Simulatie van Toren 20mtr REV2 Assemblage

Datum: Vrijdag 4 September 2020
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Studie naam: Static 1
Type Analyse: Statisch

Omschrijving

Statische berekening van een 20 meter toren voor een BESTwind 10Kw MKII windturbine

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Technische gegevens

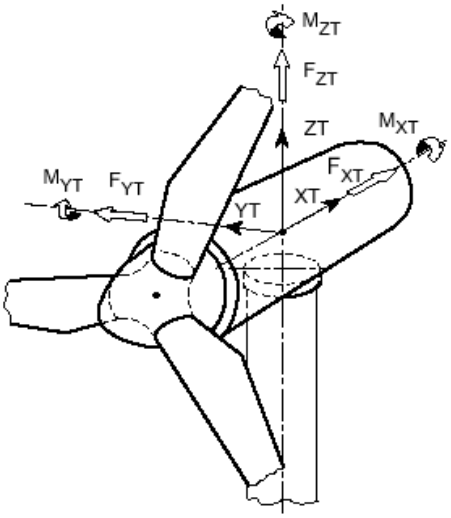
Type turbine:	Bestwatt 10Kw MKII
Vermogensregeling:	Overtrek
Nominaal vermogen:	10Kw
Maximaal vermogen:	15Kw
Aantal wieken:	3
Nominaal toerental:	Variabel 70-85 RPM
Maximaal toerental:	95 RPM
Rem:	Aerodynamische tipremmen hydraulisch bediend.
Over toeren beveiliging:	Dubbel uitgevoerd toeren opnemers
Startwindsnelheid:	2,5 m/s
Windsnelheid vollast:	9 m/s
Uitschakel windsnelheid:	25 m/s
Temperatuurbereik:	-20°C ... +30°C

Ontwerp voor IEC windklasse 2:

- Naafhoogte: 20 m
- Gewicht gondel: 965kg (inclusief wieken)
- Eigen frequentie Gondel:
    - 1p bij nominaal toeren: 1,16 - 1,41Hz
    - 3p bij nominaal toeren: 3,48 - 4,25Hz
- Hart afstand naaf tot bovenzijde mast: 312 mm
- Totale hoogte mast: 19688 mm
- Fundering: Buisfundering; lengte op basis van sondering.

Toren berekening

De richting van de krachten word hieronder weergegeven volgens het Turbine Coordinate system torentoplasten.



As X word aangeduid als de hartlijn vanuit de naaf. Dit coördinaat vertegenwoordigt de kracht die optreed in horizontale richting.
As Y word aangeduid als de horizontale lijn haaks op de rotor as. Dit coördinaat vertegenwoordigt de kracht die optreed in zijdelingse richting.
As Z word aangeduid als de hartlijn van de toren. Dit coördinaat vertegenwoordigt de kracht die optreed in verticale richting.
My word aangeduid als het koppel wat optreed om as Y, dit is het kiepmoment van de gondel.
Mx word aangeduid als het koppel wat optreed om as X, dit is het aandrijfmoment van de gondel.

Uitgangspunten

De toren van de turbine is berekend volgens de torentoplasten uit onderstaand rapport. De toren is hier berekend in het belastinggeval Extreem parkeren bij een windsnelheid op ashoogte van V_e50 =59,5 m/s (IEC klasse 2). De rotor volgt de wind, het frontaal oppervlak van de rotor geeft dan de maximale bijdrage aan het voetmoment.
Voor het simuleren van de optredende krachten in de torentop is gekozen voor het gebruik van de resultante:

Fxy:	24,12kN
Fz:	9,9kN
Mxy:	14.81kNm

```
Extreme Loads Calculation Tower

General inputs                                                                                                                  Date:     15-04-20

Wind turbine                          BW 10/15 15m tower                                                  Wind regime       61400-2{ed1.0} Safety
Load case                             Extreme tower bending moment                                                          small wind turbines.p
Filename:                             T20m-BW10.xls                                                       NEN                       1
Consequence of failure                     1.00
Load factor wind gFa                       1.35  (NVN/IEC)
Load factor gravity                        1.35  force            0.9  moment (IEC)
Material factor gM                         1.00  (IEC/NVN)
Re_16                                       355  MPa          S235J2G3
Re_40                                       355  MPa          S235J2G3
dH_torent     0.614                                            2nd mode Maak alle  CD's 0                                                    7.96E-08
Inputs for extreme loads calculation                           routine  Maak MYGH 0                                                         1.26E+07
   14.81     24.12 FXYaHtemp                 6.19 MYGHtemp               Maak FXYH 0
V_Hub        59.5   m/s        A_hub+nac      0.6  m2 (0.87m diam.)      Maak MYXH = .001 (1 N)
H_hub        15.1   m          Cd_hub+nac     1.2  -                    Maak uflex 0 met solver op FXYa
FXYa_H       24.12  kN         G_nac          4.2  kN          (pos)    dan is K_2nd =  1/alfa_flx (waarde plakken)          m_generat        440
FZR_H         9.9   kN         L_nac          0.42 m                    maak grafiek van alfa en u over de hoogte            helft rotor helft nac
MXYa_H       14.81  kNm        G_rot          5.75 kN          (pos)
H_high      14.460  m          L_rot          0.77 m           tower top moment     23.16  [kNm]     14.5    [m]
H_low        0.000  m          MYg_H          6.19 kNm         tower half moment   227.15  [kNm]      7.2    [m]
D_high       0.400  m          A_blades       7.02 m2          tower foot moment   497.64  [kNm]      0.0    [m]
D_low        0.775  m          CD_blades      1.45 -           Polynom const1:     0.636
M0           0.026  m/m        CD_tower        1.2 -           Polynom const2:    -42.01
M1           0.026  m/m        rho_Fe         8500 kg/m3       Polynom const3:       498
M2           0.026  m/m        z_0            0.03 m                              15 m voetdiameter
step         0.201  m                                           schaalft:    25.83      775                                   X is hori:
Extreme loads calculation (stresses include load factor but no material factor)                   Mininum SRF       Y is hoog        1.46
```

Het moment op de voet van de toren is in onderstaande tabel weergegeven, voor het berekenen van de funderingsbuis hanteert fa. Fubo consult de onderstaande tabel met het daarbij horende Coordinate system torenvoet.

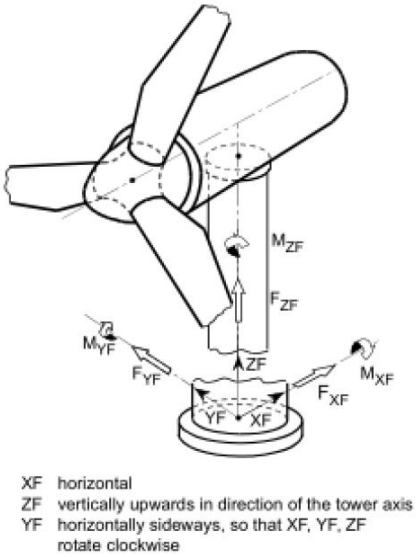


Fig. 4.A.6 Tower bottom coordinate system

	Ashoogte 15m			Ashoogte 20 m			Ashoogte 25m		
Windklasse	Fx kN	Fz kN	My kNm	Fx kN	Fz kN	My kNm	Fx kN	Fz kN	My kNm
IEC class 2	41.7	-27.9	498.0	51.07	-29.7	741.0	58.9	-43	1026.0
IEC class 3	32.5	-27.9	389.0	39.8	-29.7	579.0	45.8	-43	515.0
IEC class 4	20.8	-27.9	252.0	25.5	-29.7	374.0	29.3	-43	515.0

Model Informatie

Model name: Mast 20mtr REV2 Assembly
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Funderingsbuis	Solid Body	**Mass:2.074,44 kg** **Volume:0,265953 m^3** **Density:7.800 kg/m^3** **Weight:20.329,5 N**	**C:\Users\mk\Documents\BESTwind\Tekeningen Solidworks\Berekening 20Mtr REV3\Berekening mast 20mtr Assembly\Funderingsbuis L=6000mm.SLDPRT** Sep 2 08:29:35 2020

Ondermast	Solid Body	**Mass:1.592,5 kg** **Volume:0,204166 m^3** **Density:7.800 kg/m^3** **Weight:15.606,5 N**	**C:\Users\mk\Documents\BESTwind\Tekeningen Solidworks\Berekening 20Mtr REV3\Berekening mast 20mtr Assembly\Ondermast.SLDPRT** Aug 26 10:48:50 2020
Topmast	Solid Body	**Mass:552,458 kg** **Volume:0,0708279 m^3** **Density:7.800 kg/m^3** **Weight:5.414,08 N**	**C:\Users\mk\Documents\BESTwind\Tekeningen Solidworks\Berekening 20Mtr REV3\Berekening mast 20mtr Assembly\Topmast.SLDPRT** Aug 26 10:53:16 2020
Tussenmast	Solid Body	**Mass:909,705 kg** **Volume:0,116629 m^3** **Density:7.800 kg/m^3** **Weight:8.915,1 N**	**C:\Users\mk\Documents\BESTwind\Tekeningen Solidworks\Berekening 20Mtr REV3\Berekening mast 20mtr Assembly\Tussenmast.SLDPRT** Aug 26 15:01:52 2020

Studie Eigenschappen

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	25 Celsius
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\mk\Documents\BESTwind\Tekeningen Solidworks\Berekening 20Mtr REV3\Berekening mast 20mtr Assembly)

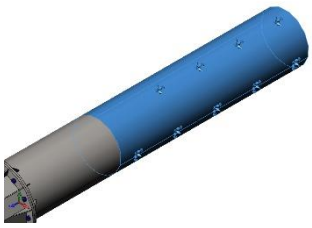
Eenheden

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Celsius
Angular velocity	Hertz
Pressure/Stress	N/mm^2 (MPa)

Materiaal Eigenschappen

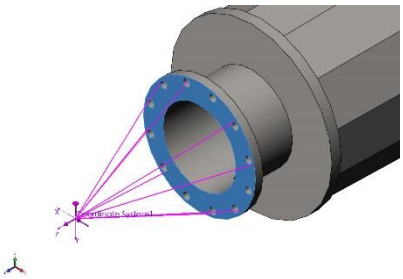
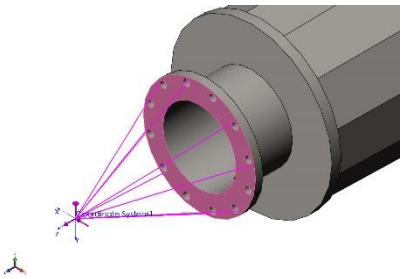
Model Reference	Properties	Components
	Name: 1.0545 (S355N) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 275 N/mm^2 **Tensile strength:** 450 N/mm^2 **Elastic modulus:** 210.000 N/mm^2 **Poisson's ratio:** 0,28 **Mass density:** 7,8 g/cm^3 **Shear modulus:** 79.000 N/mm^2 **Thermal expansion coefficient:** 1,1e-05 /Kelvin	SolidBody 1(Split Line1)(Mast 20Mtr REV3-1/Funderingsbuis L=6000mm-1), SolidBody 1(CirPattern1)(Mast 20Mtr REV3-1/Ondermast-1), SolidBody 1(Cut-Extrude1)(Mast 20Mtr REV3-1/Topmast-1), SolidBody 1(Loft-Thin1)(Mast 20Mtr REV3-1/Tussenmast-2)
Curve Data:N/A		

Lasten en Bevestiging

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 1 face(s) **Type:** Fixed Geometry

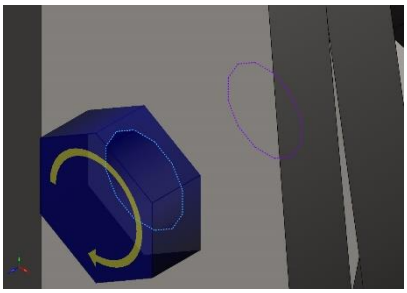
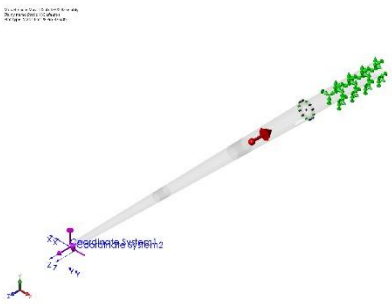
Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	24.120,1	-0,00950834	40.417,4	47.067,5
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Remote Load (Distributed connection)-1		**Entities:** 1 face(s) **Connection Type:** Distributed **Weighting Factor:** Default (Constant) **Coordinate System:** Coordinate System1 **Translational Components:** 24.120 N;---;9.900 N **Rotational Components:** ---;14.810 N.m;--- **Reference coordinates:** 0 0 0 mm
Gravity-1		**Reference:** Face< 1 > **Values:** 0 0 9,81 **Units:** m/s^2

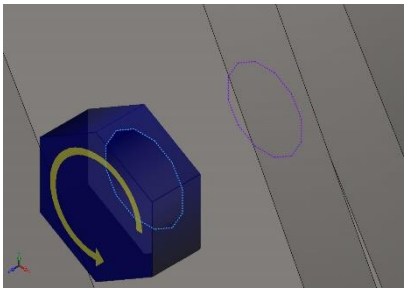
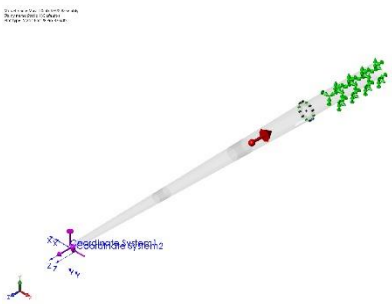
Connector Definities

Pin/Bolt/Bearing Connector

Model Reference	Connector Details	Strength Details
 Counterbore with Nut-1	**Entities:** 2 edge(s) **Type:** Bolt(Head/Nut diameter)(Counterbore) **Head diameter:** 65 mm **Nut diameter:** 65 mm **Nominal shank diameter:** 42 mm **Preload (Torque):** 3.200 **Young's modulus:** 2,1e+11 **Poisson's ratio:** 0,28 **Preload units:** N.m	Bolt Check: OK Calculated FOS: 1,56585 Desired FOS: 1,35 

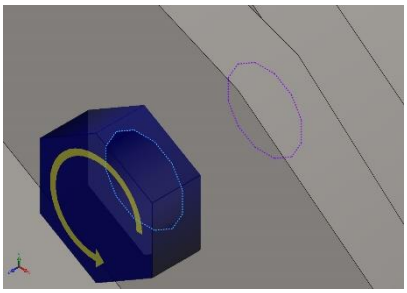
Connector Forces

Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	-1,1181e-07	4,4777e+05	4,4777e+05
Shear Force (N)	3.954,6	-69,055	0	3.955,2
Bending moment (N.m)	-2,5288	-47,136	-1,177e-11	47,204

 Counterbore with Nut-2	**Entities:** 2 edge(s) **Type:** Bolt(Head/Nut diameter)(Counterbore) **Head diameter:** 65 mm **Nut diameter:** 65 mm **Nominal shank diameter:** 42 mm **Preload (Torque):** 3.200 **Young's modulus:** 2,1e+11 **Poisson's ratio:** 0,28 **Preload units:** N.m	Bolt Check: OK Calculated FOS: 1,51901 Desired FOS: 1,35 

Connector Forces

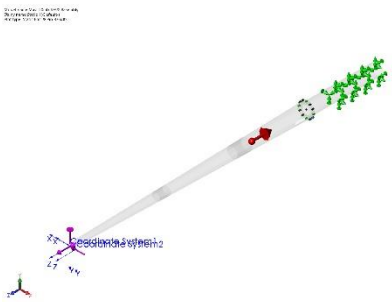
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	0	4,4041e+05	4,4041e+05
Shear Force (N)	392,61	6.265,7	0	6.277,9
Bending moment (N.m)	175,81	49,499	0	182,65



Counterbore with Nut-3

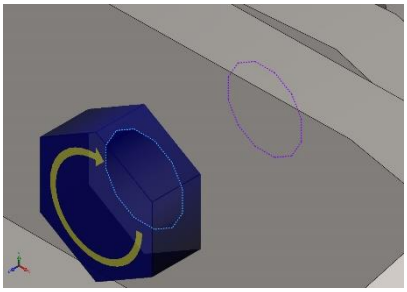
Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

Bolt Check:	OK
Calculated FOS:	1,50612
Desired FOS:	1,35



Connector Forces

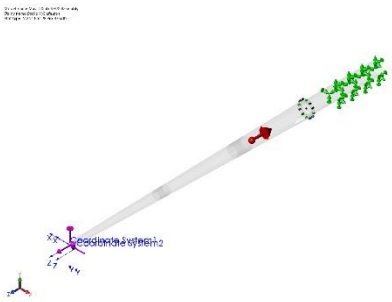
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	0	4,3071e+05	4,3071e+05
Shear Force (N)	-5.559,1	6.374	0	8.457,7
Bending moment (N.m)	187,13	193,82	0	269,41



Counterbore with Nut-4

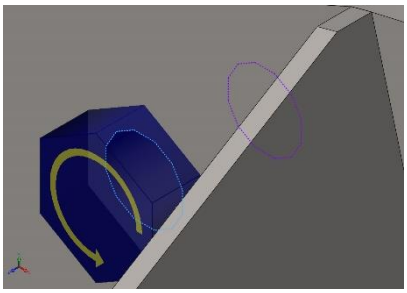
Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

Bolt Check:	OK
Calculated FOS:	1,44686
Desired FOS:	1,35



Connector Forces

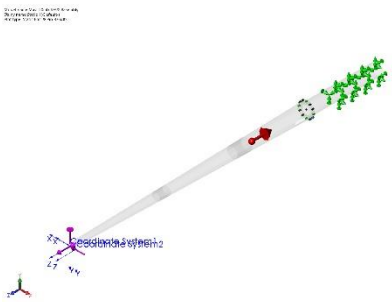
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	-3,1448e-07	0	4,4623e+05	4,4623e+05
Shear Force (N)	-8.845,9	308,09	-6,2282e-09	8.851,2
Bending moment (N.m)	-3,9251	293,88	-2,7662e-12	293,91



Counterbore with Nut-5

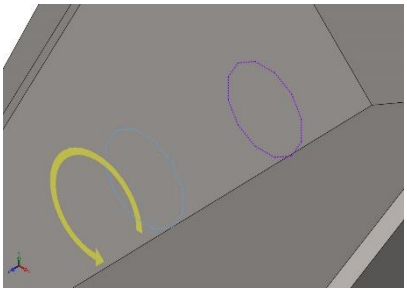
Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

Bolt Check:	OK
Calculated FOS:	1,50202
Desired FOS:	1,35



Connector Forces

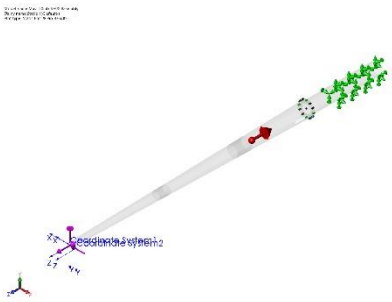
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	0	4,2717e+05	4,2717e+05
Shear Force (N)	-5.978,2	-6.426	0	8.776,9
Bending moment (N.m)	-217,43	206,73	0	300,02



Counterbore with Nut-6

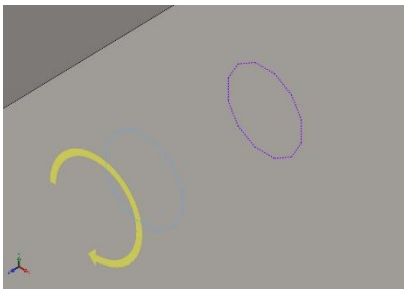
Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

Bolt Check:	OK
Calculated FOS:	1,49696
Desired FOS:	1,35



Connector Forces

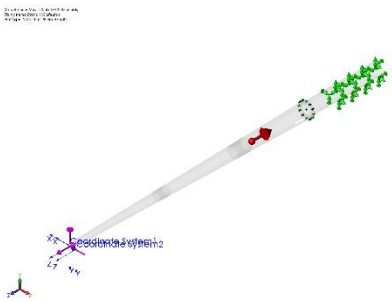
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	0	4,3568e+05	4,3568e+05
Shear Force (N)	1.980,2	-7.074,2	0	7.346,1
Bending moment (N.m)	-249,25	-59,803	0	256,32



Counterbore with Nut-7

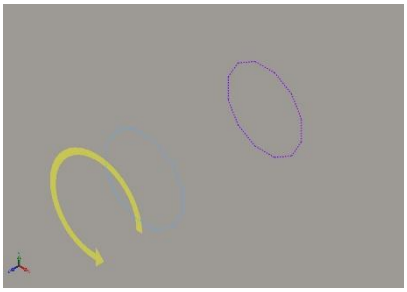
Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

Bolt Check:	OK
Calculated FOS:	1,52156
Desired FOS:	1,35



Connector Forces

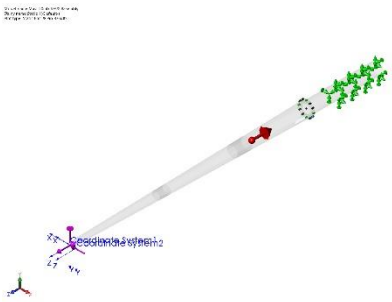
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	-3,9067e-07	4,3294e+05	4,3294e+05
Shear Force (N)	6.033,3	133,83	1,1642e-10	6.034,8
Bending moment (N.m)	6,4559	-224,85	-2,0289e-10	224,94



Counterbore with Nut-8

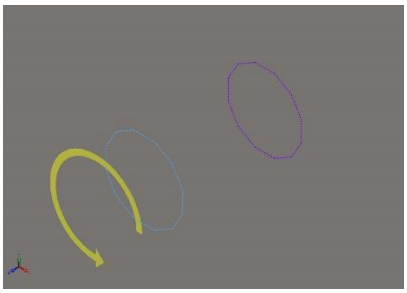
Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

Bolt Check:	OK
Calculated FOS:	1,49406
Desired FOS:	1,35



Connector Forces

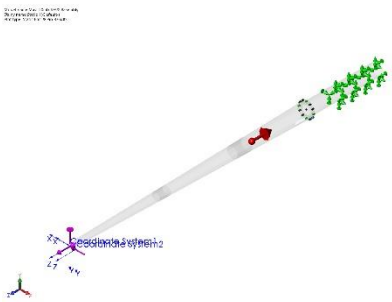
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	0	4,3675e+05	4,3675e+05
Shear Force (N)	2.668,1	6.307,5	0	6.848,6
Bending moment (N.m)	241,11	-84,273	0	255,42



Counterbore with Nut-9

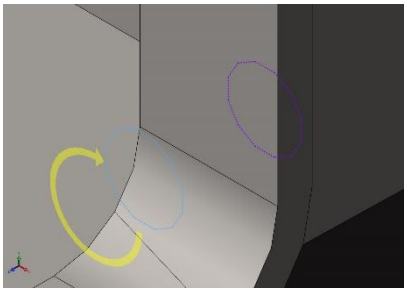
Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

Bolt Check:	OK
Calculated FOS:	1,4588
Desired FOS:	1,35



Connector Forces

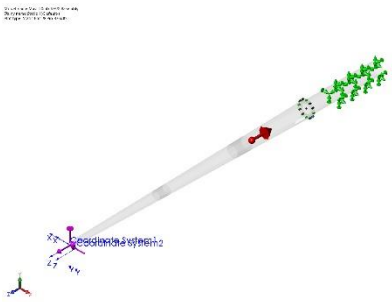
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	0	4,3895e+05	4,3895e+05
Shear Force (N)	-5.882,8	6.145,8	0	8.507,6
Bending moment (N.m)	235,42	208,51	0	314,48



Counterbore with Nut-10

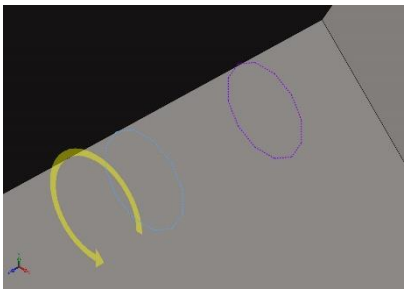
Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

Bolt Check:	OK
Calculated FOS:	1,47363
Desired FOS:	1,35



Connector Forces

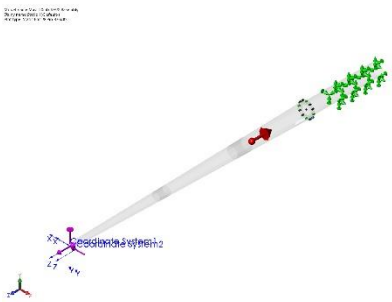
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	5,1806e-09	0	4,4134e+05	4,4134e+05
Shear Force (N)	-8.174,6	-419,99	1,1642e-10	8.185,4
Bending moment (N.m)	-12,803	267,92	1,5028e-13	268,23



Counterbore with Nut-11

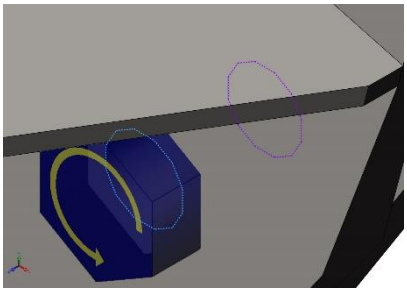
Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

Bolt Check:	OK
Calculated FOS:	1,47767
Desired FOS:	1,35



Connector Forces

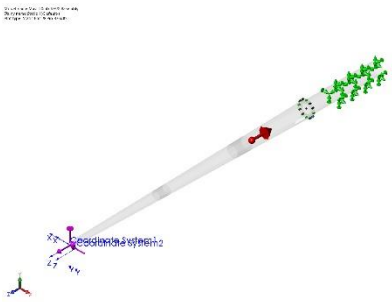
Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	0	4,4374e+05	4,4374e+05
Shear Force (N)	-4.852,5	-5.313,2	0	7.195,6
Bending moment (N.m)	-149,4	193,72	0	244,64



Counterbore with Nut-12

Entities:	2 edge(s)
Type:	Bolt(Head/Nut diameter)(Counterbore)
Head diameter:	65 mm
Nut diameter:	65 mm
Nominal shank diameter:	42 mm
Preload (Torque):	3.200
Young's modulus:	2,1e+11
Poisson's ratio:	0,28
Preload units:	N.m

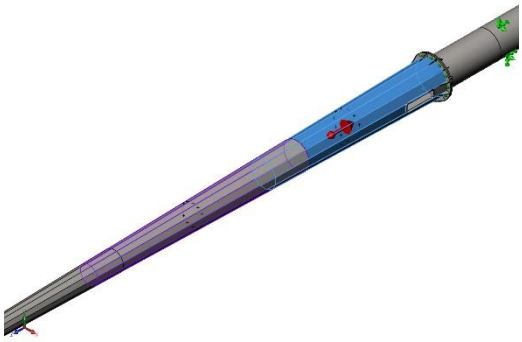
Bolt Check:	OK
Calculated FOS:	1,51419
Desired FOS:	1,35



Connector Forces

Type	X-Component	Y-Component	Z-Component	Resultant
Axial Force (N)	0	0	4,4114e+05	4,4114e+05
Shear Force (N)	144,35	-6.232,5	0	6.234,1
Bending moment (N.m)	-159,53	98,451	0	187,47

Contact Informatie

Contact	Contact Image	Contact Properties
Contact Set-1		**Type:** Bonded contact pair **Entities:** 24 face(s)

Contact/Friction force

Components	X	Y	Z	Resultant
Contact Force(N)	-8,1498E+07	2.611,6	2,2256E+06	8,1528E+07

Contact Set-2		**Type:** Bonded contact pair **Entities:** 24 face(s)

Contact/Friction force

Components	X	Y	Z	Resultant
Contact Force(N)	1,0709E+08	-21.533	-2,9116E+06	1,0713E+08

Global Contact		**Type:** No penetration (Surface to surface) **Components:** 1 component(s)

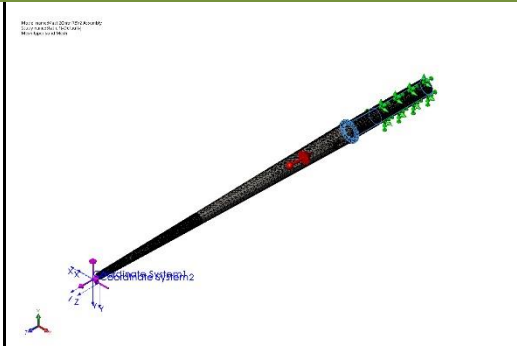
Mesh informatie

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points	4 Points
Maximum element size	281,051 mm
Minimum element size	56,2101 mm
Mesh Quality Plot	High
Remesh failed parts with incompatible mesh	Off

Mesh informatie details

Total Nodes	133810
Total Elements	66369
Maximum Aspect Ratio	112,62
% of elements with Aspect Ratio < 3	6,28
% of elements with Aspect Ratio > 10	37,9
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:12
Computer name:	BETTINK-NB33

Mesh Control Information:

Mesh Control Name	Mesh Control Image	Mesh Control Details
Control-1		**Entities:** 1 Solid Body (s) **Units:** mm **Size:** 67,2078 **Ratio:** 67,2078
Control-2		**Entities:** 1 Solid Body (s) **Units:** mm **Size:** 71,7901 **Ratio:** 71,7901

Resultante Krachten

Reaction forces

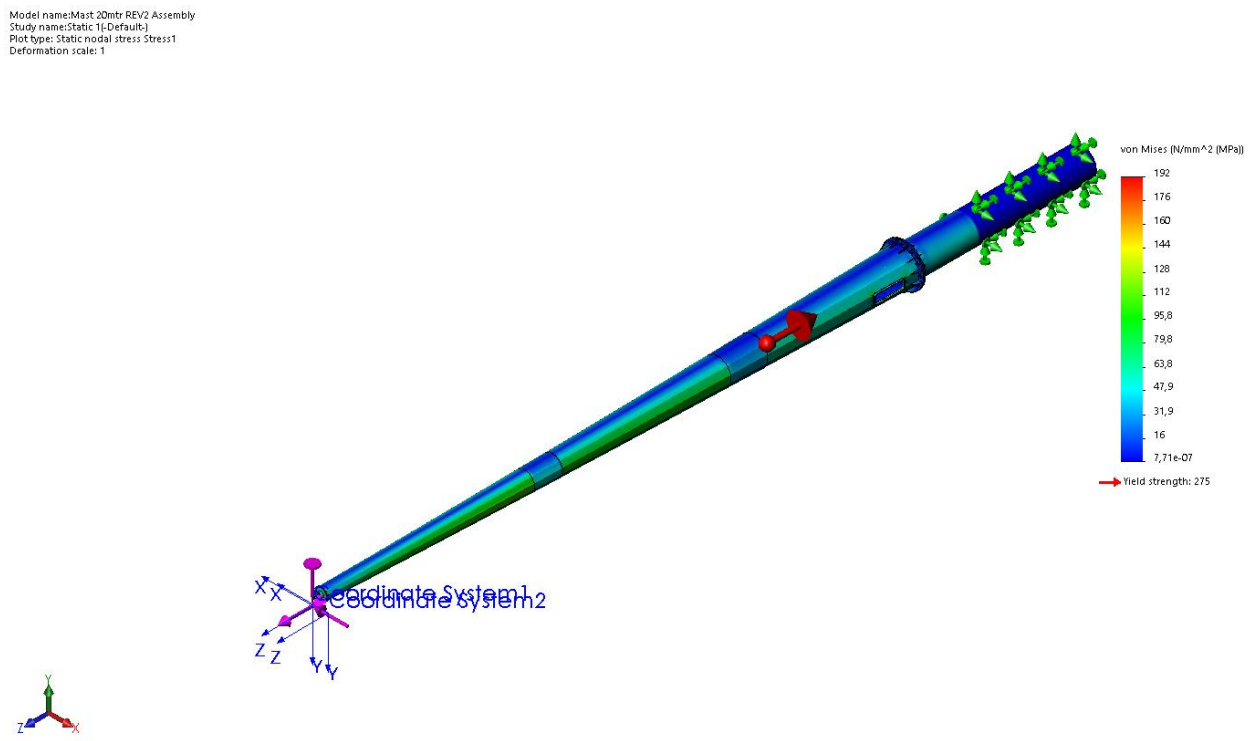
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	24.120,1	-0,00950834	40.417,4	47.067,5

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

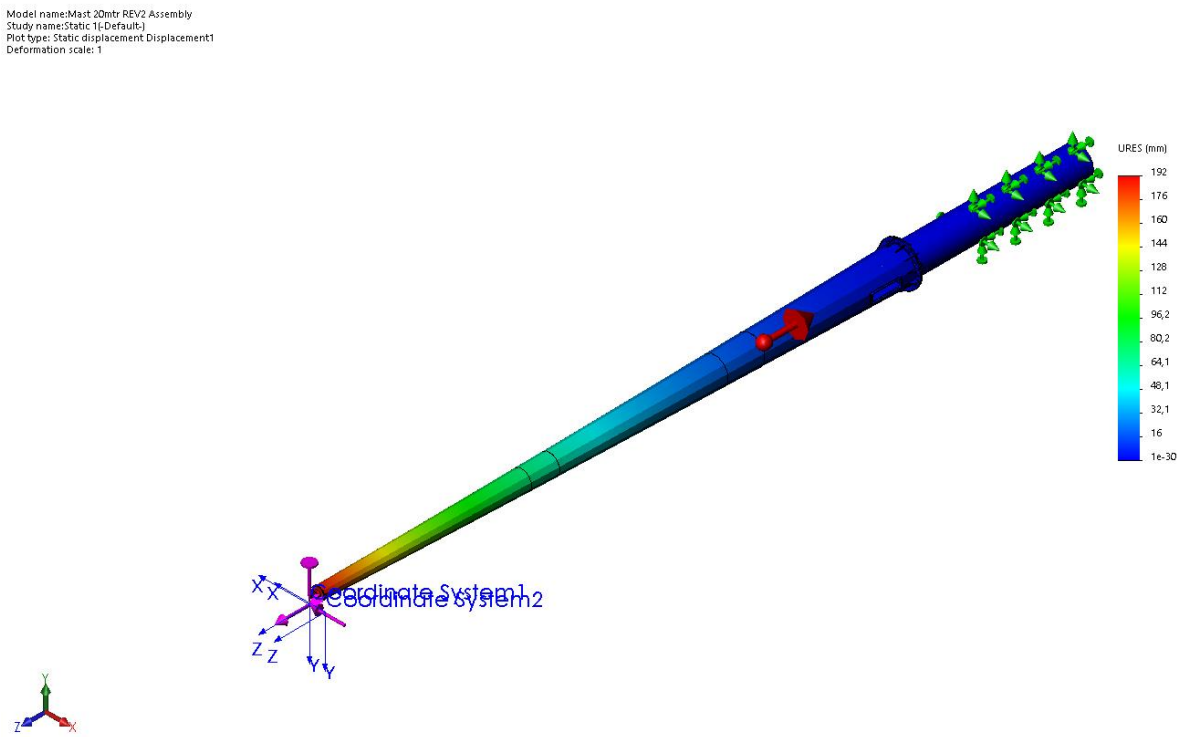
Studie Resultaten

Name	Type	Min	Max
Stress1	VON: von Mises Stress	7,71e-07 N/mm^2 (MPa) Node: 8736	192N/mm^2 (MPa) Node: 12527



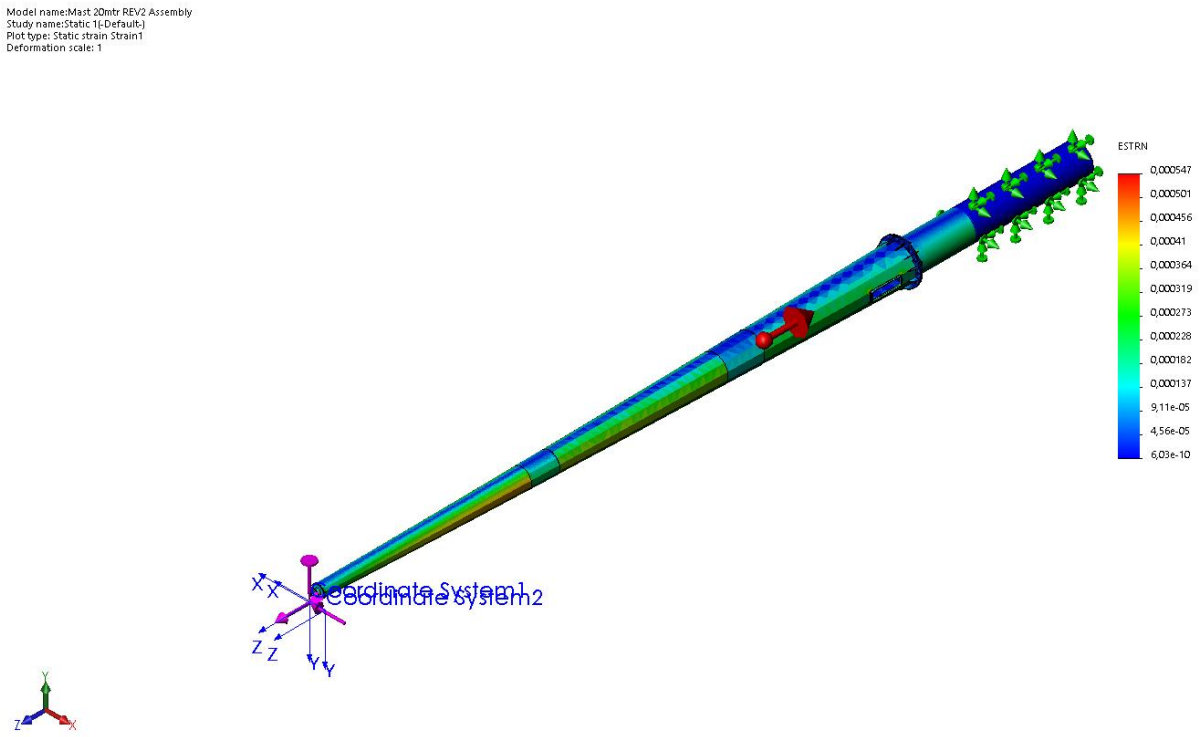
Mast 20mtr REV2 Assembly-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0mm Node: 1	192mm Node: 92210



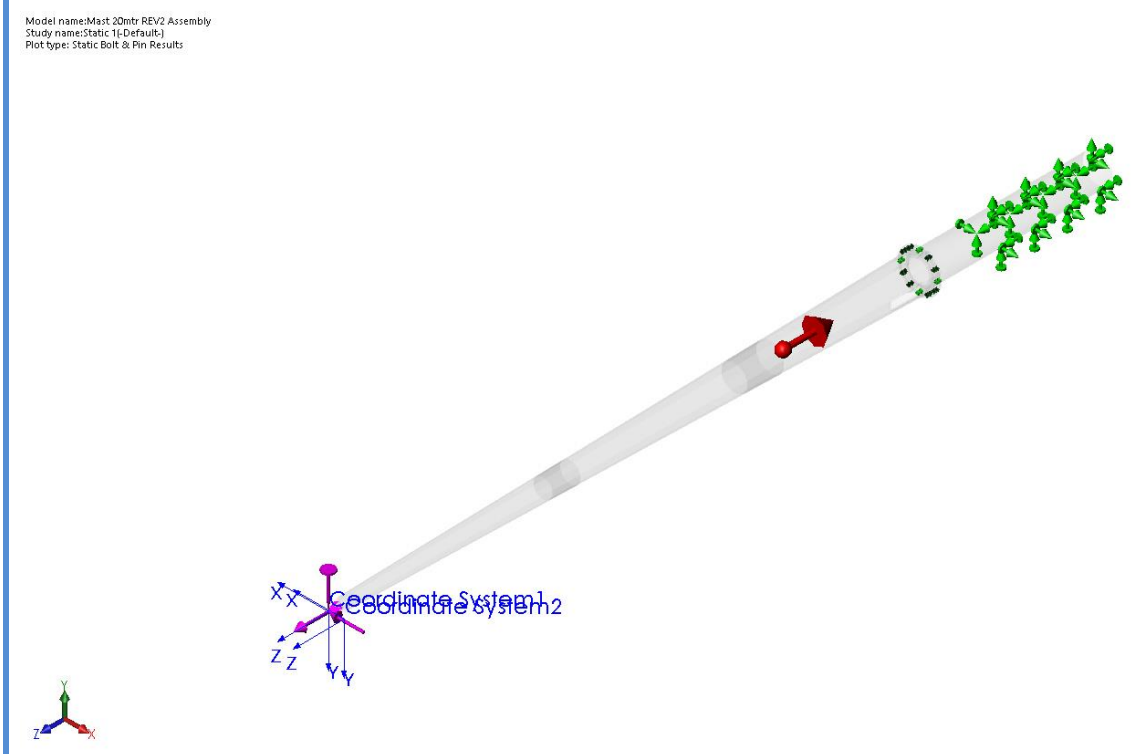
Mast 20mtr REV2 Assembly-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	6,03e-10 Element: 10223	0,000547 Element: 16268



Mast 20mtr REV2 Assembly-Static 1-Strain-Strain1

Name	Type
Pin/Bolt Check1	Static Bolt & Pin Results



Mast 20mtr REV2 Assembly-Static 1-Pin-Bolt Check-Pin-Bolt Check1

Conclusie

De spanningsreserve is gelijk aan de rekgrens/(gF*Sigma) = 275/(1.35*192) = 1,06.
Deze is groter dan 1 dus de toren is statisch goedgekeurd