BAT - Bolt Analysis Tool

User Manual

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Symbols and Abbreviations

Symbols

α_A	tightening factor
α_b	coeff. of lin. thermal expansion of the bolt
α_c	coeff. of lin. thermal expansion of the clamped part (plate)
δ_b	elastic compliance of the bolt
δ_c	elastic compliance of the clamped part (plate)
λ	under-head bearing angle of bolt
μ_{th}	coeff. of friction in bolt thread
μ_{uh}	coeff. of friction under bolt head
ν	bolt utilization factor
φ	helix angle / slope of bolt thread
Φ	load factor of concentric joint (also: force ratio or relative compliance factor)
Φ_n	load factor for concentric clamping and concentric force load introduction via the clamped parts
ρ	friction angle in bolt thread
σ_n	normal stress in the bolt
σ_v	von-Mises stress in the bolt
τ	shear stress in the bolt
A_1	nominal cross section of threaded bolt
A_3	minimal thread cross section
A_p	pitch cross section of threaded bolt
A_s	stress cross section of threaded bolt
d	nominal threaded bolt diameter
d_2	pitch diameter of threaded bolt
d_3	minimal diameter of threaded bolt
d_h	minimal contact diameter under bolt head
d_s	stress diameter of threaded bolt
F_A	external, axial bolt load
F_M	preload after tightening / assembly preload
F_{PA}	additional axial plate load
F_Q	external, shear bolt load

F_{SA}	additional axial bolt load
F_V	service preload incl. embedding and thermal influence
f_Z	plastic deformation due to embeddding
F_Z	preload loss due to embedding
l_K	joint clamped length
M_p	prevailing torque of bolt locking device
n	load introduction factor
p	pitch of bolt thread

Abbreviations

BAT	Bolt Analysis Tool
TBJ	through-bolt joint
TTJ	tapped thread joint

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1 Introduction

This document will include the BAT (Bolt Analysis Tool) User Manual [1] [2] [3].

$$p(\boldsymbol{\Theta}|\boldsymbol{y}) = \frac{p(\boldsymbol{y}|\boldsymbol{\Theta})\ p(\boldsymbol{\Theta})}{p(\boldsymbol{y})}\ , \tag{1.1}$$

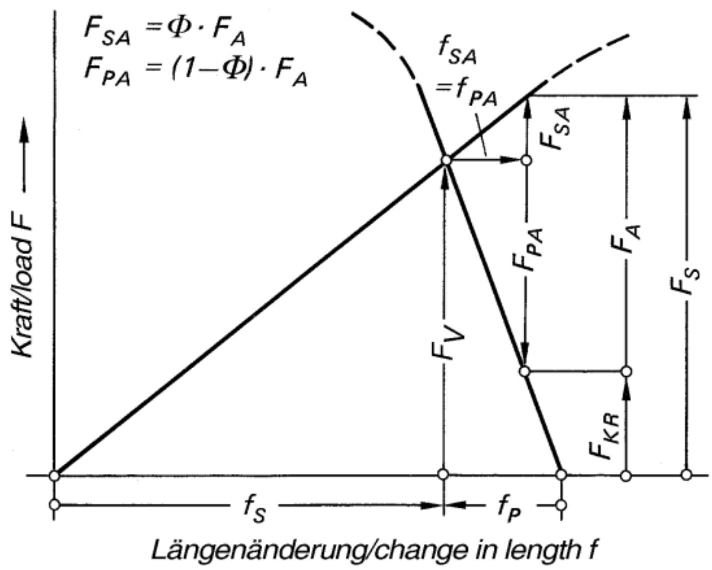

Figure 1.1: Joint diagram for the working state of a concentrically loaded bolted joint with $n = 1$ [3]

2 Bolt and Thread Geometry

D_{Km} is the *effective diameter of under head/nut friction torque* and is defined by

$$D_{Km} = \frac{D_{hole} + d_h}{2} \tag{2.1}$$

where D_{hole} is the *through-hole diameter* in the clamped parts and d_h is the *minimum bearing surface outer diamter* of the bolt head or nut.

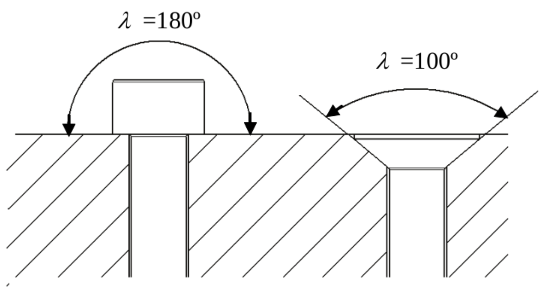

Figure 2.1: Definition of under head bearing angle [2]

3 Method B: ECSS-E-HB-32-23A

This chapter provides a quick overview and summary of the equations used in **BAT**. A detailed description can be found in the complete ECSS-E-HB-32-23A ESA handbook [2]. Some used variables in the following equations have been changed compared to [2] by the author to increase clarity and consistency.

3.1 Preload and Torques

The torque present at the thread interface M_{th} is dependent of the *axial bolt preload* F_V and is given by

$$M_{th} = F_V \tan(\varphi + \rho) \frac{d_2}{2} \tag{3.1}$$

and the *under-head torque* M_{uh} due to friction between bolt head or nut and the adjacent clamped part (or shim) is defined by

$$M_{uh} = F_V \frac{\mu_{uh} D_{Km}}{2} \frac{1}{\sin \lambda/2} \tag{3.2}$$

where λ is the *under head bearing angle* seen in Figure 2.1. It is assumed that the friction force for M_{uh} is acting at mean bearing radius of the bolt head D_{Km} (2.1). φ is the helix angle of the thread and ρ is given by the relation

$$\tan \rho = \frac{\mu_{th}}{\cos \theta/2} \tag{3.3}$$

where θ is the half angle of the thread groves (for Unified or Metric threads $\theta = 60°$).

The *total installation torque* T_A (without torque device scatter) applied to bolt head or nut during tightening to produce the axial bolt preload F_V is

$$T_A = M_{th} + M_{uh} + M_p \tag{3.4}$$

where M_p is the *prevailing torque* of the locking device. With the approximation $\tan\varphi \tan\rho \ll 1$ the expression $\tan(\varphi+\rho)$ can be written as $\tan(\varphi+\rho) \approx \tan\varphi + \tan\rho$. Now equation (3.4) can be rewritten to

$$T_A = F_V \underbrace{\left[\frac{d_2}{2}\left(\tan\varphi + \frac{\mu_{th}}{\cos {}^{\theta}\!/_{2}}\right) + \frac{\mu_{uh} D_{Km}}{2\sin {}^{\lambda}\!/_{2}}\right]}_{K} + M_p \tag{3.5}$$

where K is the *joint coefficient*.

For calculation of the minimum and maximum axial bolt preload, BAT implements the *experimental coefficient method* [2] with an explicit torque scatter torque of the tightening device $T_{scatter}$. Therefore the minimum and maximum total installation torques are defined

$$T_A^{min} = T_A - T_{scatter}, \qquad T_A^{max} = T_A + T_{scatter}. \tag{3.6}$$

To calculate the minimum and maximum *axial bolt preload after tightening* $F_M^{min/max}$, (3.5) and (3.6) are combined

$$F_M^{min} = \frac{T_A^{min} - M_p^{max}}{K^{max}}, \qquad F_M^{max} = \frac{T_A^{max} - M_p^{min}}{K^{min}}. \tag{3.7}$$

If also the thermal influence and embedding is considered, this leads to the minimum and maximum *axial bolt preload at service* $F_V^{min/max}$

$$F_V^{min} = \frac{T_A^{min} - M_p^{max}}{K^{max}} + \Delta F_{Vth} - F_Z \tag{3.8a}$$

$$F_V^{min} = F_M^{min} + \Delta F_{Vth} - F_Z \tag{3.8b}$$

$$= \frac{T_A^{min} - M_p^{max}}{\frac{d_2}{2}\left(\tan\varphi + \frac{\mu_{th}^{max}}{\cos {}^{\theta}\!/_{2}}\right) + \frac{\mu_{uh}^{max} D_{Km}}{2\sin {}^{\lambda}\!/_{2}}} + \Delta F_{Vth} - F_Z \tag{3.8c}$$

$$F_V^{max} = \frac{T_A^{max} - M_p^{min}}{K^{min}} + \Delta F_{Vth} \tag{3.9a}$$

$$F_V^{max} = F_M^{max} + \Delta F_{Vth} \tag{3.9b}$$

$$= \frac{T_A^{max} - M_p^{min}}{\frac{d_2}{2}\left(\tan\varphi + \frac{\mu_{th}^{min}}{\cos {}^{\theta}\!/_{2}}\right) + \frac{\mu_{uh}^{min} D_{Km}}{2\sin {}^{\lambda}\!/_{2}}} + \Delta F_{Vth} \tag{3.9c}$$

where ΔF_{Vth} is thermal preload change and F_Z is the preload loss due to embedding.

4 References

[1] Guidelines for threaded fasteners. ESA Guideline ESA PSS-03-208 Issue 1, Structures and Mechanism Division ESTEC, December 1989.

[2] Space engineering - threaded fasteners handbook. ECSS Handbook ECSS-E-HB-32-23A, ECSS European Cooperation for Space Standardization, 16 April 2010.

[3] Systematic calculation of highly stressed bolted joints - joints with one cylindrical bolt. VDI Guideline VDI2230 Part 1, VDI - Verein Deutscher Ingenieure, November 2015.