Understanding European Flange Design Rules (EN 1591-1) & Gasket Characterization Methods (EN 13555) & Their Application in Reducing Fugitive Emissions

Manfred Schaaf

VSP Technologies - Sealing Conference
November 21, 2013, Prince George VA
registered 2013

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Sealing Technology

- Testing Laboratory
- Testing Equipment
- Measurement Techniques
- Calculation Programs
  (service and software, EN & KTA code, FEA)
- Bolt Mounting Systems
  (Hydraulic Tensioners, Measurement Tools)
- Data Bases Designed
  (Joint Integrity Management)
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Whoever promises you that he can provide ZERO LEAKAGE, don’t trust him, it is a fairy tale!
Fire in a Refinery after a Leakage from a BFJ
Leakage from a Tank Wagon
Leakage from a Valve Body Seal
Leak Detection of Volatile Organic Compounds
Content

- Background Information
- European Standards
- Industry Experience
- Outlook
Content

- Background Information
- European Standards
- Industry Experience
- Outlook
EU Legislation
(Regulations, Directives, etc.)

Directives are transposed into National Legislation

European Commission/
Parliament/
Council of Ministers

EU Member States
EU Legislation
(Industrial Emission Directive)

BREF

Transposition Tools

... TA-Luft ...
(Technical Instruction on Air Quality Control)

VDI Guidelines

European Commission/
Parliament/
Council of Ministers

EU Member States
Guideline on Reduction of Emissions

- **EU Legislation:**
  Integrated Pollution Prevention and Control (IPPC) Directive 2008/01/EC
  Industrial Emission Directive (IED) 2010/75/EU

- **German Legislation:**
  Technical Instructions on the Air Quality Control - TA-Luft

- **VDI 2440:**
  Approval of gasket materials as high-grade sealing system in a first-time test („TA-Luft approval“)

- **VDI 2200:**
  Additional demands on high-grade sealing systems in respect of the design, the calculation, and the assembly of bolted flanged joints

  VDI 2290
  Emission control – Sealing constants for flange connections
  2012-06
Basics for design and calculation of flanged joints
- Applicable calculation rules
- Gasket characteristics

Explanations on gasket characteristics for the calculation of flange joints
- Testing procedure
- Interpretation of first-time test
- Selection / interpolation of gasket characteristics

Assembly of flanged joints

Tightness demands

No LDAR program required!
Content

- Background Information
- European Standards
- Industry Experience
- Outlook
Technical Committee TC 74

“Flanges and their Joints”

- WG 1: Basic Standards
- WG 2: Steel Flanges (PN and Class)
- WG 3: Cast Iron Flanges (PN)
- WG 4: Copper Alloy Flanges (PN and Class)
- WG 5: Aluminium Alloy Flanges (PN and Class)
- WG 8: Gaskets
- WG 9: Bolting
- WG 10: Calculation Methods
… It is recognised that industry must reduce its impact on the environment in order to ensure global development for the future. Part of industrial emissions occur through unanticipated or spurious leaks in process systems, e.g. from leaking valves, pumps or flanges. These "fugitive emissions" have not only an impact on the environment, but cause also a tremendous financial burden on industry, because it represents a huge loss of potentially valuable materials, and cause of plant inefficiency. …
It is recognised that industry must reduce its impact on the environment in order to ensure global development for the future. Part of industrial emissions occur through fugitive emissions leaks in process systems, e.g. from leaking valves, pumps or flanges. These "fugitive emissions" have not only an impact on the environment, but cause also a tremendous financial burden on industry, because it represents a significant loss of potentially valuable materials, and cause of plant inefficiency.
... The European standards for the determination of the gasket characteristics and for the flange calculation enable the determination of the required assembly bolt forces to fulfil a demanded tightness class. This shall give the industry the possibility to reduce fugitive emissions in a pro-active manner instead of implementing control measures to find leaks on site and to minimize the leaks in this reactive way. It is therefore crucial to have testing standards as well as technical delivery conditions for gaskets and gasket materials, also a calculation procedure is required for the stress and tightness analysis. ...
... The European standards for the determination of the gasket characteristics and for the flange reduce fugitive emissions in a pro-active manner instead of implementing control measures to find leaks and gasket materials, also a calculation procedure is required for the stress and tightness analysis. ...
- **prEN 13555 rev**
  Flanges and their joints - Gasket parameters and test procedures relevant to the design rules for gasketed circular flange connections
  Formal Vote 2013-11
  2014-03

- **prEN 1591-1 rev**
  Flanges and their joints - Design rules for gasketed circular flange connections - Part 1: Calculation
  2013-11

- **prEN 1591-4 rev**
  Flanges and their joints - Part 4: Qualification of personnel competency in the assembly of the bolted connections of critical service pressurized systems
  2013-12
EN 1591-1 released as an European Standard in 2001
Amendment A1 of EN 1591-1 released as an European Standard in 2009

New Issue in December 2013

Calculation method for gasketed circular flange connections with gaskets inside the bolt circle and without metal-to-metal contact of the flange faces

- leak tightness and strength criteria are satisfied
- behavior of complete flanges-bolts-gasket system is considered
- strength value of flange and bolt materials
- gasket characteristics
- thermal loads
- medium pressure
- external axial forces and bending moments
- nominal bolt load
- possible scatter due to bolting-up procedure
- changes in gasket force due to deformation of all components
- influence of connected shell or pipe
- elastic deformation balance
- flange rotation and effective compressed gasket area
- iterative determination of the required bolt force in assembly to fulfill tightness demands
- force balance (interaction between all components)
- virtual flange resistance of the flanges
- limit load theory (admissibility of plastic deformation)
# Gasket characteristics (EN 13555)

## Mechanical characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{S_{\text{max}}}(\text{RT})$</td>
<td>MPa</td>
<td>Maximum allowable gasket surface pressure at RT</td>
</tr>
<tr>
<td>$Q_{S_{\text{max}}}(T)$</td>
<td>MPa</td>
<td>Maximum allowable gasket surface pressure at T</td>
</tr>
<tr>
<td>$E_G$</td>
<td>MPa</td>
<td>Modulus of elasticity</td>
</tr>
<tr>
<td>$\Delta e_{GC}$</td>
<td>mm</td>
<td>Creep relaxation of the gasket</td>
</tr>
</tbody>
</table>

## Tightness characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{\text{min}(L)}$</td>
<td>MPa</td>
<td>Minimum required gasket surface pressure for tightness class L during assembly</td>
</tr>
<tr>
<td>$Q_{S_{\text{min}}(L)}$</td>
<td>MPa</td>
<td>Minimum required gasket surface pressure for tightness class L in operation (in dependence on the gasket surface pressure $Q_A$ applied during assembly)</td>
</tr>
</tbody>
</table>

## Additional parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_G$</td>
<td>-</td>
<td>Friction factor which is necessary for the treatment of shear forces and torsion moments</td>
</tr>
</tbody>
</table>
Testing equipment

TEMES

fl.ai1
Deformation characteristic

Compression curve
P01-IBC-GR 92x49x1.535 mm
Test number: 10-412

Collapse of the gasket:
$Q_{\text{Smax}}$
Maximum allowable gasket stress $Q_{Smax}$
Loading and unloading cycles

Compression curve
B01-SWG-GR 68.95x56.22x5.192 mm
Versuchsnummer: 10-098
Creep relaxation characteristic

Compression creep curve
D01-IBC-FA 91.7x49.05x2.845 mm
Versuchsnummer: 10-104

\[ P_{QR} = \frac{Q_R}{Q_A} \]

\[ \Delta e_{GC} \]

- loading
- heating-up
- dwell time under T
- unloading
Tightness characteristics

Leakage curve

\[ Q_{SMIN(L)} = Q_{SMIN(L)i} + \frac{(Q_A - Q_{Ai})(Q_{SMIN(L)j} - Q_{SMIN(L)i})}{(Q_A - Q_{Ai})} \]
CEN/TS 1591-4 released as an Technical Specification in 2007

Issue as an European Standard in November 2013

Process for training and competency assessment of personnel in the assembly of bolted flanged joints fitted to equipment subject to PED

- design codes increasingly require controlled bolt tightening
- ensure personnel are competent to assemble and tighten bolted joints for a leak-free status throughout its service life
- training, experience and assessment of knowledge are required to achieve competency
procedural framework must be included within operator’s quality management system

route for achieving competency in the skills

- classroom training and workshop practice
- written test
- period of monitored work site experience
- assessment by a qualified assessor

<table>
<thead>
<tr>
<th>Work-site experience</th>
<th>Earliest assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent and intense</td>
<td>3 months</td>
</tr>
<tr>
<td>Infrequent but with intense periods</td>
<td>6 months</td>
</tr>
<tr>
<td>Sporadic</td>
<td>12 months</td>
</tr>
</tbody>
</table>
the principles of bolt elongation (strain), bolt load and stress;
importance of applied and residual bolt loads;
bolt load loss and the implications;
effect of coefficient of friction on bolt load when using torque;
bolt tightening methods and their relative accuracies;
joint assembly methods and tightening procedures;
the requirements to meet a specific class of tightness;
flange, bolt and gasket types and their limitations;
functionality of gasket and seal;
factors affecting the degradation of bolted assemblies, e.g. corrosion;
common causes of joint failure and leakage;
specific health or safety requirements associated with joint components;
maintenance requirements of bolt tightening systems;
importance of certification and records.
- general health and safety precautions;
- procedure for preparing a joint for closure;
- identification of correct joint components;
- seal face preparation;
- gasket handling, preparation and installation;
- functionality of clamp or engineered joints;
- importance of alignment and gap uniformity;
- importance of using the specified lubricant;
- manual and hydraulic torque joint tightening;
- joint tightening using hydraulic bolt tensioners;
- techniques for measuring bolt strain;
- confirming joint can return to service;
- identifying defects or faults;
- variance or irregularity reporting;
- safe joint disassembly;
- safety requirements when selecting and operating bolt tightening tooling;
- calibration of bolt tightening tooling;
- recording bolted joint activity and maintenance of records.
Content

- Background Information
- European Standards
- Industry Experience
- Outlook
Although the VDI 2290 was issued only one year ago, the industry has already experience on the use of this guideline in their plants.

- Revision of pipe classes
- Imperative of EN 1591 (tightness based design)
- Greater significance of assembly
- Introduction of a quality management circle to assure proper function of BFC´s
- Reduction of incidents during start-up after turnaround
Revision of Pipe Classes

PIPE CLASSES

<table>
<thead>
<tr>
<th>Code:</th>
<th>Plant:</th>
<th>UAN:</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>43 of 69</td>
</tr>
</tbody>
</table>

Pipe Class XXXXXXXX

<table>
<thead>
<tr>
<th>Nominal pressure</th>
<th>PN 250</th>
<th>type</th>
<th>Alloy</th>
</tr>
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<tbody>
<tr>
<td>Allow. design pressure</td>
<td>MPag</td>
<td>25,0</td>
<td>EN 1092, Form E, F</td>
</tr>
<tr>
<td>Design temperature</td>
<td>ºC</td>
<td>20</td>
<td>8,0 mm</td>
</tr>
<tr>
<td>Design Code</td>
<td>AD 2000</td>
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<table>
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<td>DN</td>
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<td>25</td>
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<td>21,3</td>
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<td>60,3</td>
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<td>139,7</td>
<td>188,3</td>
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<td>323,9</td>
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<td>610,0</td>
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<table>
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<th>With mm</th>
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<tr>
<td>16,0</td>
<td>17,5</td>
<td>17,5</td>
<td>20,0</td>
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<td>22,2</td>
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<td>45,0</td>
<td>50,0</td>
<td>55,0</td>
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<tr>
<td>65,0</td>
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<table>
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<tr>
<th>Item</th>
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<th>Item description</th>
<th>Design</th>
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<tbody>
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<td></td>
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<td>Material</td>
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<td>see Note 2, 3</td>
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</table>

<table>
<thead>
<tr>
<th>DIN / EN</th>
<th>Short name</th>
<th>Norm</th>
<th>Note</th>
<th>Rev.</th>
</tr>
</thead>
</table>

Revision required
First studies have shown that the new guideline will cause large-scale changes in the sealing technology in industry facilities:

- Some popular gasket material cannot fulfill the tightness requirements for all operational conditions and/or for all nominal sizes of one pipe class.
- Also commonly used bolt materials (quality 5.6) must be replaced by bolts of higher quality because higher gasket stresses are required.
- A positive effect will be the determination of bolt forces, torques or bolt elongations as presetting for the fitters.
Possible improvements in respect of the assembly of flanged joints:

- Controlled bolt tightening method  
  *(at least torque wrenches / tables with torques)*

- Qualified fitters  
  *(individual personnel)*

- Independent check-up of the assembly quality  
  *(basis: risk analysis)*

- Installation of a quality management system in the industry plants  
  *(e.g. detailed work instructions)*
quality management circle

plant engineer → data base

data collection in data base

gasket characteristics

design
- geometry (stiffness)
- materials
- gasket

calculation
- bolted flange connection
- gasket characteristic
- assembly force, tightness proof, stress analysis

feedback & review
- feedback
- review

loads
- every state of operation

assembly
- in accordance to the requirements
- quality assurance (control)

data sheet for BFC

new calculation according EN 1591-1
→ data base
Different procedures to reduce emissions

PROACTIVE APPROACH

GASKET TESTING
CALCULATION
ASSEMBLY
LDAR

Extraordinary Shut-Downs

REACTIVE APPROACH

GASKET TESTING
CALCULATION
ASSEMBLY
LDAR

Extraordinary Shut-Downs
Different procedures to reduce emissions

PROACTIVE APPROACH

GASKET TESTING
CALCULATION
ASSEMBLY

Extraordinary Shut-Downs

REACTIVE APPROACH

GASKET TESTING
CALCULATION
ASSEMBLY

LDAR

Extraordinary Shut-Downs

$ $$
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