Preloaded Joint Analysis Methodology

An Online Continuing Education Course for Engineers

Course Number: MA-3010

Credit: 3 Hours / 3 PDH / 3 CPD

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Course Introduction

Our day-to-day reliance on structures and machines, whose primary means of assembly uses bolted connections, is inescapable. From the car you drove to work, to the plane that carried your family on vacation, to the scooter your child rides in the driveway, and even the computer on your desk, all include bolted joints in one form or another as the primary means of fastening. Hardware selection and, ultimately, accurate analysis of a bolted joint takes many factors into consideration, beginning with the materials being joined, the fastener properties, the preload torque, and the loads the bolt will carry. Therefore, this course will review the preloaded joint analysis methodology and provide the reader with a clear application of the respective analysis by examining two common bolted joint configurations. This course is intended for professional engineers in the Aerospace, Civil, Mechanical, and Structural disciplines.

Bolted Joint Nomenclature

The industry standard geometry and terminology for the bolt, nut, and insert can be found in the Fastener Design Manual, NASA RP-1228, 1990 [4], and most any mechanical engineering design textbook, such as Shigley [2]. Though there are subtle symbol differences between texts, consistently following the same symbology in your analysis will reduce potential errors. In this course, the symbols and definitions are presented below:

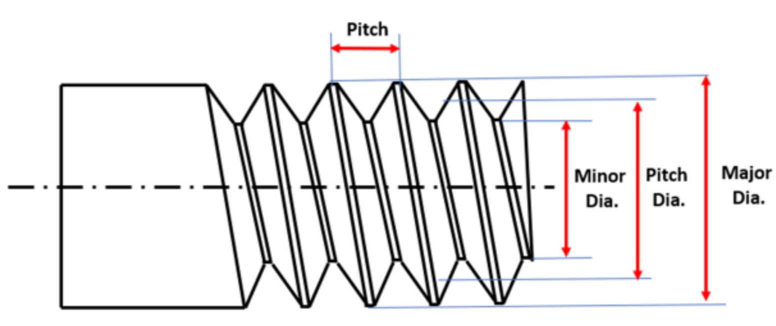


Figure 1. Bolt Thread Nomenclature.

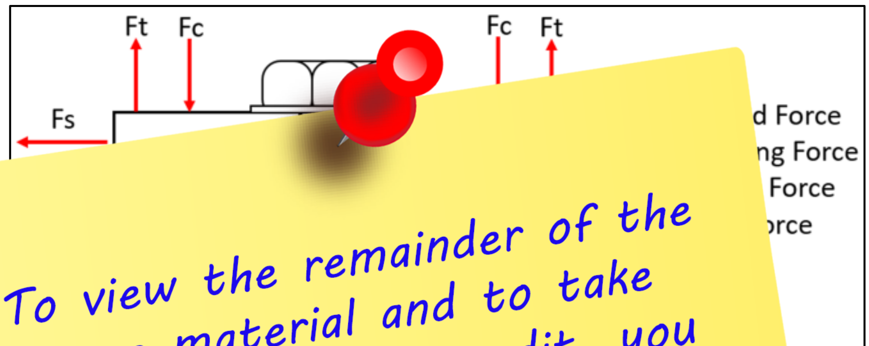
Symbol	Definition / Use
A	nominal fastener cross-sectional area in^2
a	moment arm
A_{br}	bearing area in^2
A_d	major diameter area of the fastener
A_s	fastener shear cross-sectional area in^2
A_t	fastener tensile cross-sectional area in^2
D	nominal fastener diameter in
$D_{major,ext}$	major pitch diameter, external threads, in
$D_{minor,min}$	minor pitch diameter, internal threads, in
D_p	mean thread diameter, in
D_{wash1}	Bolt head diameter or washer diameter
d_h	countersunk head diameter, in
d_t	maximum diameter of the lug through hole
d_w	effective countersunk head diameter, in
E_b	bolt modulus of elasticity, psi
E_j	joint modulus of elasticity, psi
e	edge distance or eccentricity, in
F_{br}	material bearing (yield or ultimate) strength, psi
F_{su}	material ultimate shear strength, psi
F_{sy}	material yield strength, psi
F_{tu}	material ultimate tensile strength, psi
F_{ty}	material tensile yield strength, psi
FS	Factor of Safety
K	nut factor
K_b	bolt stiffness, lb/in
K_j	joint stiffness, lb/in
L	fastener grip length, in
L_e	thread engagement length or nut thickness, in
L_i	insert thread engagement length, in
LP_i	i^{th} loading plane

l_d	length of unthreaded portion of the grip
l_h	countersunk head depth, in
l_i	abutment component thickness, in
l_t	length of threaded portion of the grip
M	applied bending moment, lb-in
MS	margin of safety
n	loading plane factor
P_b	total axial bolt load, lb
ΔP_b	change in axial bolt load, lb
P_{br}	bearing load, lb
P_{et}	externally applied axial load, lb
ΔP_j	change in joint load, lb
P_o	nominal bolt preload, lb
$P_{o,final}$	final joint preload, lb
$P_{o,initial}$	initial joint preload, lb
$P_{o,max}$	maximum expected bolt preload, lb
$P_{o,min}$	minimum expected bolt preload, lb
P_{relax}	bolt preload loss, lb
P_s	Applied shear load
P_{sep}	joint separation load, lb
P_{th}	axial bolt load due to thermal effects, lb
P_u	ultimate tensile strength
P_{ult}	ultimate tensile load, lb
p	thread pitch, in
R_b	bending load ratio
R_s	shear load ratio
R_t	tensile load ratio
SF	safety factor
SF_{sep}	safety factor for separation
S_y	yield tensile
S_{us}	ultimate shear

T	applied torque, in-lb
ΔT	change in temperature, °F
t	thickness, in
u	preload uncertainty factor (torque uncertainty factor)
V	applied shear load, lb
α	thread angle, radians
α_b	bolt coefficient of thermal expansion, in/in/°F
α_j	abutment coefficient of thermal expansion, in/in/°F
α_n	abutment n coefficient of thermal expansion, in/in/°F (usually 1 or 2)
δ	bolt deflection due to external load, in
δ_b	bolt deflection, in
δ_j	abutment deflection, in
μ	coefficient of friction between threads
μ_c	coefficient of friction between bolt head (or nut) and abutment
ψ	thread helix angle, radians
φ	joint stiffness factor

Determining Preload

We have all tightened a nut and bolt, but how tight and why? Was it to keep the nut from falling off as a result of vibration? We could just use a locking nut. Was it per the shop manual for the engine we are overhauling? Or was it to make us feel better? There is satisfaction in a completed project and in a good tight bolt. The typical preloaded bolt force diagram is presented in Figure 2.



The bolted joint ... ariety of loading condition ... the loading of the bolt joint. Bol ... revent joint separation, reduce ... but joint separation results i ... failure.

The properly preloa ... g limit or 60-90% of yield stre ... are, therefore, in compression from this load applied to th ... compression of the flanges will react to external load with the design intent that the compression of the flanges is never fully relieved, and therefore the flange faces of the joint never separate. NSTS-08307, 1989, Criteria for Preloaded Bolts [5] provides the following method for determining preload:

$$P_o = \frac{T}{KD}(1.0 \pm u) \qquad (1)$$

The uncertainty factor, u, for a hand-operated torque wrench is ±25% on a lubricated nut, while this value can be reduced to ±5% when using load sensing instrumentation such as ultrasonics