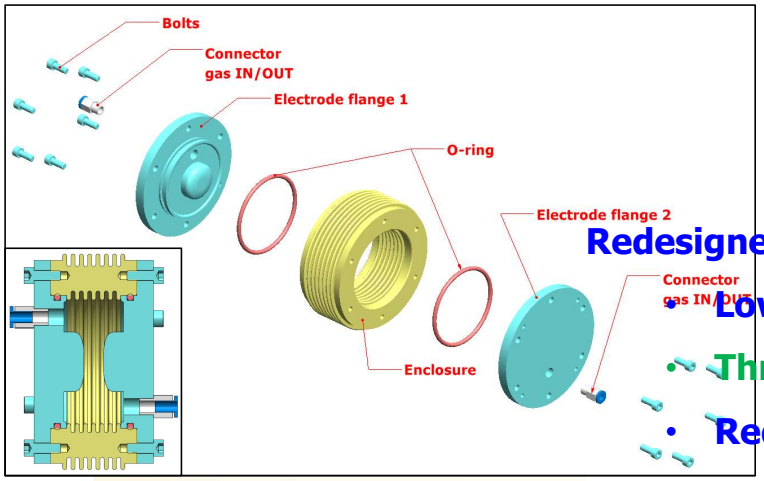
Existing design

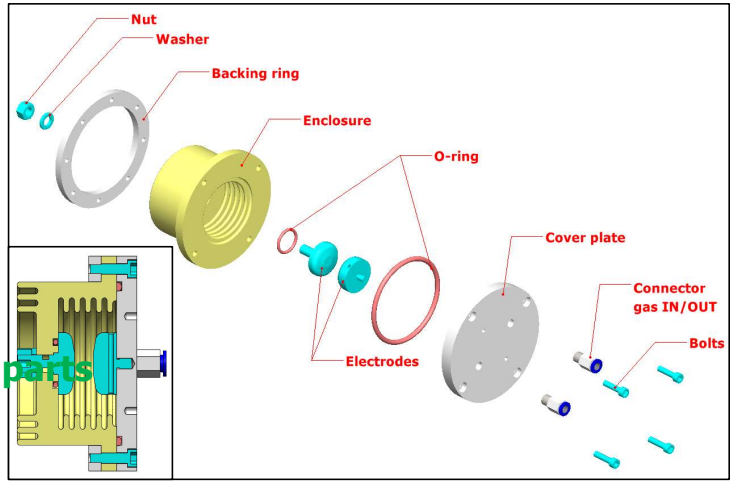
Part	Material	Existing design		Proposed design	
		Qty	Wt (g)	Qty	Wt (g)
Electrode integral with flange	Stainless steel	2	2622	Nil	
Bolt - M6 x 16 mm long	Stainless steel	12	196.8	4	65.6
Nut - M10	Stainless steel	Nil		1	12.5
Electrode 1	Stainless steel	Nil		1	89
Electrode 2	Stainless steel	Nil		1	110
Cover plate	Al. alloy	Nil		1	403
Backing ring	Al. alloy	Nil		1	109
Enclosure	Nylon 6-6	1	496	1	426
Total weight		**13**	**3314.8**	**10**	**1215.1**
Number of threaded joints		14		8 (Reduced time to assemble)	
Creepage distance (high voltage breakdown)		32/149 mm		140 mm	



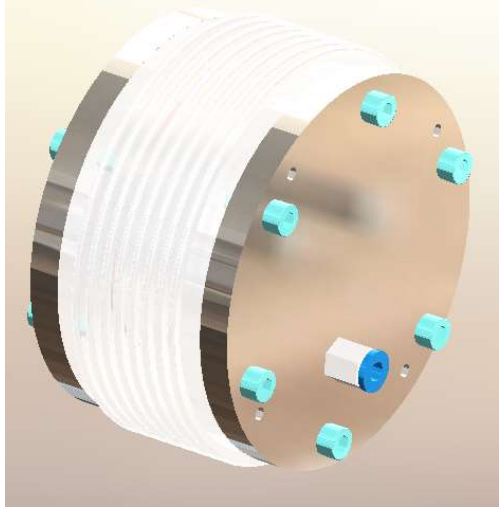
Proposed design

Conclusions





- Redesigned the switch assembly
- Lower weight
- Threaded joints only in metallic parts
- Reduced number of parts
- Reduced threaded joints
- Nearly the same creepage length
  - on the exterior
  - substantially increased through insulator



Existing design

Proposed design

Learnings from the project

- **Design of pressure vessel and cover plate**
- **Design of bolts for the above**
- **Selection of O-ring and groove dimensions**
- **Design for manufacturability**
- **CAD modelling using Solidworks 2021**
- **Finite element analysis – Static structural analysis in Ansys R2016**
- **Mechanical considerations for high voltage electrical assemblies**
- **Fabrication drawings and tolerance design considerations**

Assembly animation

Thank you