



Calcolo delle viti

LOCOMOTIVA E401

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1. OGGETTO

Lo scopo del presente documento è di giustificare la scelta delle viti utilizzate nel fissaggio delle zavorre nei seguenti montaggi:

- Montaggio zavorre corridoio. B.20.74.007.00
- Montaggio zavorre LV2. B.20.87.003.00

2. SOFTWARE ED ALTRI DOCUMENTI TENUTI PRESENTI

Software: MDesign Bolt 2014.

Altri documenti:

- Specifica Trenitalia TI 383601.
- EN 12663
- VDI2230

3. CONSIDERAZIONI GENERALI

La validazione della vite utilizzata in un'unione bullonata si realizzerà tramite calcolo rispetto alla norma VDI2230.

Per il calcolo della vite si applicheranno le accelerazioni indicate nella norma EN12663 per i casi di carichi di fatica (dinamici) che sono quelli attesi durante il normale esercizio del veicolo.

Si effettua poi una verifica applicando i carichi di prova (statici) assicurandosi che la tensione di lavoro nella vite non superi la tensione di snervamento del materiale della stessa con un coefficiente di sicurezza di 1,15.

Tensione di snervamento del materiale / tensione di lavoro attesa $\geq 1,15$.

La determinazione delle forze tramite le accelerazioni richieste dalla norma si effettuerà con un calcolo semplificato teorico che trasferisce le forze sul centro di gravità a reazioni sui supporti del dispositivo con l'aiuto di una tabella di Excel appositamente creata con i vari casi da calcolare.

3.1. Determinazione delle forze da applicare nel calcolo

Si considerano il peso e le accelerazioni richieste dalla EN 12663 per il veicolo oggetto di studio.

Le seguenti tabelle sono state ricavate dalla norma EN12663 ed indicano le accelerazioni da considerare su ognuno degli assi in base al tipo di veicolo

Table 16 — Acceleration in y-direction

Acceleration in metres per square second

Locomotives	Passenger rolling stock					Freight wagons	
Category L	Category P-I	Category P-II	Category P-III	Category P-IV	Category P-V	Category F-I	Category F-II
$\pm 0,2 g$	$\pm 0,15 g$					$\pm 0,2 g$	$\pm 0,4 g^a$

^a Applies to equipment attachments, but may be reduced for bogie vehicle and two-axle wagons with improved suspensions.

Table 17 — Acceleration in z-direction

Acceleration in metres per square second

Locomotives	Passenger rolling stock					Freight wagons	
Category L	Category P-I	Category P-II	Category P-III	Category P-IV	Category P-V	Category F-I	Category F-II
$(1 \pm 0,25) \times g$	$(1 \pm 0,15) \times g$			$(1 \pm 0,15) \times g^a$		$(1 \pm 0,3) \times g^b$	

^a $(1 \pm 0,18) \times g$ for operation on grooved rails.

^b For freight vehicle with double stage suspension $(1 \pm 0,25) \times g$. If the application produces a higher dynamic load factor (e.g. due to dynamic effects or loading conditions) then a higher value shall be applied and defined in the specification.

Table 18 — Acceleration in x-direction

Acceleration in metres per square second

Locomotives	Passenger rolling stock					Freight wagons	
Category L	Category P-I	Category P-II	Category P-III	Category P-IV	Category P-V	Category F-I	Category F-II
$\pm 0,15 g$	$\pm 0,15 g$			$\pm 0,15 g^a$	$\pm 0,2 g$	$\pm 0,3 g^b$	

^a If vehicles interface with road traffic then they shall be designed to $\pm 0,2 g$.

^b Applies to equipment attachments only.

Per la verifica del margine di sicurezza del materiale rispetto alla tensione di snervamento si utilizzano i carichi statici o di prova. Per calcolarlo si prendono le accelerazioni indicate dalla EN12663 per questi casi in base alla categoria del veicolo.

Table 13 — Accelerations in x-direction

Acceleration in metres per square second

Locomotives	Passenger rolling stock					Freight wagons	
Category	Category	Category	Category	Category	Category	Category	Category
L	P-I	P-II	P-III	P-IV	P-V	F-I	F-II
$\pm 3 g$	$\pm 5 g$	$\pm 3 g$	$\pm 3 g$	$\pm 2 g$	$\pm 2 g$	$\pm 5 g$	

Table 14 — Accelerations in y-direction

Acceleration in metres per square second

Locomotives	Passenger rolling stock					Freight wagons	
Category	Category	Category	Category	Category	Category	Category	Category
L	P-I	P-II	P-III	P-IV	P-V	F-I	F-II
$\pm 1 g$							

Table 15 — Accelerations in z-direction

Acceleration in metres per square second

Locomotives	Passenger rolling stock					Freight wagons	
Category	Category	Category	Category	Category	Category	Category	Category
L	P-I	P-II	P-III	P-IV	P-V	F-I	F-II
$(1 \pm c) \times g^a$							
^a $c = 2$ at the vehicle end, falling linearly to 0,5 at the vehicle centre.							

Nelle tabelle 1 e 2 vengono riportati i valori applicabili al caso della locomotiva E401:

Casi	g_x	g_y	g_z	Casi	g_x	g_y	g_z
Caso E1	+3g	0	-1g	Caso E2	-3g	0	-1g
Caso E3	0	+1g	-1g	Caso E4	0	-1g	-1g
Caso E5	0	0	+3g				

Tabella 1: Accelerazioni per il calcolo statico

Per ognuno degli scenari da E1 a E5 si ottengono le reazioni assiali e trasversali in ognuno dei fissaggi dell'elemento/dispositivo tramite un calcolo teorico di trasferimento di forze dal CDG ai fissaggi.

Il calcolo della vite si realizza con le reazioni più elevate ottenute in ognuno dei casi da E1 a E5.

Casi	g_x	g_y	g_z	Casi	g_x	g_y	g_z
Caso D1	0,15g	0,2g	1,25g	Caso D2	0,15g	0,2g	0,75g
Caso D3	0,15g	-0,2g	1,25g	Caso D4	0,15	-0,2g	0,75g
Caso D5	-0,15g	0,2g	1,25g	Caso D6	-0,15	0,2g	0,75g
Caso D7	0,15g	-0,2g	1,25g	Caso D8	-0,15g	-0,2g	0,75g

Tabella 2: Accelerazioni per il calcolo dinamico

Come nel caso precedente, per ognuno degli scenari da D1 a D8 si ottengono le reazioni in ognuno dei fissaggi dell'elemento/dispositivo.

Il calcolo della vite si realizza con la combinazione di sforzi più sfavorevole di tutti i casi.

3.2. Calcolo della vite ai sensi della VDI

Una volta definite le accelerazioni ed ottenute le forze risultanti nelle unioni si passa a calcolare un'unione bullonata in base ai requisiti della norma VDI2230. A tal fine si utilizza lo strumento di software di calcolo MDESIGN.

3.2.1. Calcolo a fatica

Nell'Allegato 1 viene riportata una tabella di valori da inserire come parametri di ingresso del calcolo nel programma MDESIGN.

Tra i parametri fondamentali constano i carichi a fatica assiali (massimo e minimo) e quelli trasversali.

Una volta eseguito il calcolo, il software genera un rapporto dei risultati (output data-sheet) e fornisce dei grafici tra i quali risulta di particolare interesse il Clamping graphic.

3.2.2. Calcolo statico

Nel calcolo statico si verifica che la tensione raggiunta nella vite rimane al di sotto della tensione di snervamento del materiale.

Ciò si realizza confrontando il valore σ_{max} ottenuto nei risultati del calcolo con il valore della tensione di snervamento caratteristica del materiale della vite.

Il calcolo viene considerato corretto quando: Tensione di snervamento > valore tensione nella vite

$$R_{pmin} > \sigma_{max}$$

3.2.3. Risultati del calcolo ed interpretazione

I risultati del calcolo vengono presentati in due formati:

- Scheda dei risultati o "Output data sheet". Sia per il calcolo statico che per quello dinamico.
- Grafico o "Clamping graphic" per il calcolo dinamico

Alcuni parametri indicati dal programma nei risultati sono:

- FAO: Carico di lavoro dell'unione in senso assiale.
- Fz: perdita di precarico per assestamento.
- FSAmax - FSAO: parte del carico di lavoro che si perde nella vite
- FPAmax - FPAO: parte del carico di lavoro che si perde nell'unione
- FMzul: precarico di montaggio (carico assiale nella vite) ammesso con la coppia di serraggio e percentuale di tensione di snervamento indicata.
- FMmin: precarico minimo di montaggio necessario per garantire che l'unione non si stacchi con il carico di lavoro definito. È la somma di FPAmax e Fz.
- FMmax: si ottiene moltiplicando FMmin per il fattore di coppia di serraggio αA .
- FVmin: è il precarico minimo dell'unione. Si calcola come $[(FMzul / \alpha A) - Fz]$
- FSmax: Massimo carico nella vite in esercizio. Si calcola come $(FSAmax + FMzul)$

Per la validazione dei documenti di uscita si seguono in linea generale le seguenti regole.

a) Output datasheet del calcolo dinamico:

1. Si verifica il valore finale del calcolo che indica la percentuale di precarico attesa nella vite che deve mostrare un valore che si avvicina al 90% per le coppie di serraggio CAF.

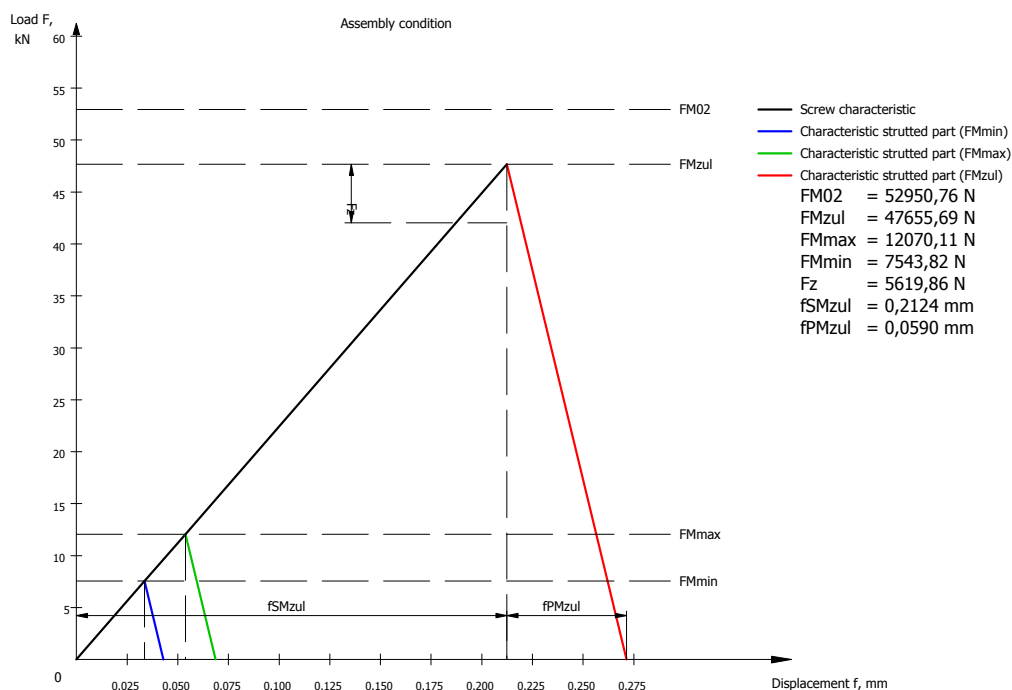
Nell'Allegato 2 viene riportato un estratto di un Output Datasheet ottenuto da MESIGN e vengono indicati alcuni dei valori da verificare/rivedere.

b) Output datasheet del calcolo statico

1. Si deve verificare che il valore della tensione massima nella vite in funzionamento, valore **σ_{zmax}** , sia inferiore al valore della tensione di snervamento del materiale della vite.

c) Clamping graphic (del calcolo dinamico)

L'aspetto del grafico di uscita del calcolo deve avere simile al seguente.



Si deve inoltre verificare che: $FM_{max} < FM_{zul} - F_z$

4. CALCOLO DELLE VITI

4.1. ZAVORRE LV2. Montaggio B.20.87.003.00

4.1.1. Descrizione dell'unione

Le zavorre vengono fissate tramite 4 viti M12X195.

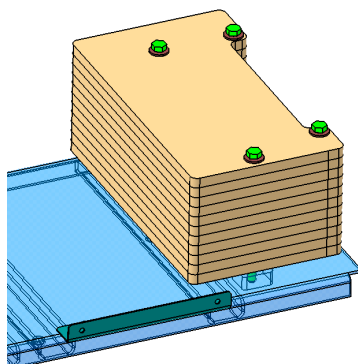


Figura 1

Per via delle peculiarità del montaggio la distribuzione delle viti non è omogenea, infatti una delle viti risulta spostata al di fuori della matrice rettangolare, concretamente sull'asse Y della vettura.

Al fine di semplificare il calcolo, si ipotizza una distribuzione omogenea che si realizza allineando la vite su Y in modo tale da ottenere una distribuzione rettangolare con quattro vertici.

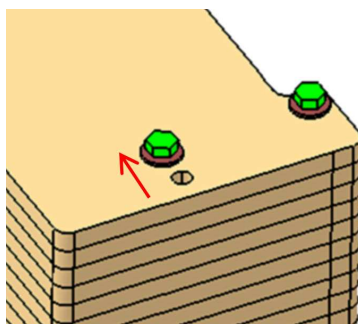


Figura 2

Nella seguente Figura 3 si illustra l'unione nel dettaglio:

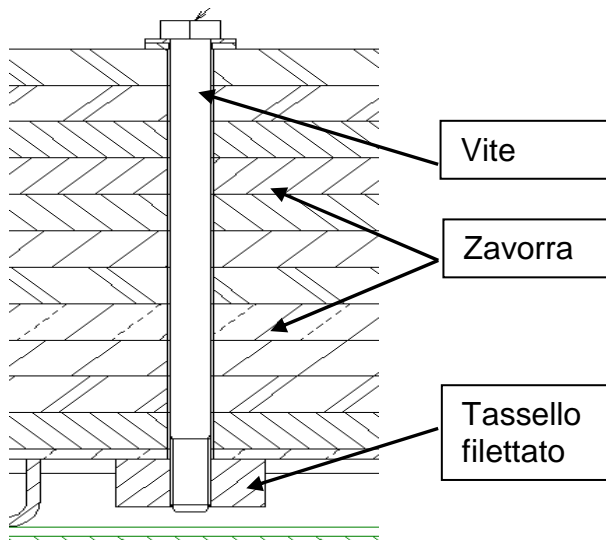


Figura 3

I valori rilevanti per il calcolo sono i seguenti:

- Massa: 120K
- Viti per fissaggio: 1
- Viti in totale: 4
- Filettatura metrica della vite: M12

- Materiale della vite: Acciaio 8.8
- Unione. Tassello filettato
- Materiali nell'unione: 1 (acciaio al carbonio)

4.1.2. Forze ottenute per viti

Le forze massime risultanti dall'applicazione delle accelerazioni nel caso statico (punto 3.1, tabella 1) vengono riportate nella tabella 3.

	MAX Qn	MAX VnX	MAX VnY
E1	1306	883	0
E2	1306	883	0
E3	770	0	294
E4	770	0	294
E5	883	0	0

Tabella 3: Forze massime per il caso statico

MAX Qn: Forza assiale massima ottenuta in uno qualunque dei supporti del dispositivo.

MAX VnX: Forza trasversale massima su X ottenuta in uno qualunque dei supporti del dispositivo.

MAX VnY: Forza trasversale massima su Y ottenuta in uno qualunque dei supporti del dispositivo.

Con i dati della tabella si sceglie di eseguire i calcoli per i casi E1.

Le forze massime risultanti dall'applicazione delle accelerazioni nel caso dinamico (punto 3.1, tabella 2) vengono riportate nella tabella 4.

	MAX Qn:	Min Qn	Max VnX	Max VnY	
D1	465	236	44	59	
D2	317	89	44	59	
D3	514	274	44	-59	
D4	367	127	44	-59	
D5	462	222	-44	59	
D6	315	75	-44	59	
D7	500	271	-44	-59	
D8	353	124	-44	-59	
	Max Q	Min Q	Max VX	Max VY	Max Shear
	514	75	44	59	73,58

Tabella 4: Forze massime per il caso dinamico

MAX Qn: Forza assiale massima ottenuta in uno qualunque dei supporti del dispositivo con accelerazioni positive.

Min Qn: Forza assiale massima ottenuta in uno qualunque dei supporti del dispositivo con accelerazioni negative.

MAX VnX: Forza trasversale massima su X ottenuta in uno qualunque dei supporti del dispositivo.

MAX VnY: Forza trasversale massima su Y ottenuta in uno qualunque dei supporti del dispositivo.

Il calcolo si esegue selezionando la combinazione di forze più severa tra tutte le forze ottenute.

4.1.3. Risultato

Le schede del risultato vengono accluse nell'allegato 1 per il calcolo statico e nell'allegato 2 per quello dinamico. In entrambi i casi si dimostra che la scelta della vite è corretta.

4.2. ZAVORRE CORRIDOIO. Montaggio B.20.74.007.00

4.2.1. Descrizione dell'unione

Si prende il caso più sfavorevole di tutte le zavorre per analizzarlo. Questo caso corrisponde al montaggio della zavorra B.20.74.120.03.

La zavorra viene fissata tramite 8 viti M8x25:

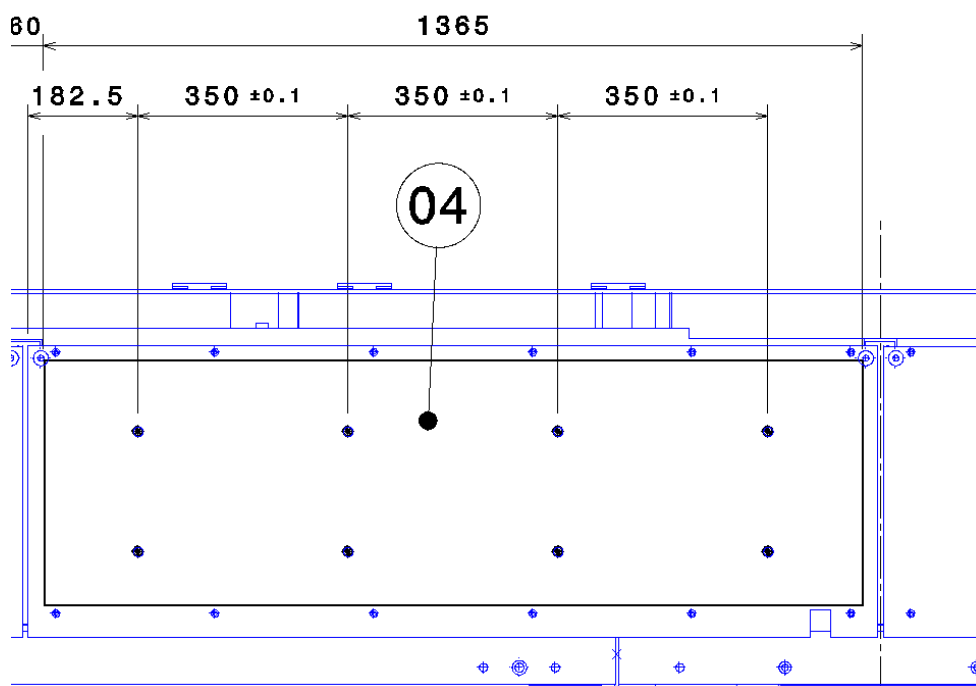


Figura 4

Nella seguente Figura 5 si illustra l'unione nel dettaglio:

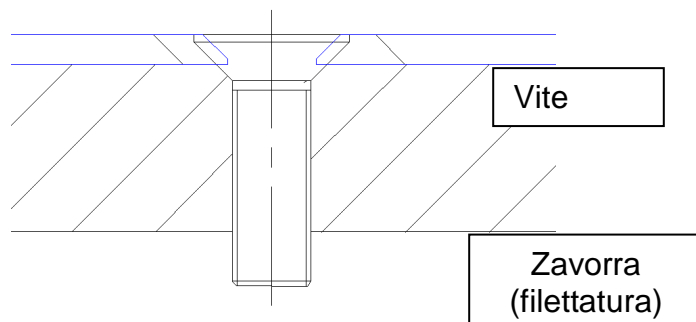


Figura 5

I valori rilevanti per il calcolo sono i seguenti:

- Massa:73.8K
- Viti per fissaggio: 1
- Viti in totale: 8
- Filettatura metrica della vite: M8
- Materiale della vite: Acciaio Inossidabile
- Unione.Tassello filettato (zavorra)
- Materiali nell'unione: 2. Alluminio (lamiera del pavimento) ed Acciaio al carbonio (zavorra)

4.2.2. Forze ottenute per vite

Forze massime per il caso statico, si veda tabella 5

	MAX Qn	MAX VnX	MAX VnY
E1	100	271	0
E2	100	271	0
E3	98	0	90
E4	98	0	90
E5	271	0	0

Tabella 5: Forze massime per il caso statico

MAX Qn: Forza assiale massima ottenuta in uno qualunque dei supporti del dispositivo.

MAX VnX: Forza trasversale massima su X ottenuta in uno qualunque dei supporti del dispositivo.

MAX VnY: Forza trasversale massima su Y ottenuta in uno qualunque dei supporti del dispositivo.

Con i dati della tabella si sceglie di eseguire i calcoli per i casi E1.

Le forze massime risultanti dall'applicazione delle accelerazioni nel caso dinamico (punto 3.1, tabella 2) vengono riportate nella tabella 6.

	MAX Qn:	Min Qn	Max VnX	Max VnY	
D1	115	111	14	18	
D2	70	66	14	18	
D3	115	111	14	18	
D4	70	66	14	18	
D5	115	111	14	18	
D6	70	66	14	18	
D7	115	111	14	18	
D8	70	66	14	18	
	Max Q	Min Q	Max VX	Max VY	Max Shear
	115	66	14	18	22,62

Tabella 6: Forzas massime per il caso dinamico

MAX Qn: Forza assiale massima ottenuta in uno qualunque dei supporti del dispositivo con accelerazioni positive.

Min Qn: Forza assiale massima ottenuta in uno qualunque dei supporti del dispositivo con accelerazioni negative.

MAX VnX: Forza trasversale massima su X ottenuta in uno qualunque dei supporti del dispositivo.

MAX VnY: Forza trasversale massima su Y ottenuta in uno qualunque dei supporti del dispositivo.

Il calcolo si esegue selezionando la combinazione di forze più severe tra tutte le forze ottenute.

4.2.3. Risultato

Le schede del risultato vengono accluse nell'allegato 3 per il calcolo statico e nell'allegato 4 per quello dinamico. In entrambi i casi si dimostra che la scelta della vite è corretta.

Input data:**Verifying calculation of high duty bolted joints according to VDI 2230
(Joints with one cylindrical bolt) - extended version**

Method of calculation	Extended
Clamping	concentric
Type of bolting	tapped thread joint
Bolted joint	single-bolted joint with transverse load
Working load	static

Bolted joint loads

Upper limit value of the axial load	FAO = 1981	N
Eccentrically applied axial load	no	
Predetermine the required minimum clamp load	no	
Torque about the bolt axis	Mt = 0	N*m
Transverse load	FQ = 1472	N
Number of force-transmitting inner interfaces	qF 1	
Working moment	MB = 0	N*m
Tightening technique	free input	
Tightening factor	$\alpha A = 1,6$	
Minimum coefficient of friction in the thread	$\mu_{Gmin} = 0,08$	
Minimum coefficient of friction at the interface	$\mu_{Tmin} = 0,1$	
Minimum coefficient of friction in the head bearing area	$\mu_{Kmin} = 0,08$	
Predetermine required safety against the transverse slipping	yes	
Required safety against the transverse slipping	SGsoll = 1,2	

Predetermine the diameter of the shearing cross section no

Consider the internal pressure to be sealed no
Working temperature of the bolt Ts = 20 °C

Bolt

Data Source	MDESIGN database
<u>Strength grade</u>	8.8 (d ≤ M16)
Young's modulus of the bolt material at RT	ESRT = 211000 N/mm ²
Minimum yield point of the bolt at RT	Rpmin = 640 N/mm ²
Tensile strength of the bolt at RT	Rm = 800 N/mm ²
Shearing strength of the bolt as an influencing factor	fBS = 0,65
<u>Bolt geometry</u>	
Own bolt geometry	no
Data Source	MDESIGN database
Thread type	standard thread
Bolt type	hexagon head bolt with shank
Designation of bolt	M12 x 100
Standard	DIN EN ISO 4014
Bolt length	ls = 195 mm
Thread angle	βGPW = 60 °
Self-locking nut	no

Specification of clamped parts

Nr.	Material	Data Source	Young's modulus EP N/mm ²	Min. tensile strength Rmmin N/mm ²	fG	fBM	Part thickness hi mm	DA mm	dh mm	T °C
1	S355 JO	MDESIGN database	205000	490	1,55	0,8	2,5	30	8	20
2	S355 JO	MDESIGN database	205000	490	1,55	0,8	165	30	8	20
3	S355 JO	MDESIGN database	205000	490	1,55	0,8	4	30	8	20
4	S355 JO	MDESIGN database	205000	490	1,55	0,8	20	30	8	20

Washers

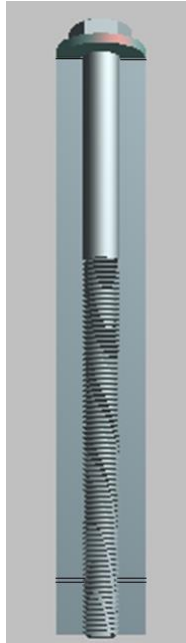
Washer under head
Spring washer under head
Data source

Spring washer input
Material
Number of spring washers
Inner diameter
Outer diameter
Thickness

no
yes
MDESIGN database (DIN 6796)
linear spring curve
spring steel (1.4310)
1
di = 13 mm
da = 29 mm
s = 3 mm

Consider the chamfer at the hole
Consider counterbore depth in the screw-in part
Predetermine amount of embedding
Amount of embedding
Predetermine the load introduction factor
Joint types according to the type of load introduction
Distance between the preloading area and the load introduction point
Predetermine the permissible assembly preload / necessary tightening torque at RT
Necessary tightening torque at RT
Determine meffmin for partial load

no
no
yes
fz = 24 µm
no
SV1
ak = 0 mm
predetermine MA
MA = 62 N*m
no



Results: Systematic calculation of high duty bolted joints according to VDI 2230

Hexagon head bolt DIN EN ISO 4014 - M12,00 x 195,00 - 8.8

General calculation values

Bolt geometry

Bolt nominal diameter	d	=	12	mm
Thread pitch	P	=	1,75	mm
Hole diameter	dh	=	13,5	mm
Outside diameter of the plane head bearing	dw	=	16,47	mm
Inside diameter of the plane head bearing	da	=	13,7	mm
Pitch diameter	d2	=	10,86	mm
Minor diameter	d3	=	9,85	mm
Shank length	l1	=	70	mm
Bolt length	ls	=	195	mm
Minor diameter of the nut thread	D1	=	10,11	mm

Clamping length	lk	=	174,5	mm
-----------------	----	---	-------	----

Deformation cone angle	φ	=	26,31	°
Limiting outside diameter of the deformation cone	DAGr	=	189,02	mm
Total height of the deformation sleeve	IH	=	0	mm
Total height of the deformation cone	IV	=	0	mm

Elastic resiliencies of the joint

Resilience of the bolt:

- at room temperature δ_{SRT} = 10,2239 E-6 mm/N

resilience spring washer

- FV δ_{Spann} = 0,0277 E-6 mm/N

- FVmin δ_{Spann} = 11,4943 E-6 mm/N

condition of spring washer $F_{vmin} = 27929N < \text{pressing force spring champfer} = 43000 < F_v = 44687N$

Resilience of the clamped parts:

- at room temperature

concentrically clamped δ_{PRT} = 1,562 E-6 mm/N

Tightening factor	α A	=	1,6	
Load introduction factor	n	=	0,7	
Load factor	Φ n	=	0,052	
Amount of embedding	fz	=	24	μm
Minimum clamp load for sealing	FKP	=	0	N
Required minimum clamp load	FKerf	=	14720	N
Loss of preload as a result of embedding	Fz	=	1030,92	N
Preload change as a result of the working temp.	$\Delta F'V_{th}$	=	0	N
Thermally induced preload change	ΔFV_{th}	=	0	N
Axial load at the opening limit	FAab	=	28376,62	N

Maximum additional bolt load	FSAmx	=	103,21	N
Maximum additional plate load	FPAmax	=	1877,79	N
Permissible assembly preload at RT	FMzul	=	45196	N
Permissible assembly preload at RT (MA)	FMzul	=	44686,51	N
Minimum necessary assembly preload	FMmin	=	17628,71	N
Maximal tolerate montage tightened load	FMmax	=	28205,93	N
Minimum preload	FVmin	=	26898,15	N
Minimum residual clamp load	FKRmin	=	25020,36	N

Working stress

Maximum bolt load in service	FSmax	=	44789,73	N
Thread torque	MG	=	34872,99	N*mm
Maximum tensile stress of the bolt in service	σ_{zmax}	=	531,54	N/mm ²
Maximal torsional stress in service	τ_{max}	=	159,82	N/mm ²
Comparative stress in the working state	σ_{redB}	=	549,27	N/mm ²
Safety against exceeding the yield point	SF	=	1,17	

Surface pressure

Bearing area:				
- bolt head	ApKmin	=	65,64	mm ²
- washer (on the head side)	ApUmin	=	207,91	mm ²

Assembled state

Surface pressure:				
- head bearing area	pMKmax	=	680,82	N/mm ²
- washer/first clamped part	pMUmex	=	214,93	N/mm ²
Limiting surface pressure:				
- washer	pGU	=	540	N/mm ²
- the first clamped part	PG1	=	759,5	N/mm ²
Safety margin against surface pressure:				
- washer/the first clamped part	SpMU	=	3,53	

Working state

Surface pressure:				
- head bearing area	pBKmax	=	682,39	N/mm ²
- washer/the first clamped part	pBUmax	=	215,43	N/mm ²
Limiting surface pressure:				
- washer	pGU	=	540	N/mm ²
- the first clamped part	PG1	=	759,5	N/mm ²
Safety against surface pressure:				
- washer/the first clamped part	SpBU	=	3,53	
- between the clamped parts	SpPI	=	11,134	
Plate1 - Plate2				

Minimum length of engagement

Shearing cross section of the internal thread	ASGM	=	560,85	mm ²
Shearing cross section of the bolt	ASGS	=	404,66	mm ²
Strength ratio	Rs	=	1,045	
Correction factor	C3	=	0,897	
Shearing strength of the screw-in part	τ_{BM}	=	392	N/mm ²
Breaking force of the bolt thread	FmS	=	67411,14	N
Stripping force of the internal thread	FmGM	=	197207,1	N
Present effective length of engagement	m _{vorheff}	=	17	mm
Present length of engagement	m _{vorh}	=	20,5	mm
Minimum length of engagement	m _{effmin}	=	9,31	mm

Safety margin against slipping and sharing of the bolt

Resulting transverse load	FQ _{max}	=	1472	N
Required minimum clamp load for friction grip	FKQ	=	14720	N
Safety margin against slipping	SG	=	1,7	
Valid is: $SG \geq SG_{soll}$				

Decisive shear cross section	A _{τ}	=	84,26	mm ²
Shearing strength of the bolt	τ_{BS}	=	520	N/mm ²
Safety margin against shearing	SA	=	29,77	
Valid is: $SA \geq 1.1$!				

Tightening torque

Necessary tightening torque at RT	MA	=	62	N*m
Utilization of the yield point during tightening	v	=	88,99	%

Input data:**Verifying calculation of high duty bolted joints according to VDI 2230
(Joints with one cylindrical bolt) - extended version**

Method of calculation	Extended	
Clamping	concentric	
Type of bolting	tapped thread joint	
Bolted joint	single-bolted joint with transverse load	
Working load	dynamic	
Bolted joint loads		
Upper limit value of the axial load	FAO = 460	N
Lower limit value of the axial load	FAU = 128	N
Eccentrically applied axial load	no	
Predetermine the required minimum clamp load	no	
Torque about the bolt axis	Mt = 0	N*m
Transverse load	FQ = 62,43	N
Number of force-transmitting inner interfaces	qF 1	
Working moment	MB = 0	N*m
Tightening technique	free input	
Tightening factor	$\alpha_A = 1,6$	
Minimum coefficient of friction in the thread	$\mu_{Gmin} = 0,08$	
Minimum coefficient of friction at the interface	$\mu_{Tmin} = 0,1$	
Minimum coefficient of friction in the head bearing area	$\mu_{Kmin} = 0,08$	
Predetermine required safety against the transverse slipping	yes	
Required safety against the transverse slipping	SGsoll = 1,8	
Predetermine the diameter of the shearing cross section	no	
Consider the internal pressure to be sealed	no	
Working temperature of the bolt	Ts = 20	°C
Bolt		
Data Source	MDESIGN database	
<u>Strength grade</u>	8.8 (d <= M16)	
Young's modulus of the bolt material at RT	ESRT = 211000	N/mm²
Minimum yield point of the bolt at RT	Rpmin = 640	N/mm²
Tensile strength of the bolt at RT	Rm = 800	N/mm²
Shearing strength of the bolt as an influencing factor	fBS = 0,65	
<u>Bolt geometry</u>		
Own bolt geometry	no	
Data Source	MDESIGN database	
Thread type	standard thread	
Bolt type	hexagon head bolt with shank	
Designation of bolt	M12 x 100	
Standard	DIN EN ISO 4014	
Bolt length	ls = 195	mm
Thread angle	$\beta_{GPW} = 60$	°
Self-locking nut	no	

Specification of clamped parts

Nr.	Material	Data Source	Young's modulus EP N/mm ²	Min. tensile strength Rmmin N/mm ²	fG	fBM	Part thickness hi mm	DA mm	dh mm	T °C
1	S355 JO	MDESIGN database	205000	490	1,55	0,8	2,5	30	8	20
2	S355 JO	MDESIGN database	205000	490	1,55	0,8	165	30	8	20
3	S355 JO	MDESIGN database	205000	490	1,55	0,8	4	30	8	20
4	S355 JO	MDESIGN database	205000	490	1,55	0,8	20	30	8	20

Washers

Washer under head
Spring washer under head
Data source

Spring washer input
Material
Number of spring washers
Inner diameter
Outer diameter
Thickness

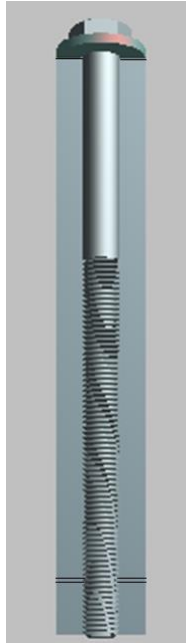
no
yes
MDESIGN database (DIN 6796)
linear spring curve
spring steel (1.4310)
1
di = 13 mm
da = 29 mm
s = 3 mm

Consider the chamfer at the hole
Consider counterbore depth in the screw-in part
Predetermine amount of embedding
Amount of embedding
Predetermine the load introduction factor
Joint types according to the type of load introduction
Distance between the preloading area and the load introduction point
Predetermine the permissible assembly preload / necessary tightening torque at RT
Necessary tightening torque at RT
Thread cutting

no
no
yes
fz = 24 µm
no
SV1
ak = 0 mm
predetermine MA
MA = 62 N*m
rolled before heat treatment

Determine meffmin for partial load
Alternating stress within the fatigue strength range
Number of alternating cycles

no
yes
N = 2000000



Results: Systematic calculation of high duty bolted joints according to VDI 2230

Hexagon head bolt DIN EN ISO 4014 - M12,00 x 195,00 - 8.8

General calculation values

Bolt geometry

Bolt nominal diameter	d	=	12	mm
Thread pitch	P	=	1,75	mm
Hole diameter	dh	=	13,5	mm
Outside diameter of the plane head bearing	dw	=	16,47	mm
Inside diameter of the plane head bearing	da	=	13,7	mm
Pitch diameter	d2	=	10,86	mm
Minor diameter	d3	=	9,85	mm
Shank length	l1	=	70	mm
Bolt length	ls	=	195	mm
Minor diameter of the nut thread	D1	=	10,11	mm

Clamping length	lk	=	174,5	mm
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Deformation cone angle	φ	=	26,31	°
Limiting outside diameter of the deformation cone	DAGr	=	189,02	mm
Total height of the deformation sleeve	IH	=	0	mm
Total height of the deformation cone	IV	=	0	mm

Elastic resiliencies of the joint

Resilience of the bolt:

- at room temperature	δ_{SRT}	=	10,2239	E-6 mm/N
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resilience spring washer

- FV	δ_{Spann}	=	0,0277	E-6 mm/N
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- FVmin	δ_{Spann}	=	11,4943	E-6 mm/N
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condition of spring washer $F_{vmin} = 27929N < \text{pressing force spring champfer} = 43000 < F_v = 44687N$

Resilience of the clamped parts:

- at room temperature	δ_{PRT}	=	1,562	E-6 mm/N
concentrically clamped				

Tightening factor	α A	=	1,6	
Load introduction factor	n	=	0,7	
Load factor	Φ n	=	0,052	
Amount of embedding	fz	=	24	μm
Minimum clamp load for sealing	FKP	=	0	N
Required minimum clamp load	FKerf	=	624,3	N
Loss of preload as a result of embedding	Fz	=	1030,92	N
Preload change as a result of the working temp.	$\Delta F'V_{th}$	=	0	N
Thermally induced preload change	ΔFV_{th}	=	0	N
Axial load at the opening limit	FAab	=	28376,62	N
Maximum additional bolt load	FSAmx	=	23,97	N
Maximum additional plate load	FPAmx	=	436,03	N
Permissible assembly preload at RT	FMzul	=	45196	N
Permissible assembly preload at RT (MA)	FMzul	=	44686,51	N
Minimum necessary assembly preload	FMmin	=	2091,25	N
Maximal tolerate montage tightened load	FMmax	=	3346,01	N
Minimum preload	FVmin	=	26898,15	N
Minimum residual clamp load	FKRmin	=	26462,12	N
Working stress				
Maximum bolt load in service	FSmax	=	44710,48	N
Thread torque	MG	=	34872,99	N*mm
Maximum tensile stress of the bolt in service	σ_{zmax}	=	530,6	N/mm ²
Maximal torsional stress in service	τ_{max}	=	159,82	N/mm ²
Comparative stress in the working state	σ_{redB}	=	548,36	N/mm ²
Safety against exceeding the yield point	SF	=	1,17	
Alternating stress				
Continuous alternating stress acting on the bolt	σ_a	=	0,1	N/mm ²
Average bolt load	FSm	=	44701,83	N
Stress amplitude of the endurance limit	σ_{ASV}	=	48,88	N/mm ²
Safety margin against fatigue failure	SD	=	476,18	
Surface pressure				
Bearing area:				
- bolt head	ApKmin	=	65,64	mm ²
- washer (on the head side)	ApUmin	=	207,91	mm ²
Assembled state				
Surface pressure:				
- head bearing area	pMKmax	=	680,82	N/mm ²
- washer/first clamped part	pMUmex	=	214,93	N/mm ²
Limiting surface pressure:				
- washer	pGU	=	540	N/mm ²
- the first clamped part	PG1	=	759,5	N/mm ²
Safety margin against surface pressure:				
- washer/the first clamped part	SpMU	=	3,53	
Working state				
Surface pressure:				
- head bearing area	pBKmax	=	681,18	N/mm ²
- washer/the first clamped part	pBUmax	=	215,04	N/mm ²
Limiting surface pressure:				
- washer	pGU	=	540	N/mm ²
- the first clamped part	PG1	=	759,5	N/mm ²
Safety against surface pressure:				
- washer/the first clamped part	SpBU	=	3,53	
- between the clamped parts	SpPI	=	11,154	
Plate1 - Plate2				

Minimum length of engagement

Shearing cross section of the internal thread	ASGM	=	560,85	mm ²
Shearing cross section of the bolt	ASGS	=	404,66	mm ²
Strength ratio	Rs	=	1,045	
Correction factor	C3	=	0,897	
Shearing strength of the screw-in part	τ_{BM}	=	392	N/mm ²
Breaking force of the bolt thread	FmS	=	67411,14	N
Stripping force of the internal thread	FmGM	=	197207,1	N
Present effective length of engagement	m _{vorheff}	=	17	mm
Present length of engagement	m _{vorh}	=	20,5	mm
Minimum length of engagement	m _{effmin}	=	9,31	mm

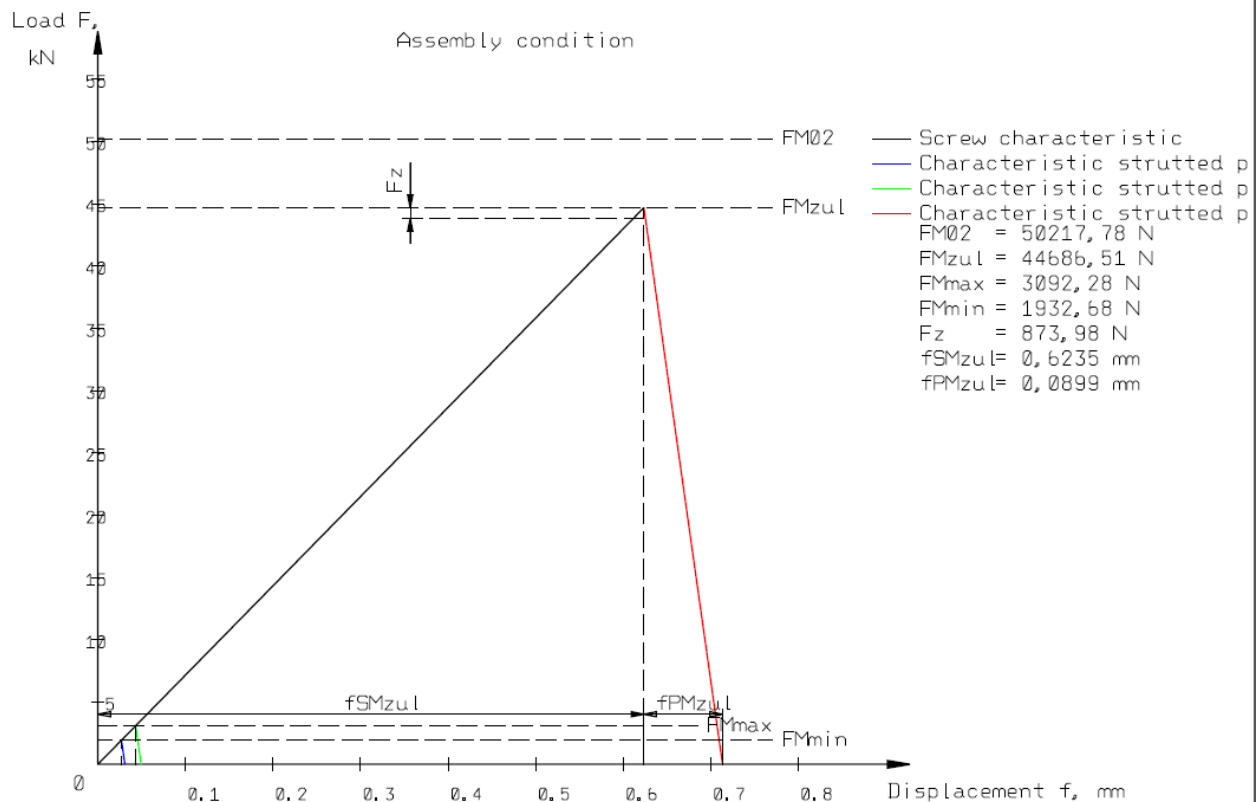
Safety margin against slipping and sharing of the bolt

Resulting transverse load	FQ _{max}	=	62,43	N
Required minimum clamp load for friction grip	FKQ	=	624,3	N
Safety margin against slipping	SG	=	42,39	
Valid is: $SG \geq SG_{soll}$!				

Decisive shear cross section	A _{τ}	=	84,26	mm ²
Shearing strength of the bolt	τ_{BS}	=	520	N/mm ²
Safety margin against shearing	SA	=	701,86	
Valid is: $SA \geq 1.1$!				

Tightening torque

Necessary tightening torque at RT	MA	=	62	N*m
Utilization of the yield point during tightening	v	=	88,99	%



Input data:**Verifying calculation of high duty bolted joints according to VDI 2230
(Joints with one cylindrical bolt) - extended version**

Method of calculation	Extended
Clamping	concentric
Type of bolting	tapped thread joint
Bolted joint	single-bolted joint with transverse load
Working load	static

Bolted joint loads

Upper limit value of the axial load	FAO = 100	N
Eccentrically applied axial load	no	
Predetermine the required minimum clamp load	no	
Torque about the bolt axis	Mt = 0	N*m
Transverse load	FQ = 271	N
Number of force-transmitting inner interfaces	qF 1	
Working moment	MB = 0	N*m
Tightening technique	free input	
Tightening factor	$\alpha A = 1,6$	
Minimum coefficient of friction in the thread	$\mu_{Gmin} = 0,09$	
Minimum coefficient of friction at the interface	$\mu_{Tmin} = 0,1$	
Minimum coefficient of friction in the head bearing area	$\mu_{Kmin} = 0,09$	
Predetermine required safety against the transverse slipping	yes	
Required safety against the transverse slipping	SGsoll = 1,2	

Predetermine the diameter of the shearing cross section no

Consider the internal pressure to be sealed no
Working temperature of the bolt Ts = 20 °C

Bolt

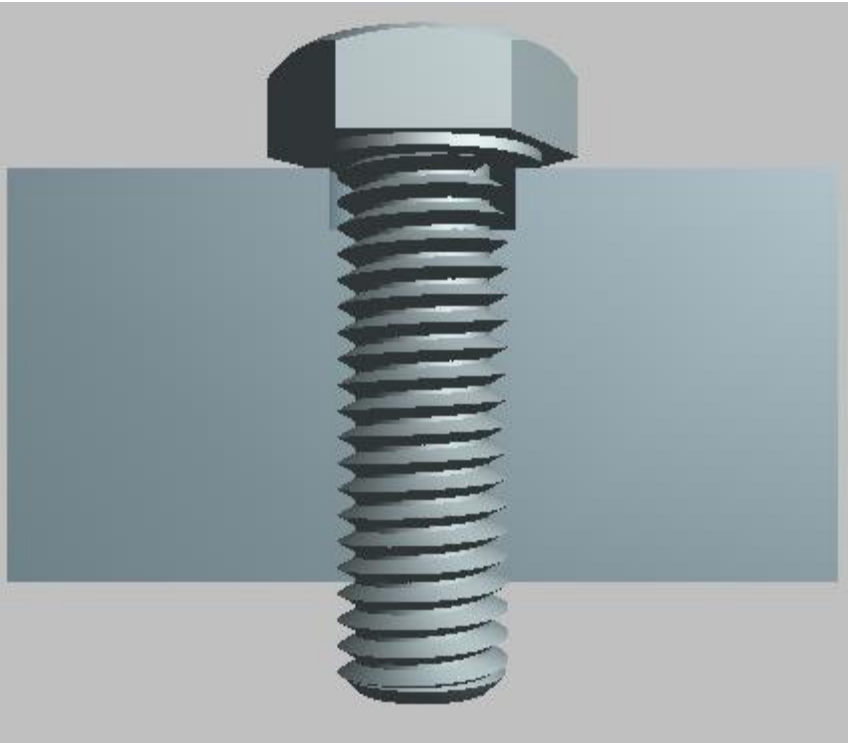
Data Source	MDESIGN database
<u>Strength grade</u>	A2-70
Young's modulus of the bolt material at RT	ESRT = 200000 N/mm ²
Minimum yield point of the bolt at RT	Rpmin = 450 N/mm ²
Tensile strength of the bolt at RT	Rm = 700 N/mm ²
Shearing strength of the bolt as an influencing factor	fBS = 0,72
<u>Bolt geometry</u>	
Own bolt geometry	no
Data Source	MDESIGN database
Thread type	standard thread
Bolt type	hexagon head bolt, threaded to head
Designation of bolt	M8 x 25
Standard	DIN EN ISO 4017
Bolt length	ls = 25 mm
Thread angle	$\beta_{GPW} = 60$ °
Self-locking nut	no

Specification of clamped parts

Nr.	Material	Data Source	Young's modulus E N/mm ²	Min. tensile strength R_{min} N/mm ²	fG	fBM	Part thickness s mm	DA mm	dh mm	T °C
1	AW-6082	MDESIGN database	75000	290	0,9	0,59	3	40	9	20
2	S355 JO	MDESIGN database	205000	490	1,55	0,8	17	40	8	20

Washers

Washer under head	no
Spring washer under head	no
Consider the chamfer at the hole	no
Consider counterbore depth in the screw-in part	no
Predetermine amount of embedding	yes
Amount of embedding	fz = 13 μ m
Predetermine the load introduction factor	no
Joint types according to the type of load introduction	SV1
Distance between the preloading area and the load introduction point	ak = 0 mm
Predetermine the permissible assembly preload / necessary tightening torque at RT	predetermine MA
Necessary tightening torque at RT	MA = 13 N*m
Determine meffmin for partial load	no



Results: Systematic calculation of high duty bolted joints according to VDI 2230

Hexagon head bolt DIN EN ISO 4017 - M8 x 25 - A2-70

General calculation values

Bolt geometry

Bolt nominal diameter	d	=	8	mm
Thread pitch	P	=	1,25	mm
Hole diameter	dh	=	9	mm
Outside diameter of the plane head bearing	dw	=	11,47	mm
Inside diameter of the plane head bearing	da	=	9,2	mm
Pitch diameter	d2	=	7,19	mm
Minor diameter	d3	=	6,47	mm
Bolt length	ls	=	25	mm
Minor diameter of the nut thread	D1	=	6,65	mm

Clamping length	lk	=	3	mm
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Deformation cone angle	φ	=	26,01	°
Limiting outside diameter of the deformation cone	DAGr	=	12,93	mm
Total height of the deformation sleeve	IH	=	0	mm
Total height of the deformation cone	IV	=	0	mm

Elastic resiliencies of the joint

Resilience of the bolt:				
- at room temperature	δ_{SRT}	=	1,72	E-6 mm/N

Resilience of the clamped parts:				
- at room temperature				
concentrically clamped	δ_{PRT}	=	2,4195	E-6 mm/N

Tightening factor	α_A	=	1,6	
Load introduction factor	n	=	0,7	
Load factor	Φ_n	=	0,409	
Amount of embedding	fz	=	13	μm
Minimum clamp load for sealing	FKP	=	0	N
Required minimum clamp load	FKerf	=	2710	N
Loss of preload as a result of embedding	Fz	=	3140,5	N
Preload change as a result of the working temp.	$\Delta F'_{Vth}$	=	0	N
Thermally induced preload change	ΔF_{Vth}	=	0	N
Axial load at the opening limit	FAab	=	7903,55	N

Maximum additional bolt load	FSAmx	=	40,91	N
Maximum additional plate load	FPAmx	=	59,09	N
Permissible assembly preload at RT	FMzul	=	13590,96	N
Permissible assembly preload at RT (MA)	FMzul	=	12496,53	N
Minimum necessary assembly preload	FMmin	=	5909,59	N
Maximal tolerate montage tightened load	FMmax	=	9455,34	N
Minimum preload	FVmin	=	4669,83	N
Minimum residual clamp load	FKRmin	=	4610,75	N

Working stress

Maximum bolt load in service	FSmax	=	12537,45	N
Thread torque	MG	=	7154,76	N*mm
Maximum tensile stress of the bolt in service	σ_{zmax}	=	342,5	N/mm ²
Maximal torsional stress in service	τ_{max}	=	114,52	N/mm ²
Comparative stress in the working state	σ_{redB}	=	356,57	N/mm ²
Safety against exceeding the yield point	SF	=	1,26	

Surface pressure

Bearing area:				
- bolt head	ApKmin	=	36,85	mm ²

Assembled state

Surface pressure:				
- head bearing area	pMKmax	=	339,1	N/mm ²
Limiting surface pressure:				
- the first clamped part	PG1	=	261	N/mm ²

Working state

Surface pressure:				
- head bearing area	pBKmax	=	340,21	N/mm ²
Limiting surface pressure:				
- the first clamped part	PG1	=	261	N/mm ²
Safety against surface pressure:				
- between the clamped parts	SpPl	=	24,836	
Plate1 - Plate2				

Minimum length of engagement

Shearing cross section of the internal thread	ASGM	=	373,87	mm ²
Shearing cross section of the bolt	ASGS	=	266,2	mm ²
Strength ratio	Rs	=	1,092	
Correction factor	C3	=	0,897	
Shearing strength of the screw-in part	τ_{BM}	=	392	N/mm ²
Breaking force of the bolt thread	FmS	=	25624,05	N
Stripping force of the internal thread	FmGM	=	131461,49	N
Present effective length of engagement	mvorheff	=	17	mm
Present length of engagement	mvorh	=	17	mm
Minimum length of engagement	meffmin	=	5,81	mm

Safety margin against slipping and sharing of the bolt

Resulting transverse load	FQmax	=	271	N
Required minimum clamp load for friction grip	FKQ	=	2710	N
Safety margin against slipping	SG	=	1,7	
Valid is: $SG \geq SG_{soll}$				

Decisive shear cross section	A_{τ}	=	36,61	mm ²
Shearing strength of the bolt	τ_{BS}	=	504	N/mm ²
Safety margin against shearing	SA	=	68,08	
Valid is: $SA \geq 1.1!$				

Tightening torque

Necessary tightening torque at RT	MA	=	13	N*m
Utilization of the yield point during tightening	v	=	82,75	%

Input data:**Verifying calculation of high duty bolted joints according to VDI 2230
(Joints with one cylindrical bolt) - extended version**

Method of calculation	Extended	
Clamping	concentric	
Type of bolting	tapped thread joint	
Bolted joint	single-bolted joint with transverse load	
Working load	dynamic	
Bolted joint loads		
Upper limit value of the axial load	FAO = 115	N
Lower limit value of the axial load	FAU = 66	N
Eccentrically applied axial load	no	
Predetermine the required minimum clamp load	no	
Torque about the bolt axis	Mt = 0	N*m
Transverse load	FQ = 22,62	N
Number of force-transmitting inner interfaces	qF 1	
Working moment	MB = 0	N*m
Tightening technique	free input	
Tightening factor	$\alpha A = 1,6$	
Minimum coefficient of friction in the thread	$\mu G_{min} = 0,09$	
Minimum coefficient of friction at the interface	$\mu T_{min} = 0,1$	
Minimum coefficient of friction in the head bearing area	$\mu K_{min} = 0,09$	
Predetermine required safety against the transverse slipping	yes	
Required safety against the transverse slipping	SGsoll = 1,8	
Predetermine the diameter of the shearing cross section	no	
Consider the internal pressure to be sealed	no	
Working temperature of the bolt	Ts = 20	°C
Bolt		
Data Source	MDESIGN database	
<u>Strength grade</u>	A2-70	
Young's modulus of the bolt material at RT	ESRT = 200000	N/mm²
Minimum yield point of the bolt at RT	Rpmin = 450	N/mm²
Tensile strength of the bolt at RT	Rm = 700	N/mm²
Shearing strength of the bolt as an influencing factor	fBS = 0,72	
<u>Bolt geometry</u>		
Own bolt geometry	no	
Data Source	MDESIGN database	
Thread type	standard thread	
Bolt type	hexagon head bolt, threaded to head	
Designation of bolt	M8 x 25	
Standard	DIN EN ISO 4017	
Bolt length	ls = 25	mm
Thread angle	$\beta GPW = 60$	°
Self-locking nut	no	

Specification of clamped parts

Nr.	Material	Data Source	Young's modulus EP N/mm ²	Min. tensile strength Rmmin N/mm ²	fG	fBM	Part thickness hi mm	DA mm	dh mm	T °C
1	AW-6082	MDESIGN database	75000	290	0,9	0,59	3	40	9	20
2	S355 JO	MDESIGN database	205000	490	1,55	0,8	17	40	8	20

Washers

Washer under head

no

Spring washer under head

no

Consider the chamfer at the hole

no

Consider counterbore depth in the screw-in part

no

Predetermine amount of embedding

yes

Amount of embedding

fz = 13 μ m

Predetermine the load introduction factor

no

Joint types according to the type of load introduction

SV1

Distance between the preloading area and the load introduction point

ak = 0 mm

Predetermine the permissible assembly preload / necessary tightening torque at RT

predetermine MA

Necessary tightening torque at RT

MA = 13 N*m

Thread cutting

rolled before heat treatment

Determine meffmin for partial load

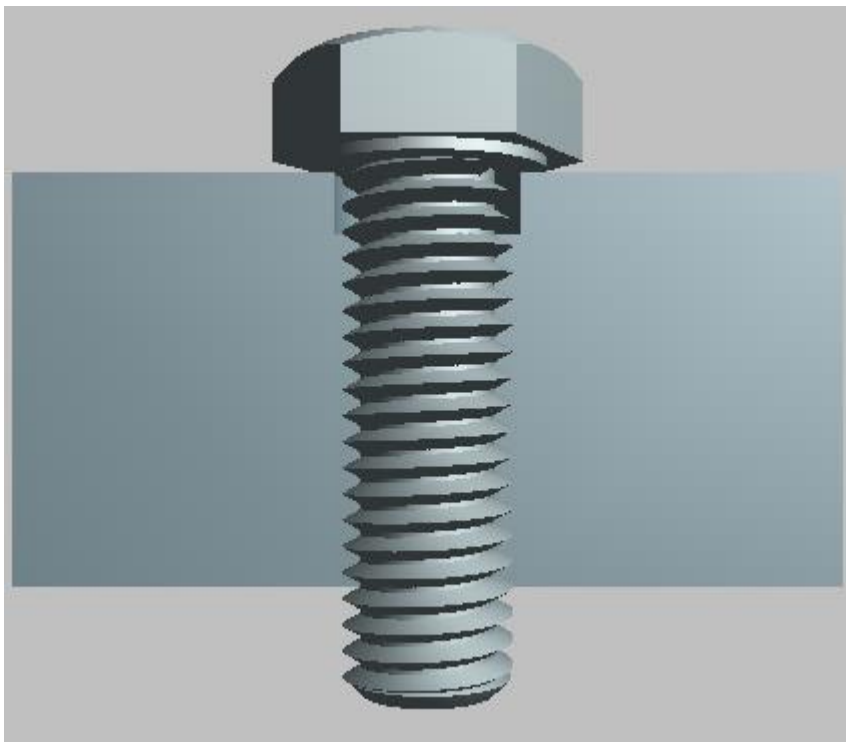
no

Alternating stress within the fatigue strength range

yes

Number of alternating cycles

N = 2000000



Results: Systematic calculation of high duty bolted joints according to VDI 2230

Hexagon head bolt DIN EN ISO 4017 - M8 x 25 - A2-70

General calculation values

Bolt geometry

Bolt nominal diameter	d	=	8	mm
Thread pitch	P	=	1,25	mm
Hole diameter	dh	=	9	mm
Outside diameter of the plane head bearing	dw	=	11,47	mm
Inside diameter of the plane head bearing	da	=	9,2	mm
Pitch diameter	d2	=	7,19	mm
Minor diameter	d3	=	6,47	mm
Bolt length	ls	=	25	mm
Minor diameter of the nut thread	D1	=	6,65	mm

Clamping length	lk	=	3	mm
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Deformation cone angle	φ	=	26,01	°
Limiting outside diameter of the deformation cone	DAGr	=	12,93	mm
Total height of the deformation sleeve	IH	=	0	mm
Total height of the deformation cone	IV	=	0	mm

Elastic resiliencies of the joint

Resilience of the bolt:				
- at room temperature	δ_{SRT}	=	1,72	E-6 mm/N

Resilience of the clamped parts:				
- at room temperature				
concentrically clamped	δ_{PRT}	=	2,4195	E-6 mm/N

Tightening factor	α_A	=	1,6	
Load introduction factor	n	=	0,7	
Load factor	Φ_n	=	0,409	
Amount of embedding	fz	=	13	μm
Minimum clamp load for sealing	FKP	=	0	N
Required minimum clamp load	FKerf	=	226,2	N
Loss of preload as a result of embedding	Fz	=	3140,5	N
Preload change as a result of the working temp.	$\Delta F'_{Vth}$	=	0	N
Thermally induced preload change	ΔF_{Vth}	=	0	N
Axial load at the opening limit	FAab	=	7903,55	N

Maximum additional bolt load	FSAmx	=	47,05	N
Maximum additional plate load	FPAmx	=	67,95	N
Permissible assembly preload at RT	FMzul	=	13590,96	N
Permissible assembly preload at RT (MA)	FMzul	=	12496,53	N
Minimum necessary assembly preload	FMmin	=	3434,65	N
Maximal tolerate montage tightened load	FMmax	=	5495,44	N
Minimum preload	FVmin	=	4669,83	N
Minimum residual clamp load	FKRmin	=	4601,88	N

Working stress

Maximum bolt load in service	FSmax	=	12543,58	N
Thread torque	MG	=	7154,76	N*mm
Maximum tensile stress of the bolt in service	σ_{zmax}	=	342,67	N/mm ²
Maximal torsional stress in service	τ_{max}	=	114,52	N/mm ²
Comparative stress in the working state	σ_{redB}	=	356,73	N/mm ²
Safety against exceeding the yield point	SF	=	1,26	

Alternating stress

Continuous alternating stress acting on the bolt	σ_a	=	0,27	N/mm ²
Average bolt load	F _{Sm}	=	12533,56	N

Stress amplitude of the endurance limit	σ_{ASV}	=	54,19	N/mm ²
Safety margin against fatigue failure	SD	=	197,88	

Surface pressure

Bearing area:				
- bolt head	A _{pKmin}	=	36,85	mm ²

Assembled state

Surface pressure:				
- head bearing area	p _{MKmax}	=	339,1	N/mm ²
Limiting surface pressure:				
- the first clamped part	PG1	=	261	N/mm ²

Working state

Surface pressure:				
- head bearing area	p _{BKmax}	=	340,38	N/mm ²
Limiting surface pressure:				
- the first clamped part	PG1	=	261	N/mm ²

Minimum length of engagement

Shearing cross section of the internal thread	ASGM	=	373,87	mm ²
Shearing cross section of the bolt	ASGS	=	266,2	mm ²
Strength ratio	R _s	=	1,092	
Correction factor	C ₃	=	0,897	
Shearing strength of the screw-in part	τ_{BM}	=	392	N/mm ²
Breaking force of the bolt thread	F _{mS}	=	25624,05	N
Stripping force of the internal thread	F _{mGM}	=	131461,49	N
Present effective length of engagement	m _{vorheff}	=	17	mm
Present length of engagement	m _{vorh}	=	17	mm
Minimum length of engagement	m _{effmin}	=	5,81	mm

Safety margin against slipping and sharing of the bolt

Resulting transverse load	F _{Qmax}	=	22,62	N
Required minimum clamp load for friction grip	F _{KQ}	=	226,2	N
Safety margin against slipping	SG	=	20,34	
Valid is: $SG \geq SG_{soll}$				

Decisive shear cross section	A _{τ}	=	36,61	mm ²
Shearing strength of the bolt	τ_{BS}	=	504	N/mm ²
Safety margin against shearing	SA	=	815,62	
Valid is: $SA \geq 1.1!$				

Tightening torque

Necessary tightening torque at RT	MA	=	13	N*m
Utilization of the yield point during tightening	v	=	82,75	%

