Bolted connectors
1. The function of bolted connectors
   The function
   Physical parameters
   Crimped versus bolted connectors
   Advantages of bolted connectors

2. Presentation of GHP connectors
   History of the screws
   Screw designs
   Multi shear level: screw of GPH
   Installation with cordless impact wrench
   Low voltage bolted connectors
   Medium voltage bolted connectors
   Tests according to EN 61238
   High voltage screwed connectors
   Bimetallic contacts
   Split bolted contacts

3. Applications
   Requirements of EDF
   Examples

4. Conclusion
1. The function of bolted connectors
The function of bolted connectors

Connecting of power cables or with other energy devices

- Low voltage, medium voltage and high voltage
- With conductor cross sections 6 – 300 – 630 – 1000 – 2000 – 2500 mm²

The connection must transmit electrical energy - means high current - during the whole lifetime without negative influence on:

→ the own function
→ joints, terminations and plugs concerning their thermal, mechanical and insulation behaviour
Electrical Contact – Quality Factor

quality factor $k = \frac{R_{\text{connector}}}{R_{\text{conductor}}}$

- homogeneous conductor
- connection
- non conductive layer
- micro contacts
- pretented contact area
- mechanical supporting area $A_i$
- electrical conductive area $A_w$

$A_w << A_s$
Behaviour of the Electrical Contact

Behaviour of the quality factor: \( k = \frac{R_{\text{connector}}}{R_{\text{conductor}}} \)

- **Contact formation**
- **Contact during life time**
- **Accelerated ageing of the contact**
- **Intermitting of the contact**

**Nexans**
The connector resistance $R_{\text{conn}}$ depends on:
- the resistance of the connector body and of the screws (material, shape)
- the contact resistance between conductor and connector body
- the contact resistance between conductor and screw tip
- the contact resistance between the wires of the conductor

*) the temperature can be influenced by heat transfer due to conduction, radiation, convection (continuous current) and heat storage (short circuit current)
A low contact resistance $R_{\text{conn}}$ between:
- conductor and connector body
- conductor and screw tip
- the wires of the conductor can be achieved by
  - a high contact force $F$
  - grooves to break non-conductive layers and to generate a defined contact area

Contact resistance: $R = \frac{C_Q}{(0.1 F/N)^m}$


Effects on the Contact Resistance

- grooves
- current path
- conductor
- oxide layer
- force $F$
- contact force $F_c$ [N]
Contact Resistance depending on the Screwing Moment

screwing moment $M_{\text{screw}}$

contact force $F_c$

connector resistance $R_{\text{conn}}$

$F_{\text{screw}} = \frac{M_{\text{screw}}}{k_1 P + k_2 \mu_S d_2 + k_3 \mu_S D}

k_1: 0.16
k_2: 0.58
k_3: 0.5
The electrical resistance of a connection can be increased by:

- chemical ageing, means increasing of oxide layers and due to that constriction of micro contacts

- floating - especially of aluminium conductors - and due to that reducing of the contact force

- Both effects will be accelerated at higher temperatures

- Because of that the electrical losses should be as small as possible
Compression connections – crimping

- For every cross section a special crimp connector is needed.
- A copper conductor needs a copper connector.
- An aluminium conductor needs an aluminium connector.
- Heavy tools and a lot of different dies are necessary

Bolted connections – screwing

- Are range taking concerning conductor cross section for low and medium voltage application.
- Are adapted to the cross section range of the accessories.
- Copper and aluminium conductors, which could be round or sectoral shaped, stranded or solid, can be connected
- No special tools for the installation.
Advantages of Bolted Connectors

- Range taking concerning conductor cross section for low and medium voltage application

- Adapted to the cross section range of the accessories

- Copper and aluminium conductor

- Round, sectoral shaped

- Stranded, solid

- No special tools for the installation.
2. Presentation of the GHP connectors
History of Screw Development

Development of bolted contacts since the eighties worldwide.

1. **Headless screws (grub screw) with inner hexagon**
   - installation with a torque wrench which shows the required moment
   - or depending on the „intuition“ of the installer

2. **Shear screws with one shear level**
   - predetermination of the right shear moment by the manufacturer
   - usable for low voltage connectors / high voltage connectors

3. **Multilevel shear screws for medium voltage application**
   - predetermination of the right shear moment regarding the cross section
     → NPAG screw: biggest conductor with the biggest moment (contact force)
   - screw shears off nearly flash with the surface of the connector
     → no negative influence on the electrical field of the accessories
Design of Bolted Contacts/Screws depending on the Voltage Level

- **Low Voltage**
  - big excentricity and rel. big excess length after shear-off allowed
  - screws with 1 - 2 shear levels

- **Medium Voltage**
  - only small excentricity and small excess length after shear-off
  - screws with 2 - 4 shear levels

- **High Voltage**
  - round conductor channel especially adapted to the conductor
  - no excentricity
  - one shear level
  - high force screws for aluminium Milliken conductor with big cross section
Multi Shear Level Screw from NPAG

The NPAG multi shear level screw is the only one on the market which has both main advantages.

- Biggest moment for the biggest cross section: means biggest contact force for the biggest conductor with the biggest nominal current

- Installation with standard keys which are commercially available

- During shear off the contact part of the screw will not be influenced (no constriction of the contact part).
Low Voltage Screwing Connectors
Low Voltage Screwing Connectors

Screws with one (max. two) shear levels

- sectoral shaped or round conductor channel
- rel. big excentricity
- grooves cross and lengthwise
  → piercing of solid conductors
## Typical Low Voltage Screwing Connectors

<table>
<thead>
<tr>
<th></th>
<th>Al in mm²</th>
<th></th>
<th>Cu in mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>se</td>
<td>re</td>
<td>sm</td>
</tr>
<tr>
<td>416 MS-SV</td>
<td>6-16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE1650</td>
<td>25-50</td>
<td>10-50</td>
<td>35-50</td>
</tr>
<tr>
<td>SE25150</td>
<td>35-150</td>
<td>25-50</td>
<td>35-120</td>
</tr>
<tr>
<td>35150 SV</td>
<td>35-150</td>
<td>35-50</td>
<td>35-120</td>
</tr>
<tr>
<td>25150 SV</td>
<td>25-150</td>
<td>25-50</td>
<td>35-120</td>
</tr>
<tr>
<td>SE150300</td>
<td>150-300</td>
<td>/</td>
<td>150-300</td>
</tr>
</tbody>
</table>
Medium Voltage Screwing Connectors
Medium Voltage Screwing Connectors

- Screws with 2 - 4 shear levels, made of brass with tinned surface or made of aluminium alloy
- Connector body made of aluminium alloy
- Sectoral shaped or round conductor channel with small excentricity, with or without separating web, tinned surface
- Centering rings (plastic)
- Additional tinned tubes for very small cross section.
## Typical Medium Voltage Screwing Connectors

<table>
<thead>
<tr>
<th></th>
<th>Al in mm²</th>
<th>Cu in mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rm(v)</td>
<td>re</td>
</tr>
<tr>
<td>M16-95</td>
<td>16-95</td>
<td>16-95</td>
</tr>
<tr>
<td>M50-150</td>
<td>50-150</td>
<td>50-150</td>
</tr>
<tr>
<td>M70-240*)</td>
<td>70-240</td>
<td>70-240</td>
</tr>
<tr>
<td>M95-240</td>
<td>95-240</td>
<td>95-240</td>
</tr>
<tr>
<td>MRL(T)95-240</td>
<td>95-240</td>
<td>95-240</td>
</tr>
<tr>
<td>M120-300</td>
<td>120-300</td>
<td>120-300</td>
</tr>
<tr>
<td>M185-400</td>
<td>185-400</td>
<td>185-400</td>
</tr>
<tr>
<td>M400-630</td>
<td>400-630</td>
<td>400-630</td>
</tr>
</tbody>
</table>

*) sectoral shaped conductor possible
Test according to EN 61238-1

- **Electrical test procedure**

  6 connectors have to be tested:
  - 200 load cycles
    (median connector 100°C; reference conductor: 120 – 140 °C)
  - 6 short circuits
    (reference conductor: 250 – 270 °C)
  - 800 load cycles
  - measuring of the resistance and of the temperature.

- **Mechanical test procedure**

  3 connectors have to be tested:
  - tensile force F during 1 min
  → no damaging or sliding
High Voltage Screwing Connector

- Screws with one shear level (up to 100 .. 120 Nm)
- High force screws for Aluminium Milliken conductor
- Round conductor channel especially adapted to the conductor
- No excentricity
- Connecting parts up to 2000 (2500) mm² according to customer requirements
Electrical and mechanical requirements

- Transmission of electrical energy during the whole lifetime without negative influence on
  → the own function
  → joints, terminations and plugs concerning their thermal, mechanical and insulation behaviour

- Ensure the required tensile strength
Lean Bolted Connector M70 – 240 for round and sectoral shaped Al and Cu conductor

- Optimized fine thread for a big force and a high stability

- Integrated separation web against moisture and oil; absolutely leakproof because of machining

- Well defined grooves: very good electrical contact and mechanical behaviour
Connecting of copper and aluminium by a very high force → ideal electrical contact between both materials

Manufacturing of cable lugs or other by forging and / or machining for an especially high current carrying capability
Floating of the conductor channel

Stamp: manufactured by wire-electro discharge machining at NPAG

Floating of the conductor channel by a stamp

Machining afterwards → pyramidal grooves
Split Bolt Connectors

Split screw with one shear level

Available:
- 70 – 240 mm²
- 120 – 300 mm²
- 185 – 400 mm²

Split with grooves to reduce the electrical resistance

Special shape for adjustment during connection of both parts

Split Bolt Branch Connector according to customer requirements
3. Applications
EDF wants the introduction of bolted contacts for the whole range of the medium accessories: joints, terminations and connectors by 2010.

All the accessories need to pass the electrical qualification tests on the contacts (IEC 61238) and the products (Cenelec HD629.1 S1).

The product redesign program is now half way. The joints, outdoor terminations and 400A connectors are already qualified.
EDF will change from deep indent to bolted contacts until 2010. 

>>> NPAG developed connectors and lugs for that reason.

- **M70-240** connector
- **400A T-plug lug**
- **Indoor/outdoor lugs**
- **Branch connector**

For cross sections 70mm² - 240mm² round and sectoral shaped aluminium and copper conductors (50 mm² is possible by using tinned aluminium tubes)

- **250 A elbow and straight lug** (with screwed copper PIN)
  for cross sections 35 – 95 mm² round stranded copper and aluminium conductor
**Electrical test procedure**

6 connectors have to be tested.

- 200 load cycles: median connector 100°C; reference conductor: 120 – 140 °C
- 6 short circuits: reference conductor: 250 – 270 °C
- 800 load cycles
- measuring of the resistance and of the temperature

**Mechanical test procedure**

3 connectors have to be tested.

- tensile force F during 1 min → no damaging or sliding
Test of Bolted Contacts for EDF according to EN 61238-1

Test arrangement
240 mm² aluminium round stranded

Heating cycle with 800 A

400A T-plug lug

6 barrels

reference conductor
Test of Bolted Contacts for EDF according to EN 61238-1

Figure 5.5 shows the graph of the resistance factors $k$ of the terminal lugs.

**Barrel**

Barrel with 240 mm$^2$ aluminium round stranded

**Palm**
Test of Bolted Contacts for EDF according to EN 61238-1

Connector M 70-240

Electrical test with 240 mm² copper
Current cycle: $I_N = 1020 \, \text{A}$; $t_N = 50 \, \text{min}$.
Cooling cycle: $t_C = 25 \, \text{min}$.
Temperature of the reference conductor: $\Theta_R = 130^\circ\text{C}$
Temperature of median connector: $\Theta_{\text{Median}} = 100^\circ\text{C}$

Tensile test with 240 mm² copper

![Graph of Resistance Ratio](image1)

![Graph of Tensile Test](image2)

Figure 5.1: Resistance factors
Export of NPAG Products into around 50 Countries

NPAG Hof (Germany)
4. Conclusion
Bolted contacts are getting more and more the standard in ‘advanced countries’ in electrotechnical applications.

Nexans has with GPH the state of the art in the development of this product line.

Special and customised designs are possible based on an in depth product knowledge.