2014 Us-China Workshop

Challenges for QTT structure

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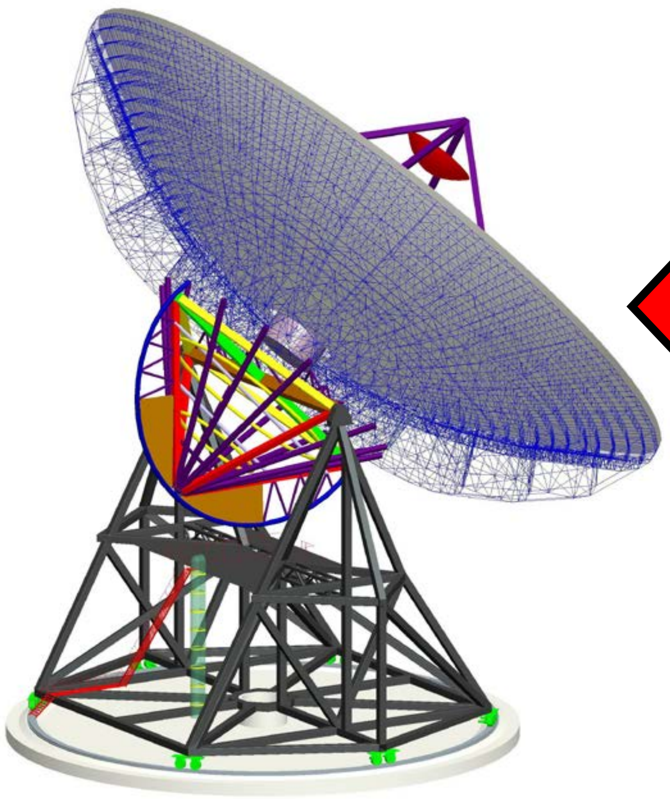
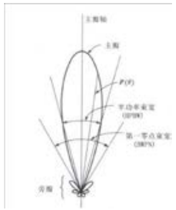
Aim to design a large diameter high frequency antenna (QTT)!



1. Best electrical performance
   - High gain
   - Low side-lobes



2. High pointing accuracy
   - Blind pointing ≤4arcs ,
     Repeatability precision
     ≤2.5arcs (6mm)

Telescope scheme- Antenna system

- Receiver System

Type	Band (cm)	RF Freq (GHz)	Focus	Feed	Poln	Science Goals
Single Pixel	100	0.15 – 0.6	Primary	Kildal	Linear	Pulsar, RRT
	30	0.6 – 4	Primary	Horn	Linear	Pulsar, RRT, HI, OH, Galaxies
	5	2 – 12	Greg.	Horn	Linear	Molecular spectrum, Galaxies; VLBI
	1	12 – 36	Greg.	Horn	Linear	Pulsar, H2O, NH3, VLBI
	0.6	36 – 50	Greg.	Horn	Linear	Molecular spectrum, High-z CO
	0.3	72 – 115	Greg.	Horn	Linear	Molecular spectrum, Galaxies
Dual-Band	13/3.6	2.2 – 2.5 8 – 9	Greg.	Horn	Circular	VLBI, space exploration, System measurement (3.6cm)
	3.6/0.9	8 – 9 30 – 34	Greg.	Horn	Circular	VLBI, space exploration
Multi-Pixel	15	1 – 2	Primary	PAF	Linear	Pulsar, RRT, HI, OH, Galaxies
	0.3	80 – 115	Greg.	Horn(7/13 Beam)	Linear	Molecular spectrum, Galaxies

Main Specifications of QTT

Panel accuracy (r.m.s)

- Main reflector: ≤0.3mm(use active surface); ≤0.2mm(long time adjustment)
  - single panel: ≤0.07mm
- Sub-reflector: ≤0.07mm
  - single panel: ≤0.03mm

Azimuth track (r.m.s)

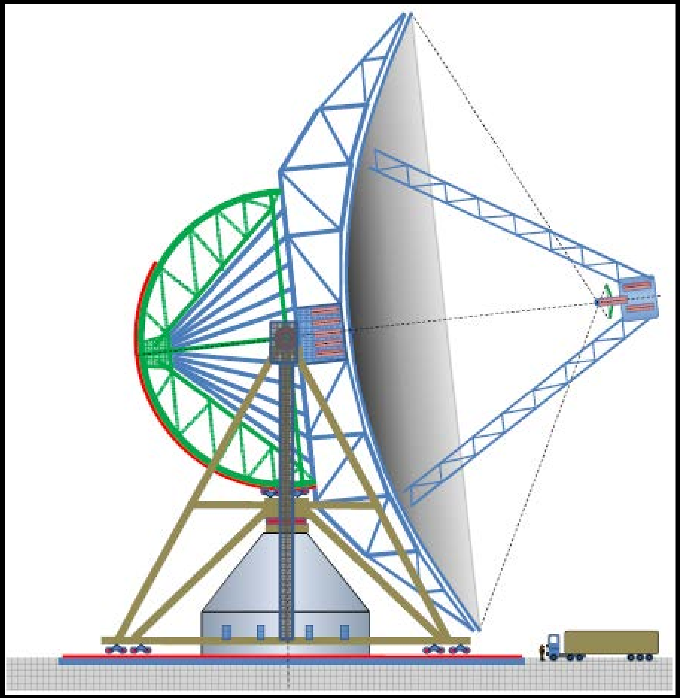
↓

Flatness ≤0.2mm; Flatness at weld joints ≤0.1mm

Pointing accuracy (r.m.s)

↓

Blind pointing ≤4arcs , Repeatability precision ≤2.5arcs (6mm)



Telescope scheme- Antenna system

- QTT Electric Performances

Band	100cm	30cm	5cm	1cm	6mm	3mm
Efficiency (Optimum El.)	60%	63%	63%	60% ~50%	54% ~30%	30% ~12%
System Noise (k)	30	25	20	20	45	100

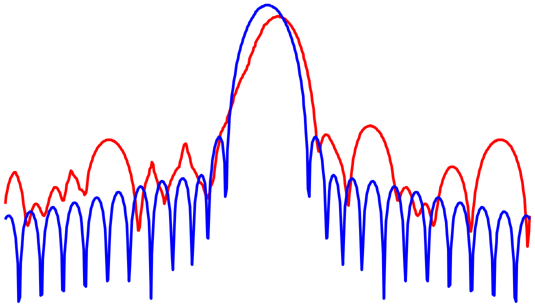
When design and fabrication antenna the following questions must be considered

- **Weight**
- **Resonance frequency**
- **Precision of shaft systems**
  - Elevation bearings error (influence elevation axis precision)
  - Azimuth bearings error (influence azimuth axis precision)
  - Wheel error (influence azimuth axis precision)
  - Azimuth track error (influence azimuth axis precision)
  - Subreflector adjustment mechanism error (influence electric axis precision)
  - Feed changing mechanism error (influence electric axis precision)
- **Reflector surface error**
  - Gain
- **Servo control scheme**

. . . . . .

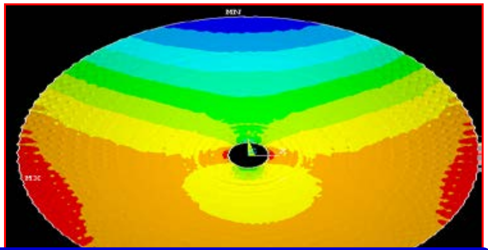
Structure challenges!

Structure meet the best electrical performance requirement (QTT)



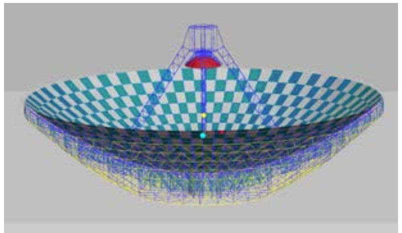
Best electrical performance —antenna→

- High gain
- Low side-lobes



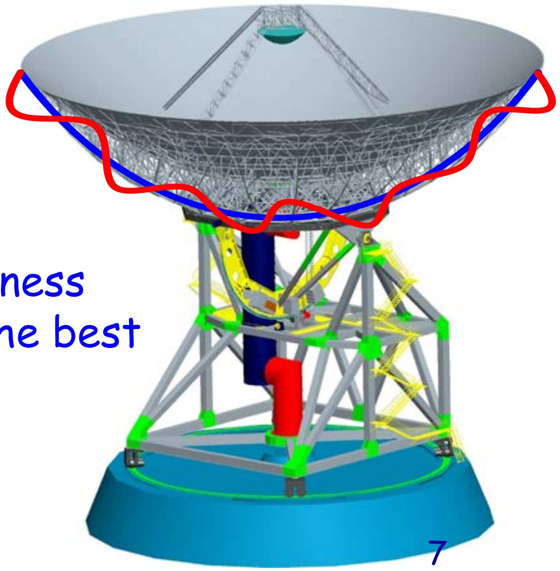
phase uneven distribution

↓ structure



- **"Homology" (EL:7°-89°)**
- **High reflector surface accuracy**

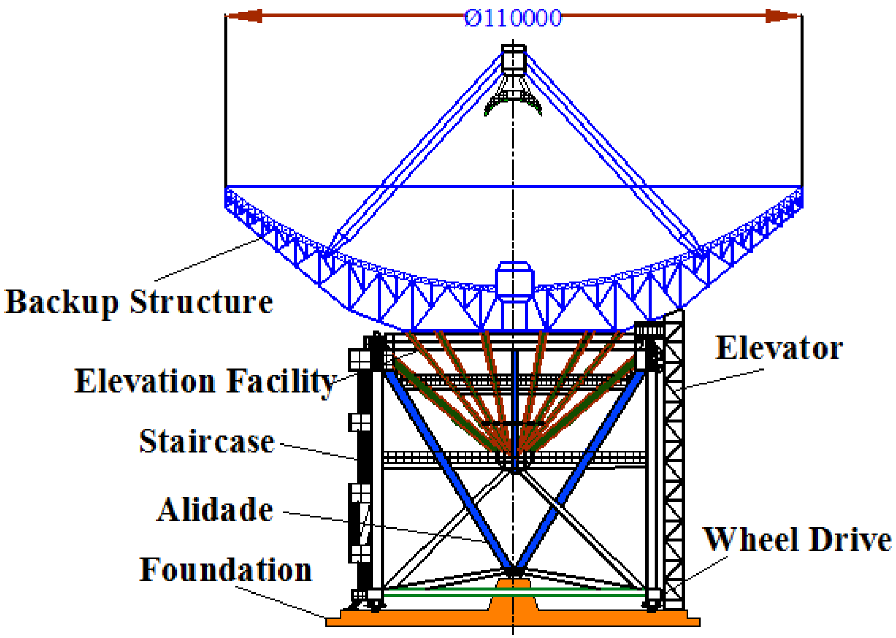
reflector: ≤0.3mm(use active surface)
≤0.2mm(long time adjustment)



The critical issue for structure design → the optimal structural stiffness distribution ways to meet the best electrical performance

optimization: topology, structure type, shape

Weight vs. stiffness



diameter ↑-> antenna softening

stiffness↑ -> meet requirement

↓

weight ↑

weight goal of 4,500 tons for QTT !

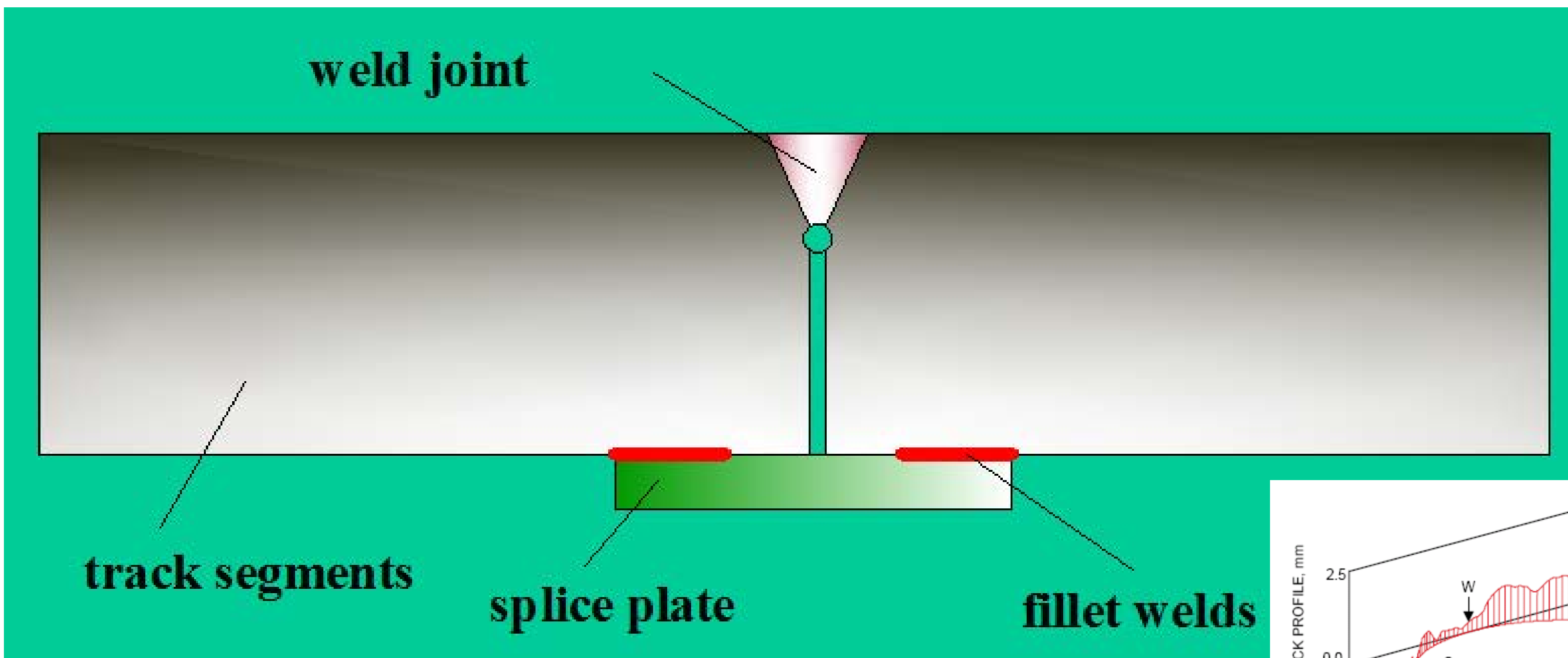
table hints how to achieve

Diameter	110m
Rotating in EL	**2,550,000**
Reflector Panels	300,000
Backup Structure	900,000
Elevation Wheel	900,000
Ballast	300,000
Mechanical Components	100,000
Payload	50,000
Rotating in AZ	**1,300,000**
Alidade Structure	800,000
Mechanical Components	250,000
Payload	250,000
Fixed	**650,000**
Mechanical Components	150,000
Structure	500,000
Total Weight [kg]	4,500,000

Challenges for azimuth track

Track flatness requirements:

- Flatness: 0.2mm
- Joints: less than 0.1mm
- Track diameter : 70m



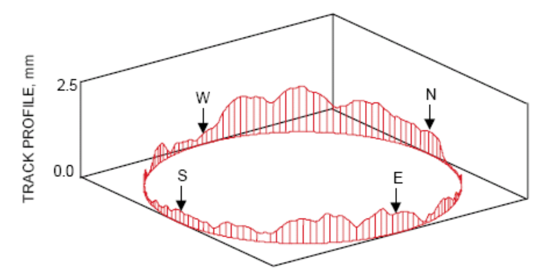
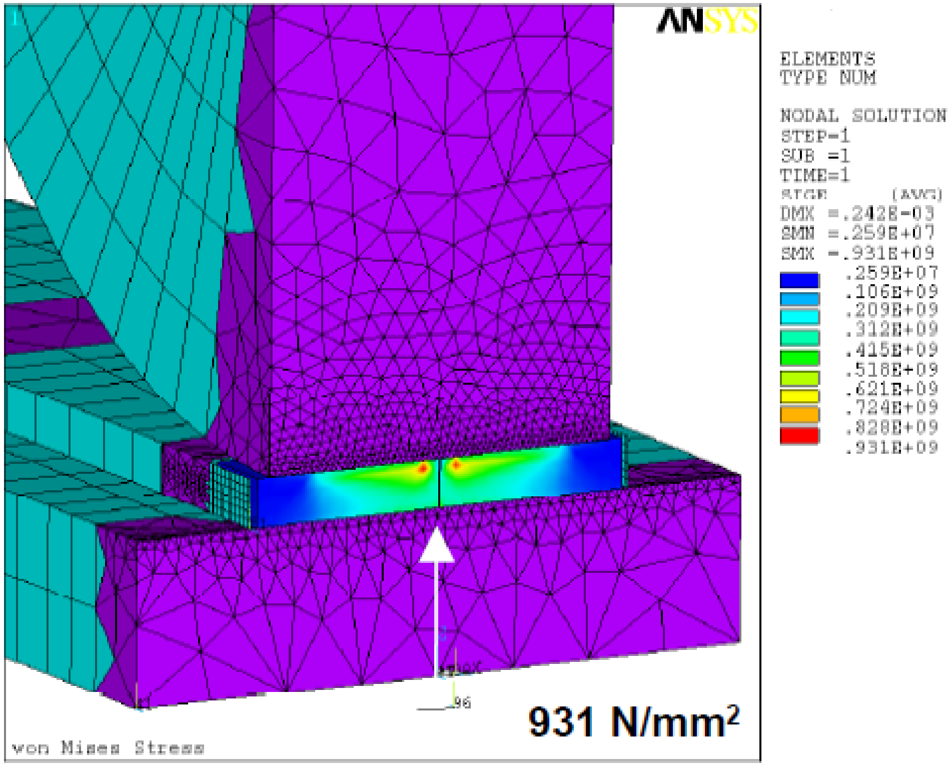


Fig. 1. Track profile of the DSS-26 antenna.

Challenges for azimuth track

- Discontinuous tracks with mitered joints



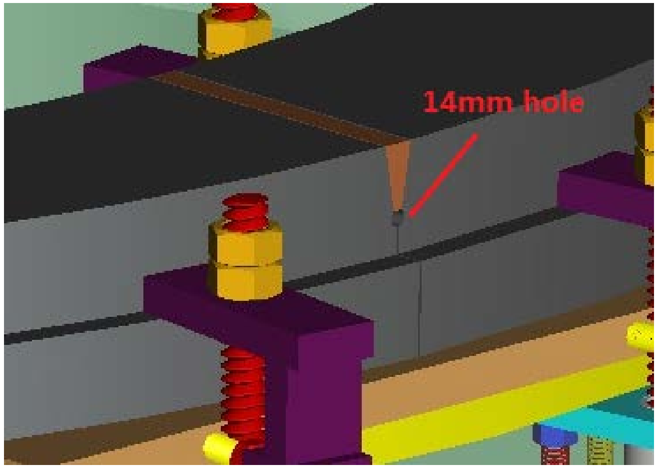
Stress raisers at mitered gap

Finite elements calculations of the stress in the wear plate with gaps

The discontinuous track concept avoids any welding, at the expense of stress raisers and related failures

Challenges for azimuth track

- Continuous tracks



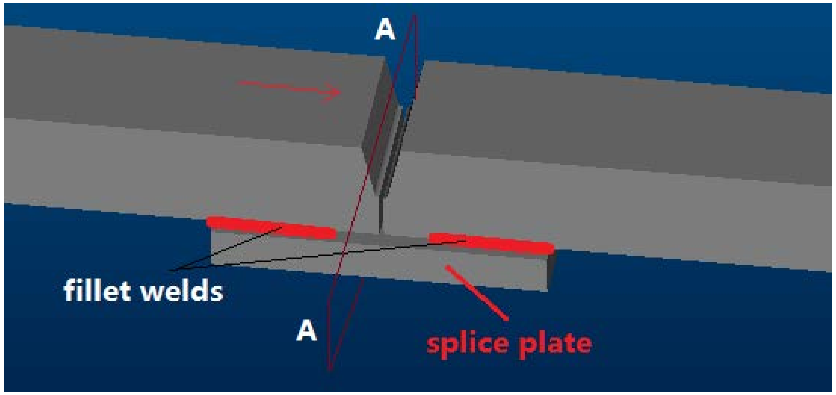
Continuous tracks with welded joints

- The continuous track concept looks for a compromise between required hardness at the track surface and weld-ability of the track, at the expense of the welding risk of materials difficult to weld, and related cracks during welding or before the end of the proposed lifetime by fatigue

Challenges for azimuth track

◆ **The critical issue for the continuous track?**

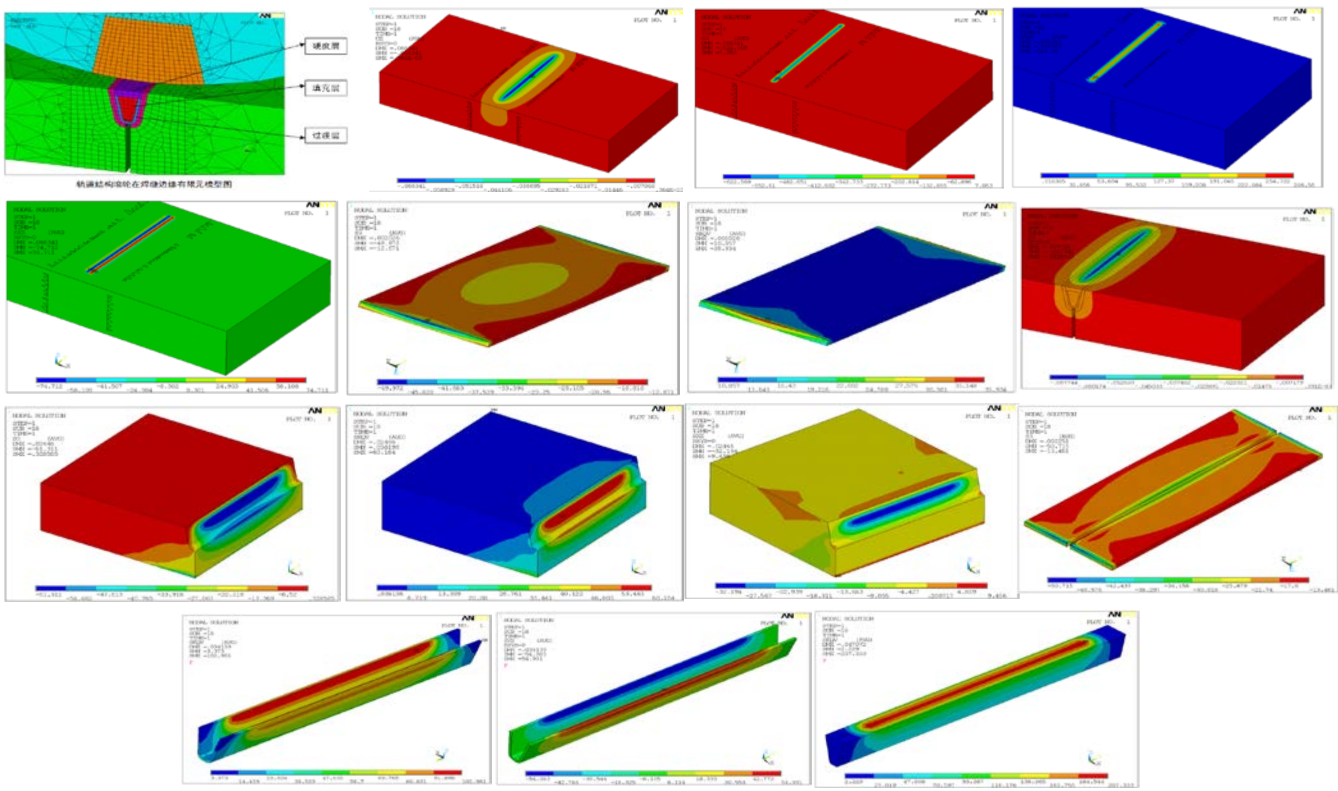
Welding of the tracks



- Track materials usually use alloy steel
- The surface of alloy steel was heat treated to improve surface hardness, in order to withstand antenna heavy loads
- The high hardness alloy steel is difficult to weld, and related cracks during welding or before the end of the proposed lifetime by fatigue

Challenges for azimuth track

- **static FEA** (finite element analysis)
  - track:500mm*200mm,250t;wheel:1200mm*400mm

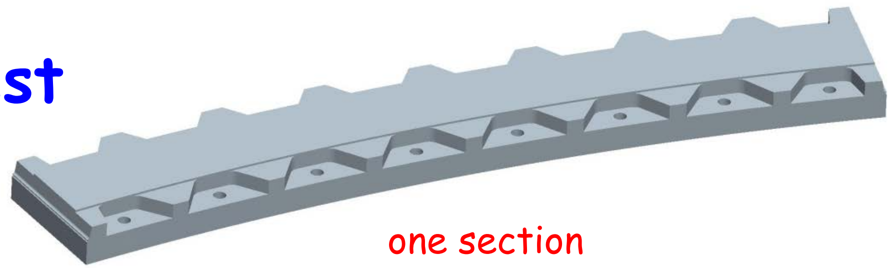


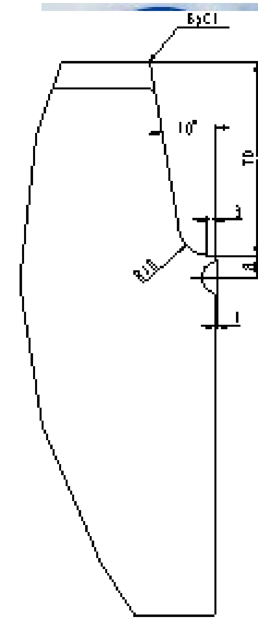
Track welding craft should be investigated!

Challenges for azimuth track

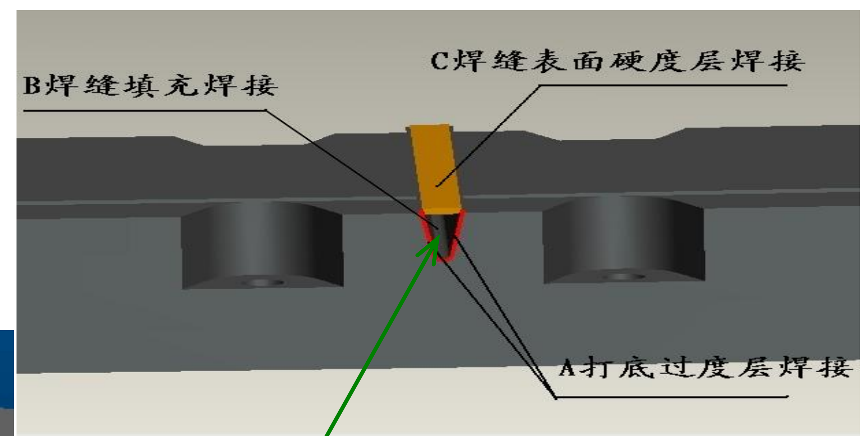
◆ Track welding test

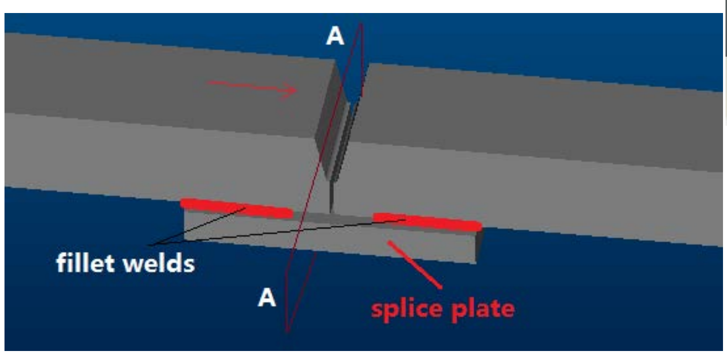
Trial preparation:





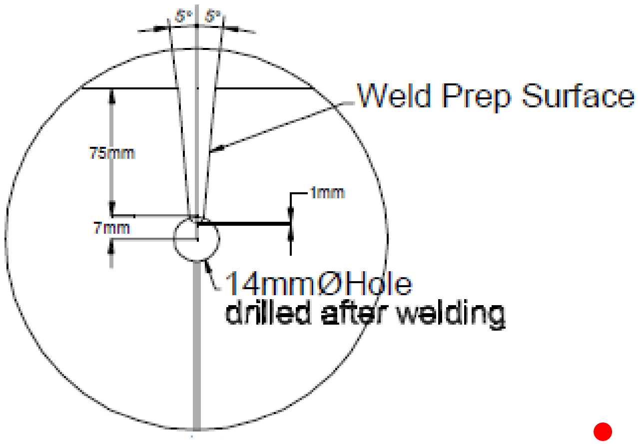
- Track: section type
- Diameter of track: 25-m(SD 40)
- Track material :42CrMo
- Hardness: HRC44
- Surface tolerance: <0.02mm
- Thick: 200mm
- Wide: 350mm

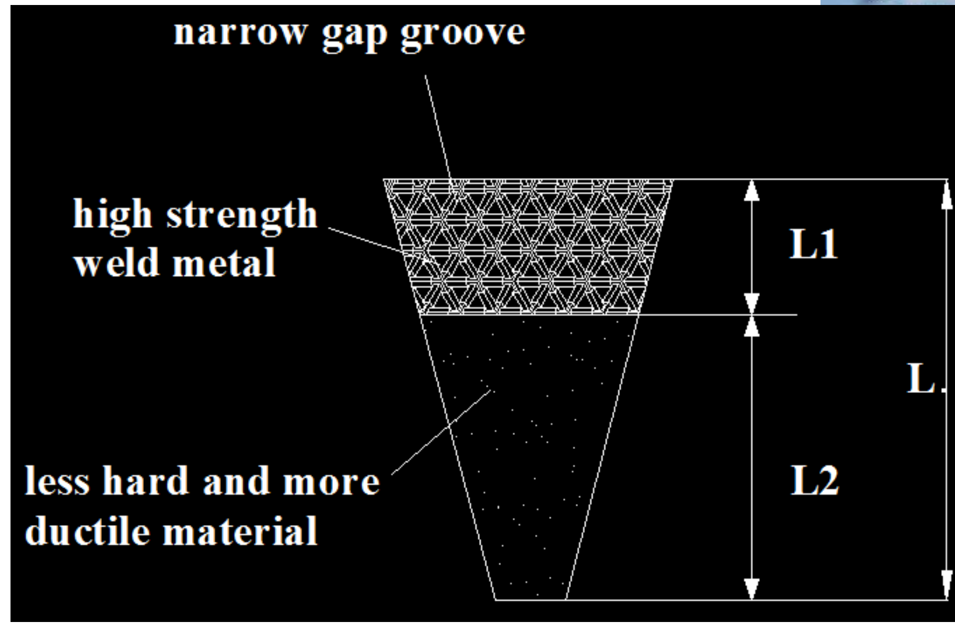


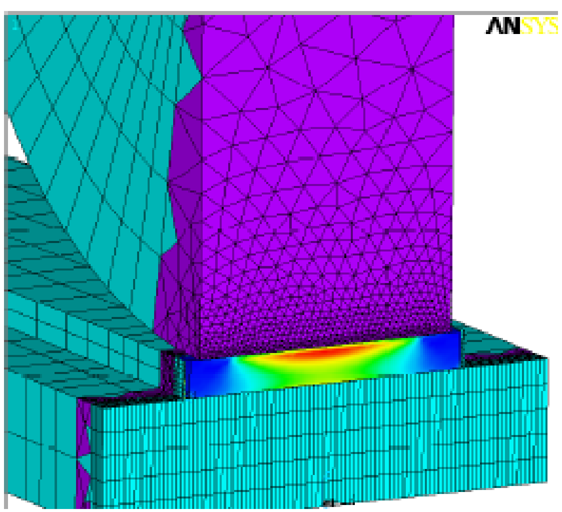


Challenges for azimuth track

- **Welding procedure**



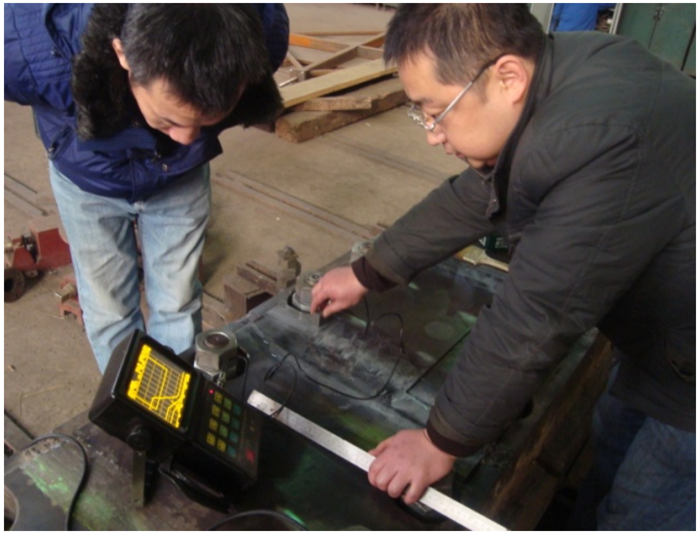




finite element calculations

- The narrow gap groove weld across the top surface extends L down
- The high strength weld metal is used only in the top L1. A less hard and more ductile material is used for the rest of the weld
- Using mechanical method to correction weld deformation
- Welding joint was heat treated to release stress
- Hole was drilled through the full width of the track at the base of the narrow gap groove weld in order to reduces the stress raisers
- Ultrasonic, Tension, Bend, Charpy impact test

Challenges for azimuth track



Challenges for azimuth track

◆ Results of first stage

Twice welding carried out in stage one:

- First joint: large deformation(1.5mm), appear cracks
- Second joint: flatness(0.21mm), surface cracks

Possible reasons:

- Unreasonable heat treating time and temperature gradient chosen

So the heat treating craft should be improved

first welding joint

second welding joint

Challenges for azimuth track

◆ Results of second stage

Efforts:

- Changing pre-deformation amount

Results:

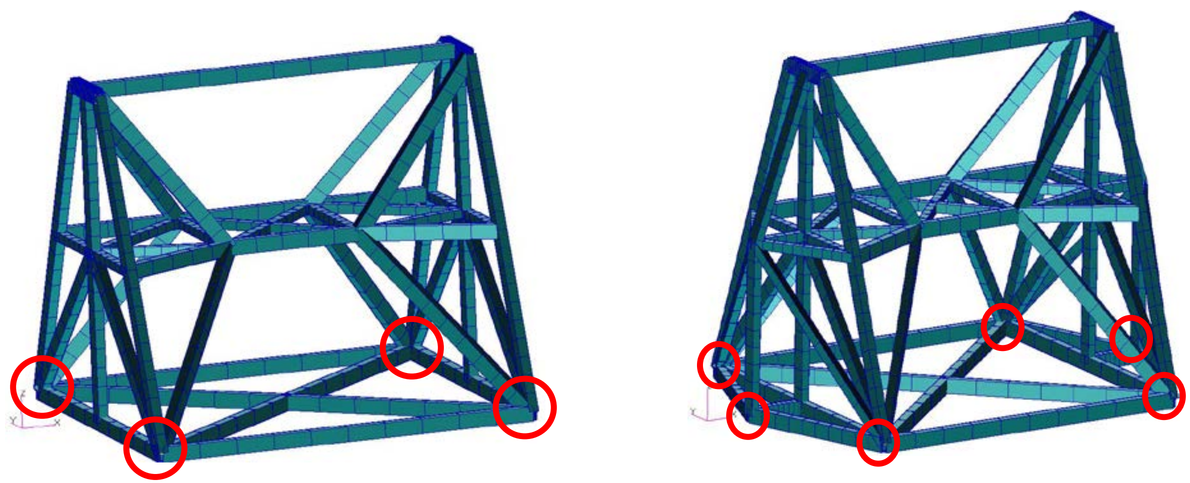
- Flatness: 0.26mm
- Ultrasonic inspection: no cracks
- Joints quality, surface hardness: required

Future:

- A larger dimensions track will be designed and tested!

Challenges for alidade

4-point versus 6-point? (2012 International Advisory Workshop)



- Decrease alidade deformation, reduce wheel and track loads
- Difference: two symmetrical supporting points were added to the track in order to share the alidade's loads

Challenges for alidade

- **Alidade**

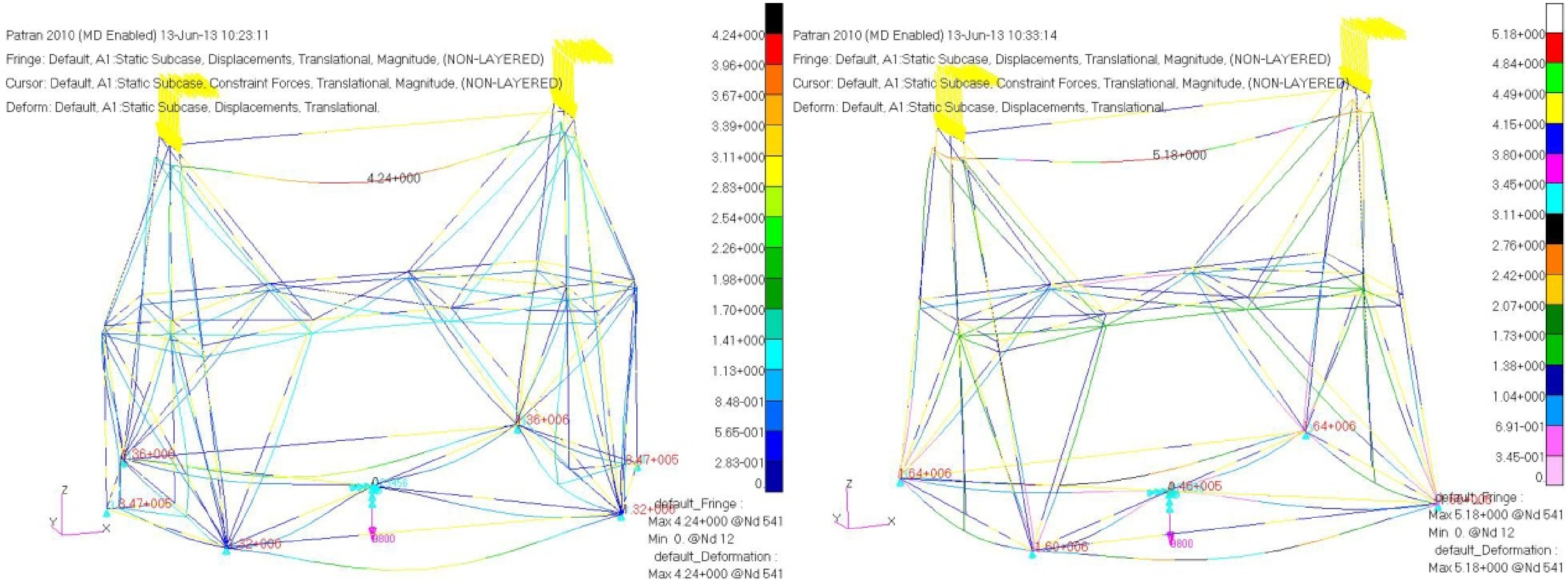
  4-point versus 6-point?

  - Compare two structures using simulation analysis
  - Preliminary results

Challenges for alidade

◆ FEA (finite element analysis)

Compare 4-point with 6-point structure



Maximum supporting loads for each points of 4-point and 6-point structure

Challenges for alidade

◆ FEA (finite element analysis)

	Weight (t)	front supporting point (single) (t)	back supporting point(single) (t)	pintle (t)	sideways supporting (single) (t)	alidade loads (t)
4-point alidade	206	163.577	167.127	14.875		470
6-point alidade	264.4	135.066	138.590	14.183	86.474	470

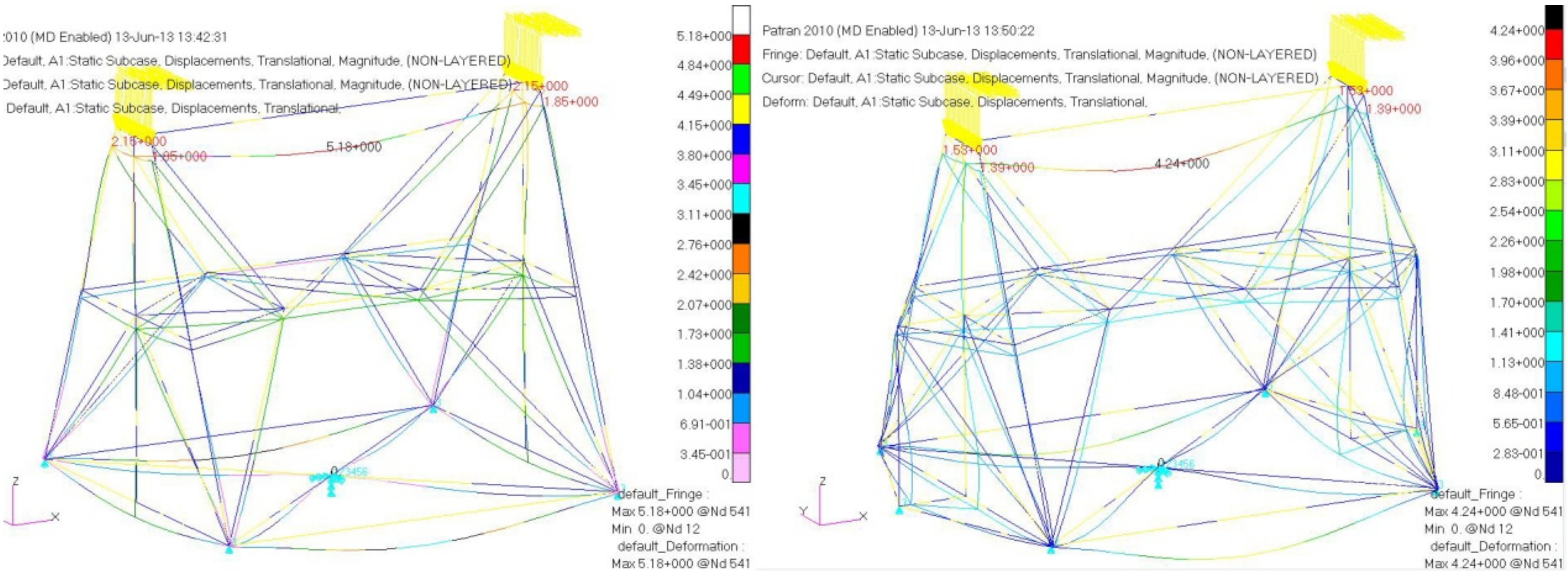
calculation results

- The ability for 6-point structure to share the wheel load is limited, in addition it not very good to share the alidade load

Challenges for alidade

◆ FEA (finite element analysis)

Compare 4-point with 6-point structure



deformation value of bearing block installation plane

Challenges for alidade

◆ FEA (finite element analysis)

			deformation (mm)			
			X	Y	Z	
4-point alidade	node number	120	-0.843	-0.477	-1.924	2.154
		121	-0.239	-0.363	-1.795	1.847
		98	-0.177	-0.419	-2.367	2.41
6-point alidade	node number	120	-0.439	-0.354	-1.426	1.534
		121	-0.068	-0.269	-1.361	1.389
		98	0.104	-0.311	-1.514	1.549

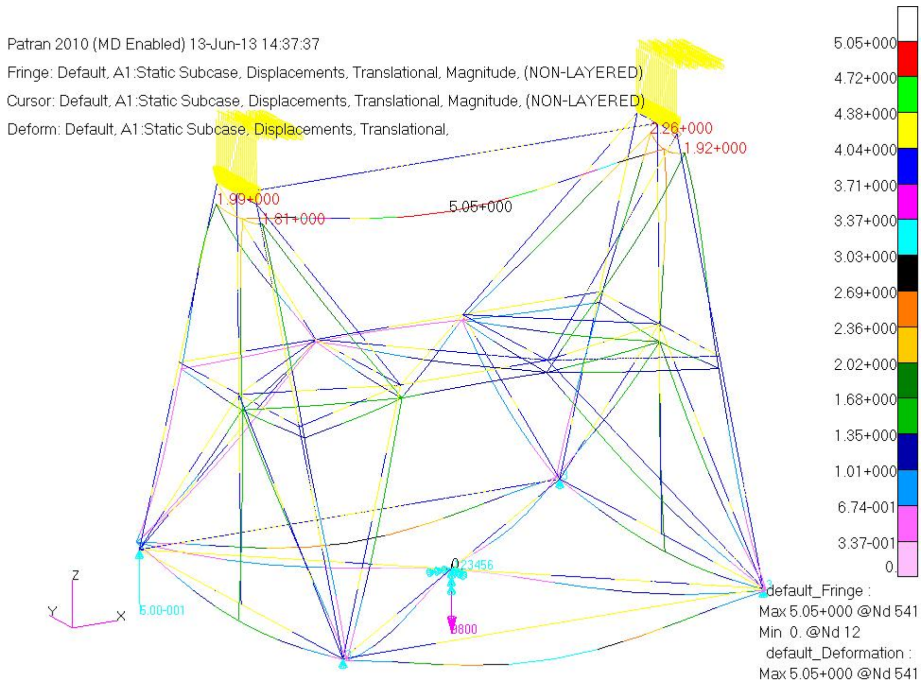
calculation results

- 6-point structure could improve the deformation of bearing block installation plane, but the effect is not obvious

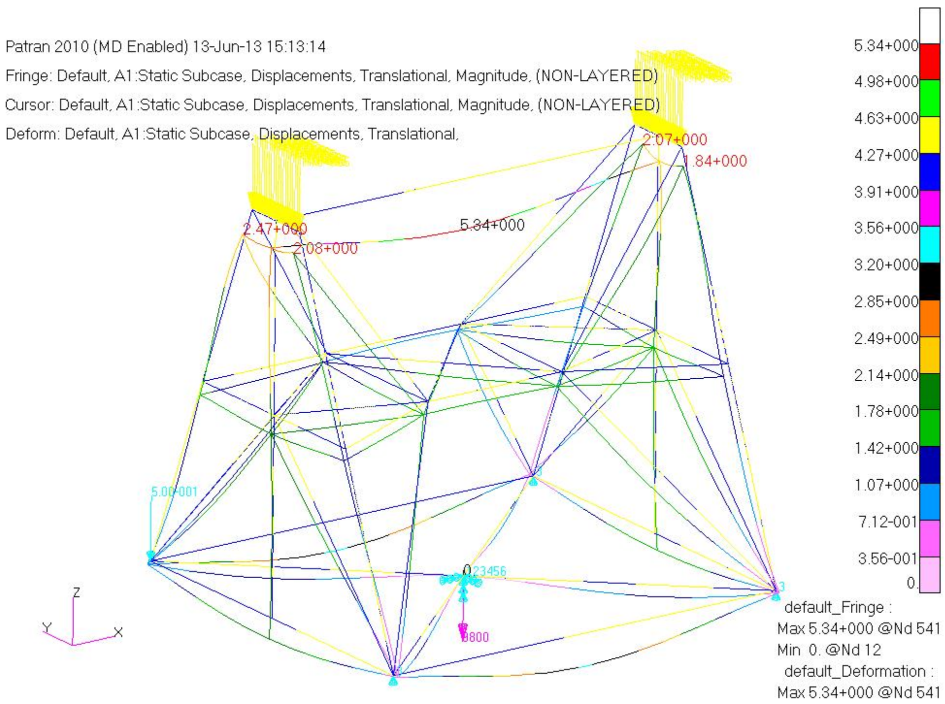
Challenges for alidade

◆ **FEA (finite element analysis)**

Deformation of bearing block installation plane is influenced by track flatness



node 28 Z 0.5mm



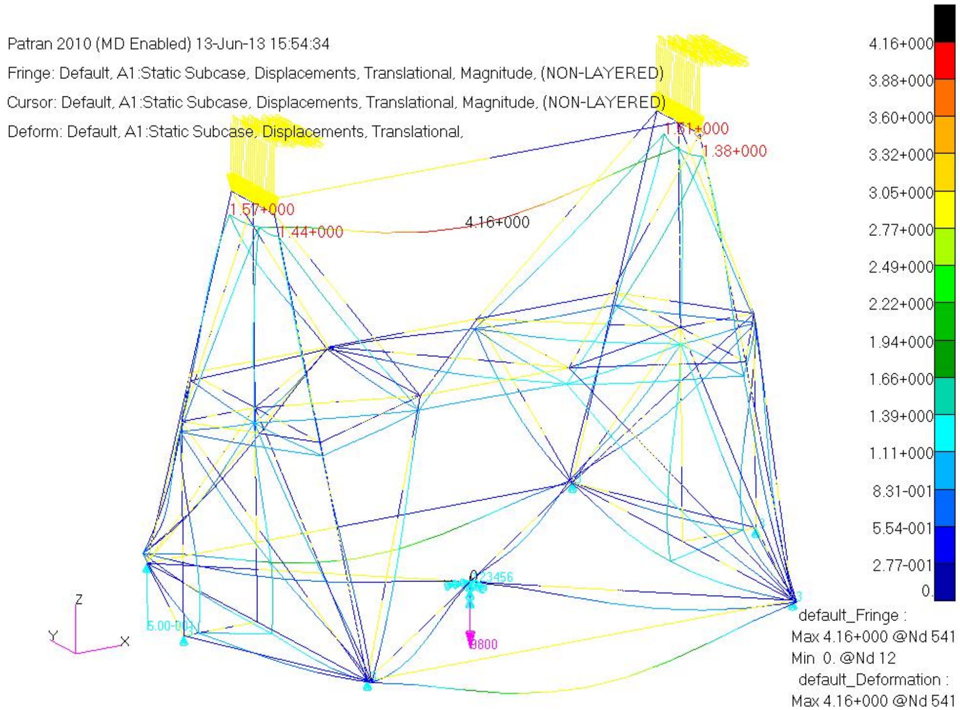
node 28 Z -0.5mm

calculation of 4-point structure

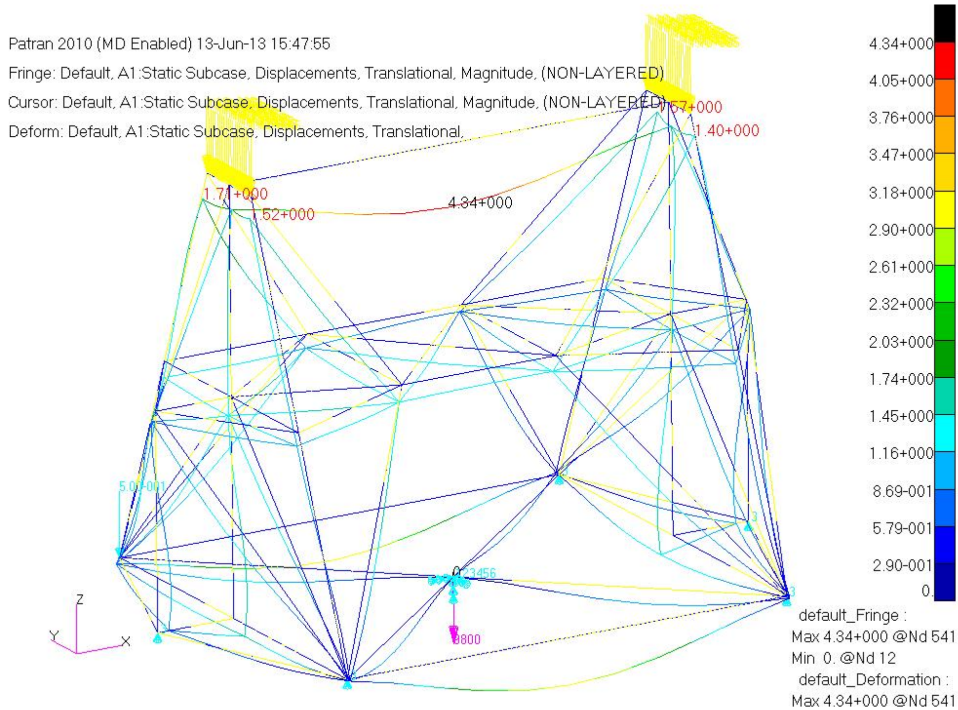
Challenges for alidade

◆ FEA (finite element analysis)

Deformation of bearing block installation plane is influenced by track flatness



node 28 Z 0.5mm



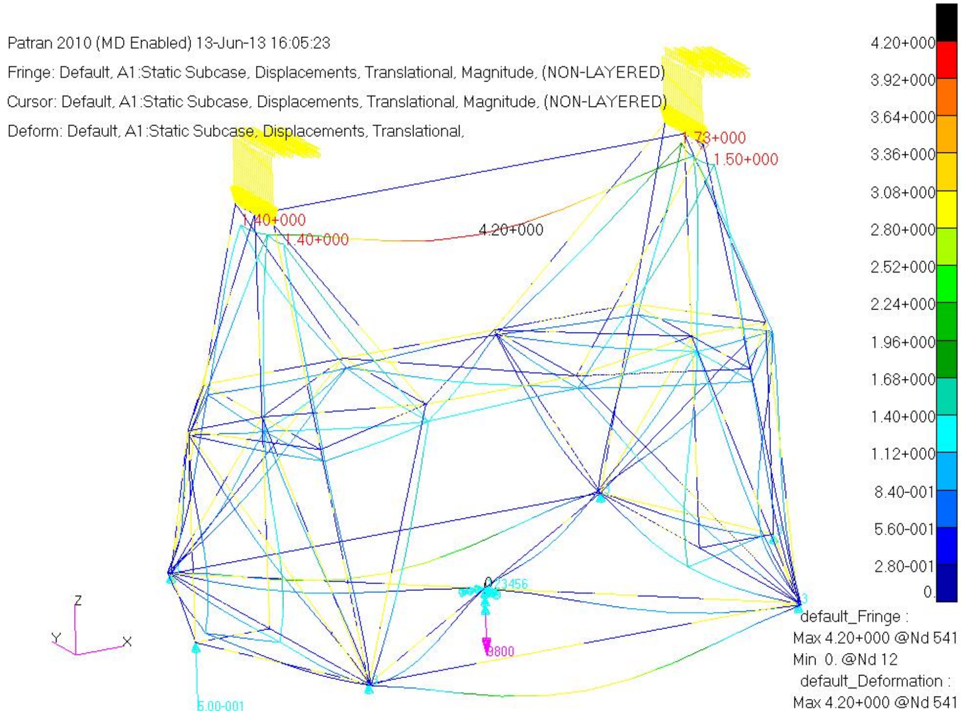
node 28 Z -0.5mm

calculation of 6-point structure

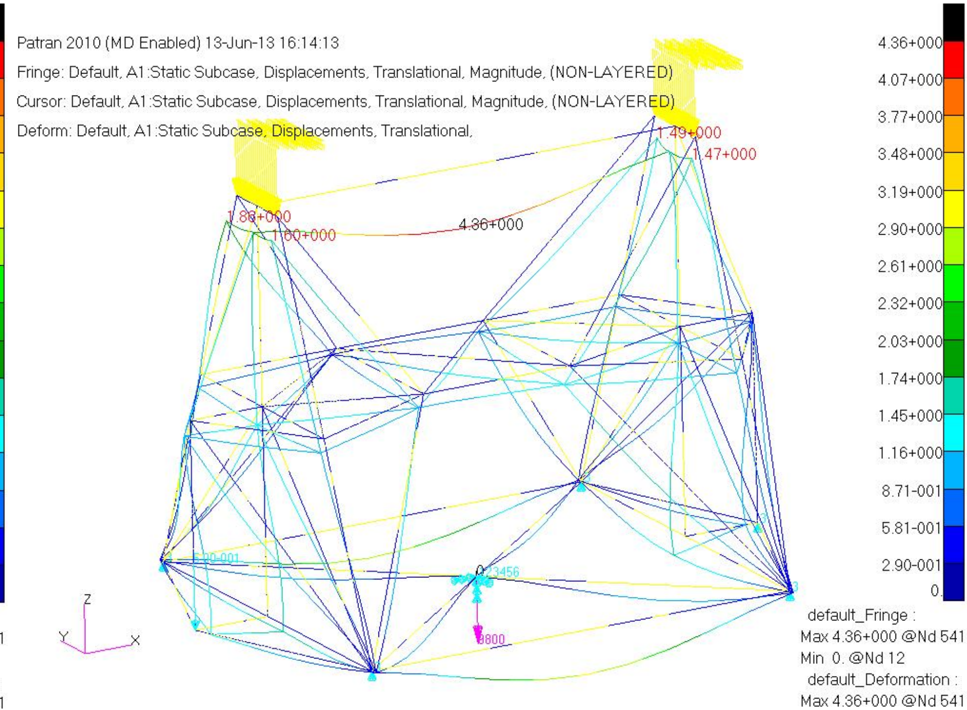
Challenges for alidade

- **FEA (finite element analysis)**

Deformation of bearing block installation plane is influenced by track flatness



node 556 Z 0.5mm



node 556 Z -0.5mm

calculation of 6-point structure

Challenges for alidade

- **FEA (finite element analysis)**

Results:

- Because of track flatness, the bearing block installation plane may produce an asymmetry change
- Antenna pointing may influenced by track surface change

Challenges for alidade

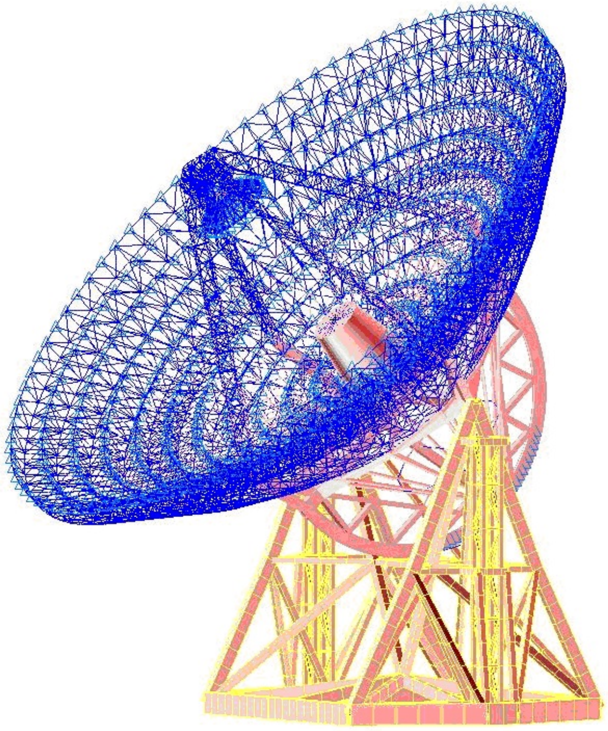
◆ Preliminary, qualitative results

- Compare with 4-point structure, the ability of 6-point structure for sharing the wheel load is limited, but it can decrease the deformation of bearing block installation plane
- Because of the influence of the track flatness, the interference factors of 6-point structure will increase, which may bring a certain influence on pointing correction
- For the additional two points, it may increase the machining and installation cost. So compared with the improvement of structure accuracy, it may become an hindrance rather than a benefit.

For the quantitative study of QTT alidade, it need specific scheme of antenna structure, and this work will be carried out in the future!

Challenges for reflector panel accuracy

Reflector surface error influenced by:

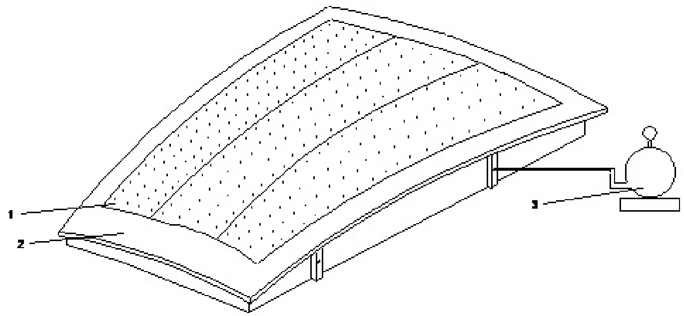


- Panel fabrication error
- Gravity deformation
- Backup structure
- Active surface actuators

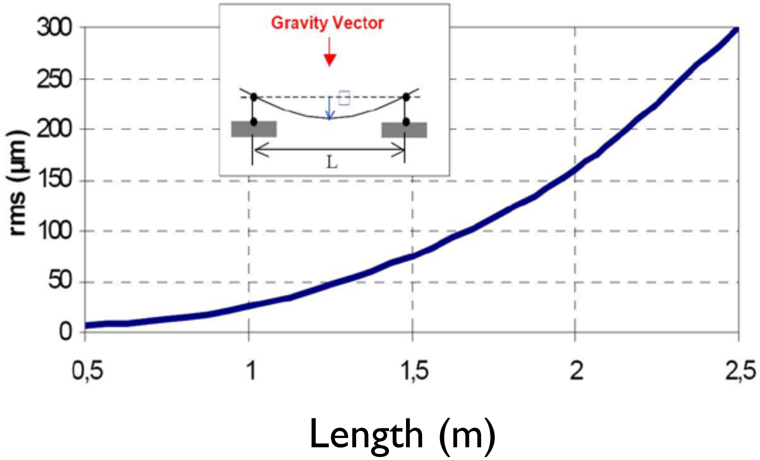
……

Challenges for reflector panel accuracy

◆ Panel fabrication craft



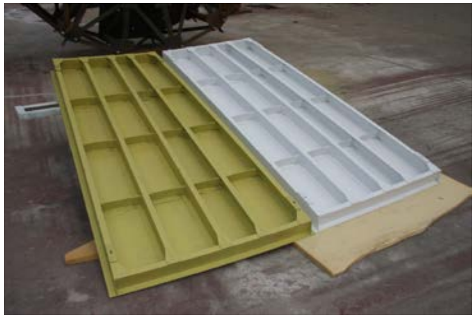
1. aluminum skins
2. negative pressure model
3. vacuum pump



negative pressure + glue + riveting

⬇

connect aluminum skins to rib frame



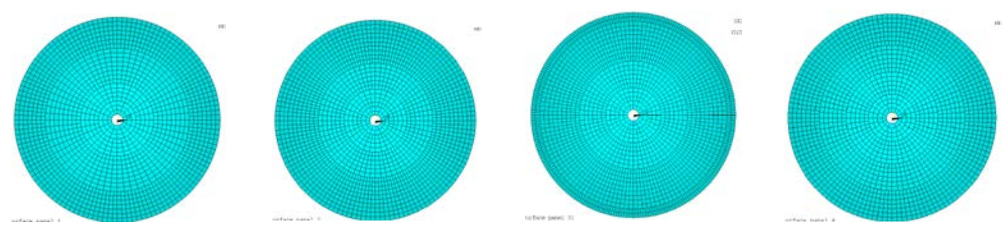
The panel fabrication craft in China:

For single panel area : 5m^2
Accuracy (r.m.s): 0.1mm

Challenges for reflector panel accuracy

◆ Primary reflector dividing scheme

Panel accuracy (r.m.s) {
- main reflector: ≤0.3mm(use active surface);
- ≤0.2mm(long time adjustment)
- single panel: ≤0.07mm



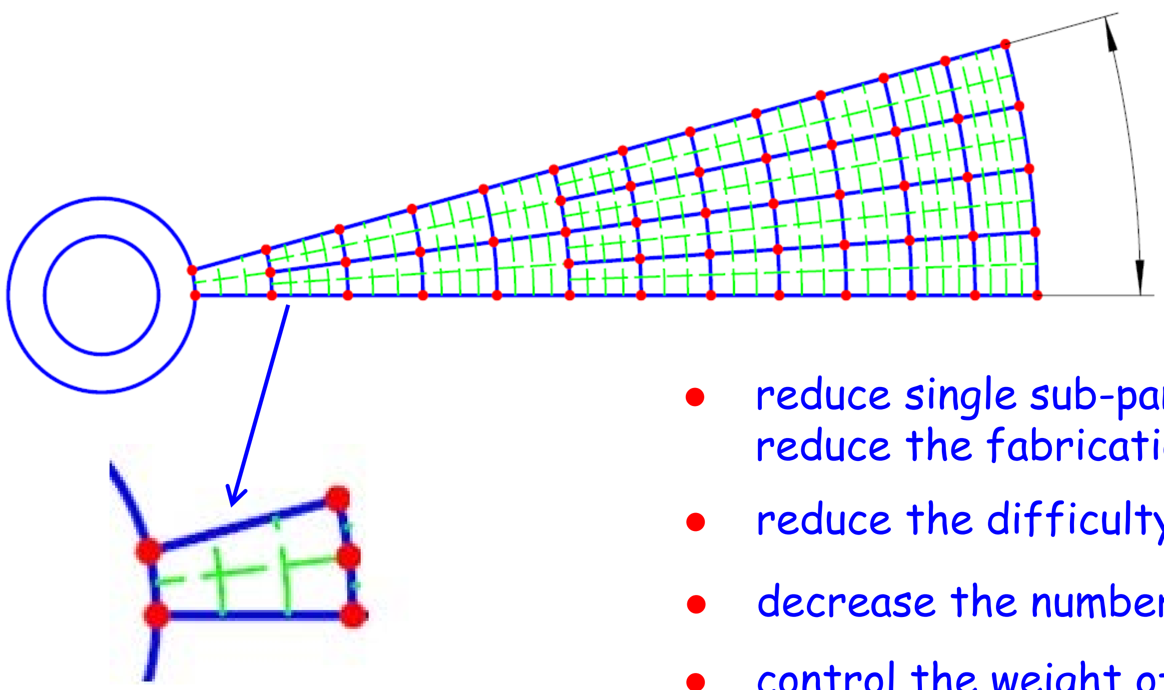
- According to traditional method QTT: 26 rings, from inside to outside 64×2、96×2、192×8、384×15 total 7616 panels, need about 7500 actuators(ave single panel: 1.396m^2,Amin=0.975m^2,Amax=2.01m^2)

Drawbacks {
- panel number too many
- Increase the difficulty of BUS design
- Increase the number of actuators
- Increase the weight of antenna

Challenges for reflector panel accuracy

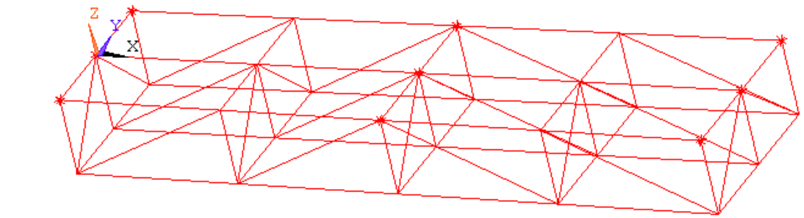
◆ Primary reflector dividing scheme

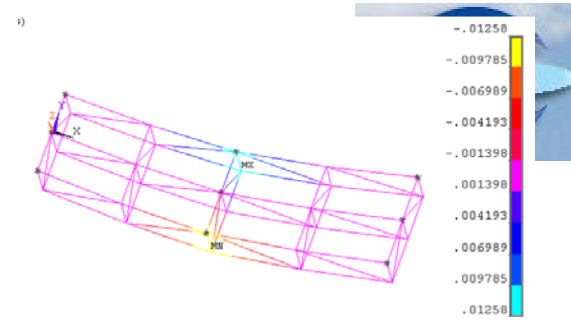
- Combination panel scheme may be the suitable choice



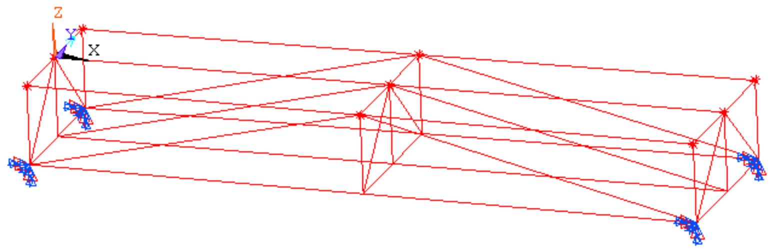
- reduce single sub-panel area, this can reduce the fabrication difficulty
- reduce the difficulty of BUS design
- decrease the number of actuators
- control the weight of antenna

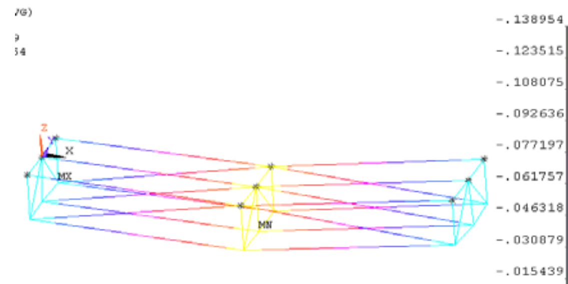
4 combination panel schemes & FEA results



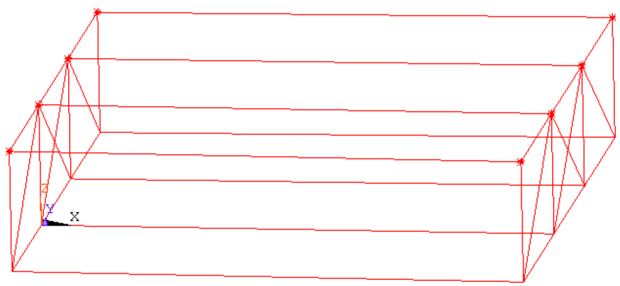


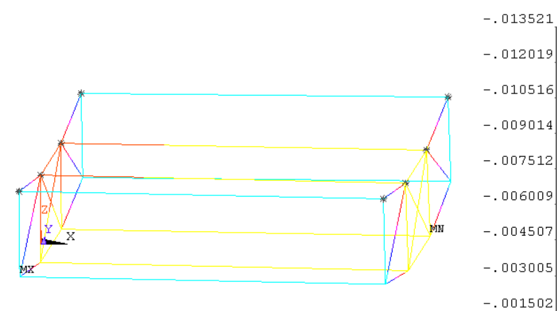
2x2-1 scheme



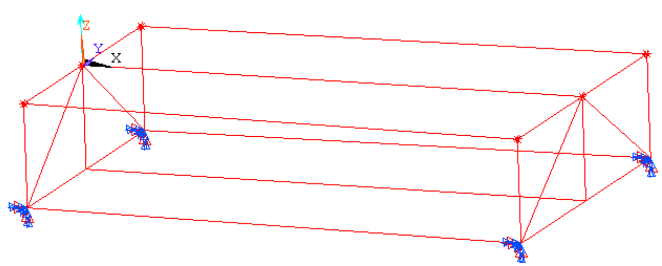


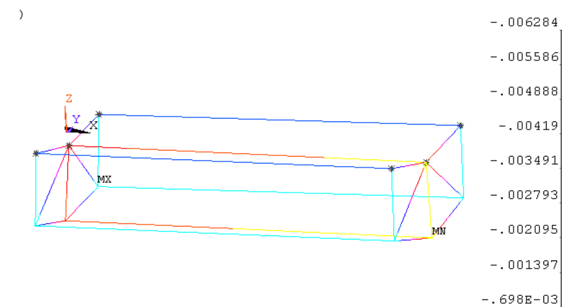
2x2-2 scheme





1x3 scheme





1x2 scheme

Challenges for reflector panel accuracy

- **Primary reflector dividing scheme**

panel form	direction of gravity	deformation of Zmin (mm)	deformation of Zmax (mm)	combination panel weight (Kg)	frame weight (Kg)	frame/combination panel
2x2-1	X	−0.00445	0.00524	100	153.34	1.5334
	Y	−0.01258	0.01258			
	Z	−0.042	0.042			

panel form	direction of gravity	deformation of Zmin (mm)	deformation of Zmax (mm)	combination panel weight (Kg)	frame weight (Kg)	frame/combination panel
2x2-2	X	−0.00076	0.00107	100	126.95	1.2695
	Y	−0.042	0.042			
	Z	−0.0139	−0.0154			

calculation results

Challenges for reflector panel accuracy

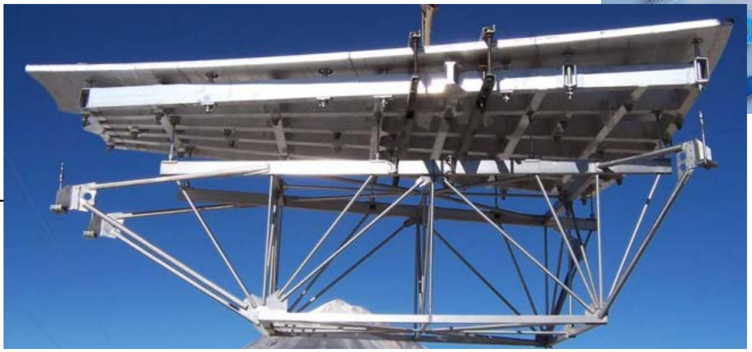
◆ **Results**

- A combination panel its about 140-150tons;
- If combination panel connected with sub-frame, the weight of sub-frame is about 2-2.5times of combination panel

Future:

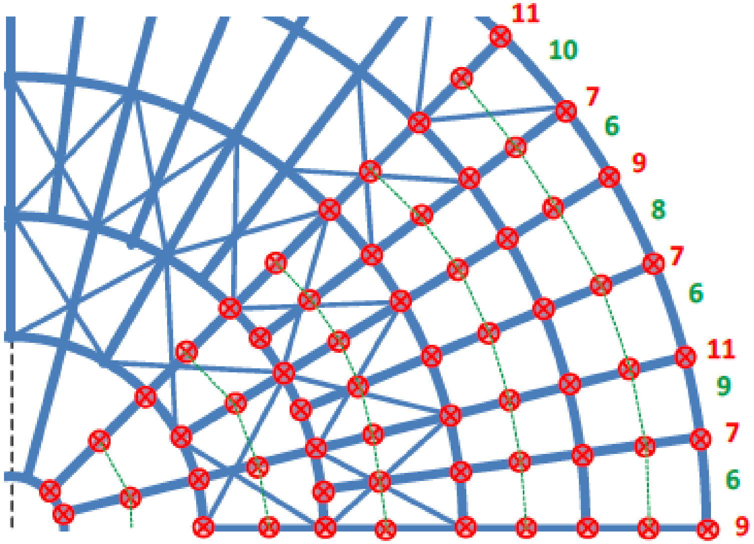
- Optimization panel schemes

Combination scheme

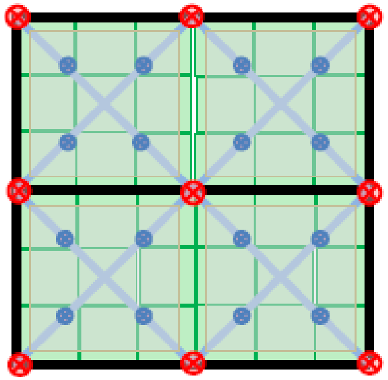


LMT combination panel

1 Overall Reflector Concept

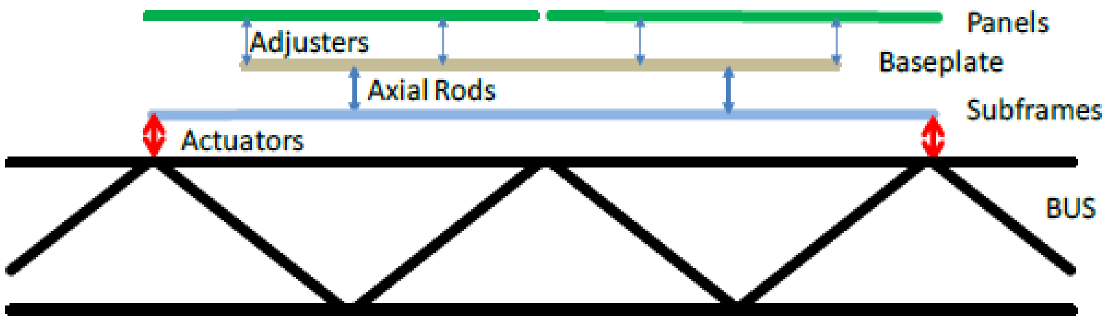


Layout of Backup Structure, Actuators and Panel Units



Panels Units

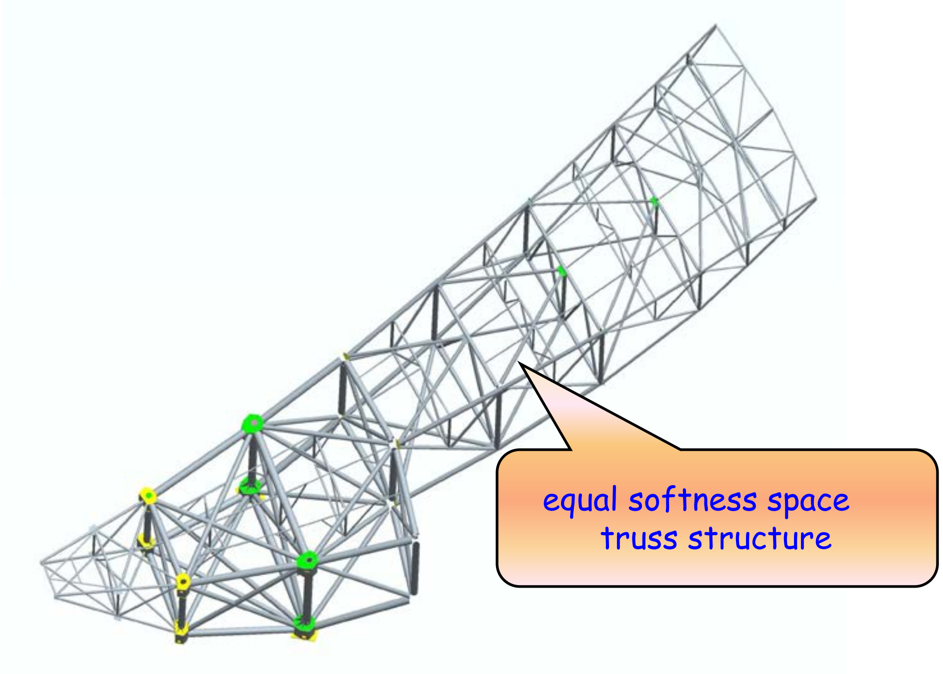
2 Iso-static Panel Concept

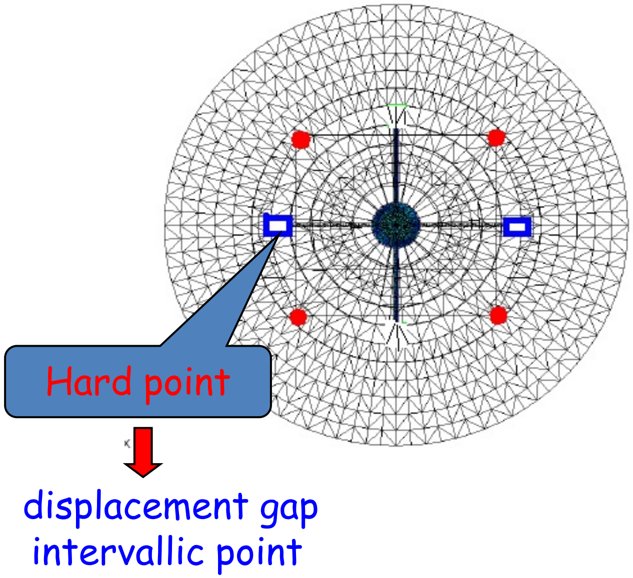


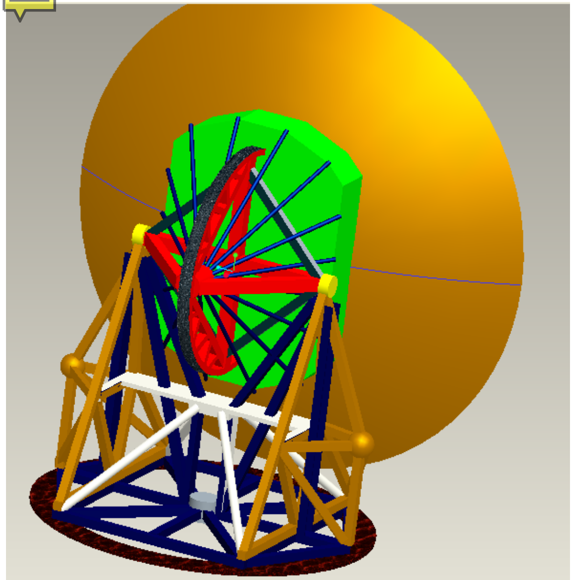
Challenges for reflector panel accuracy

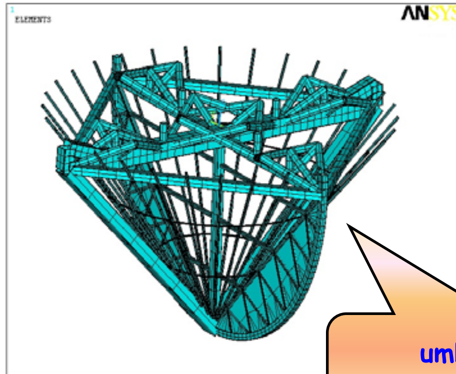
◆ **Main reflector deformation**

Reflector deformation was mainly induced by back up structure (**BUS**) deformation, and “hard point”



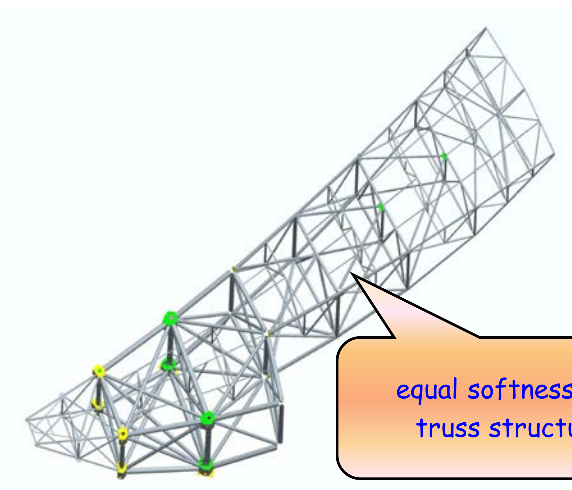




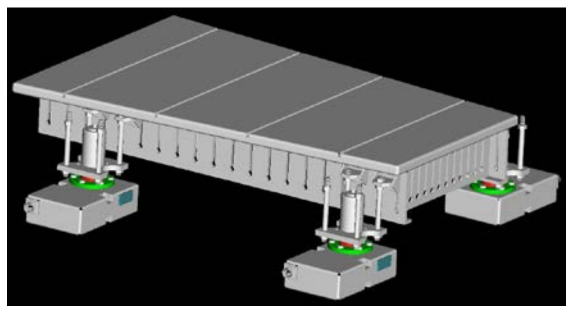


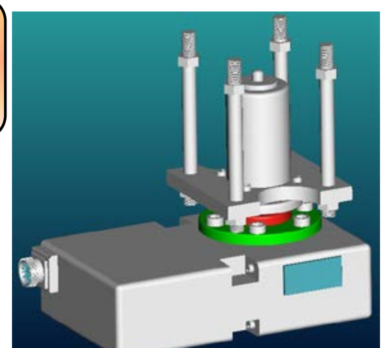
umbrella support structure

In order to make deformation coordination the Connecting strategy between reflector and alidade should be investigated



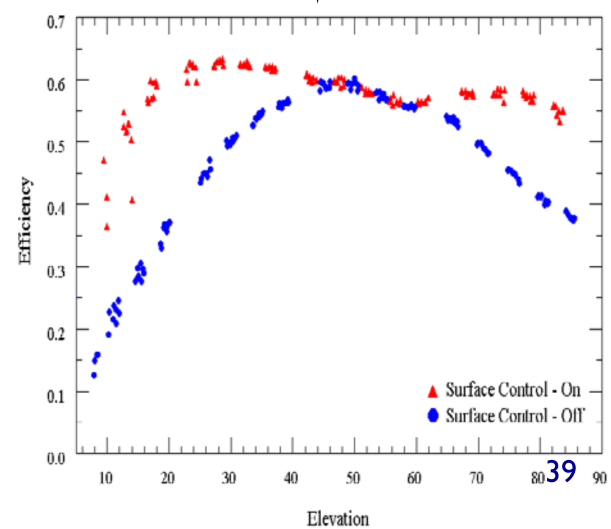
equal softness space truss structure





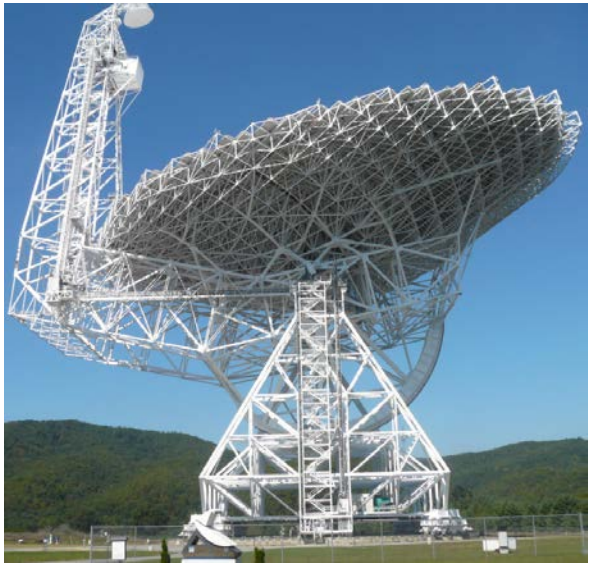
in order to meet the frequency requirements

"homologous" + active surface



Challenge for reflector panel accuracy

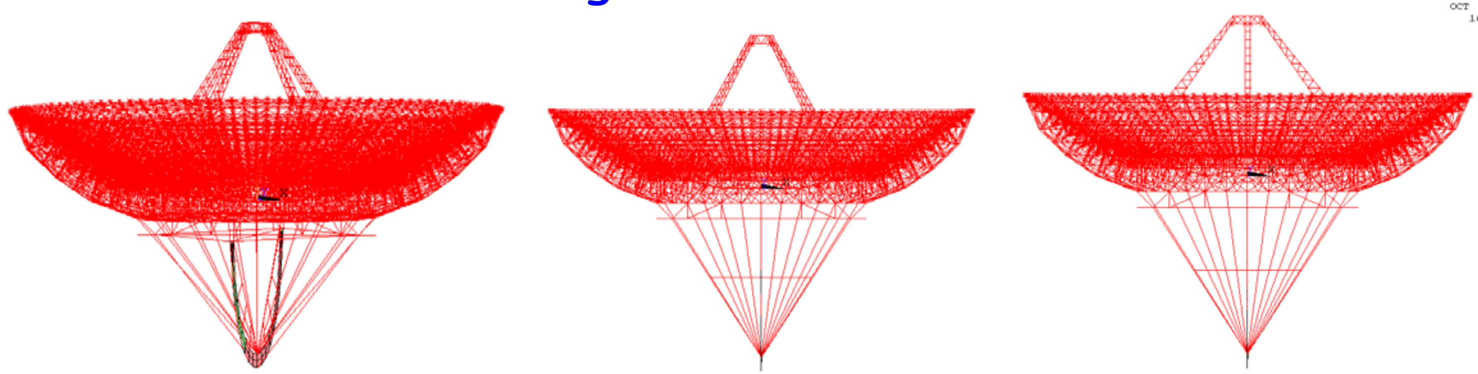
- Reflector and alidade connecting

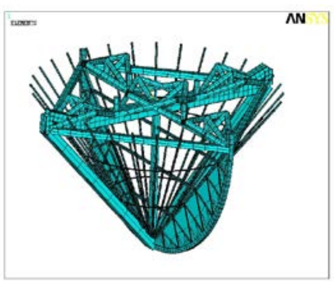

- Effelsberg 100m “umbrella”
- GBT 100m “space truss”
- DSN “dual gear”

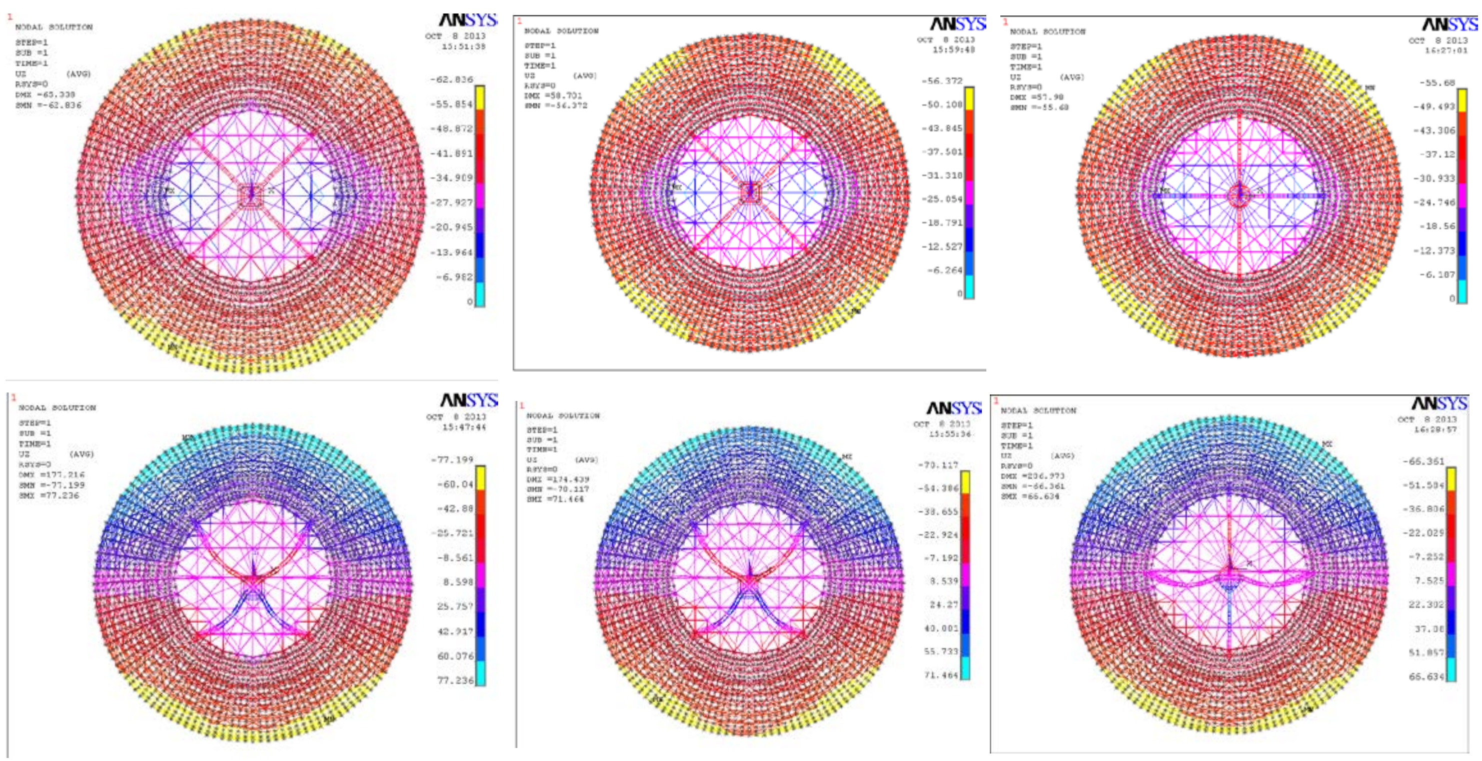
Challenge for reflector panel accuracy

- Reflector and alidade connecting



3 umbrella supporting schemes

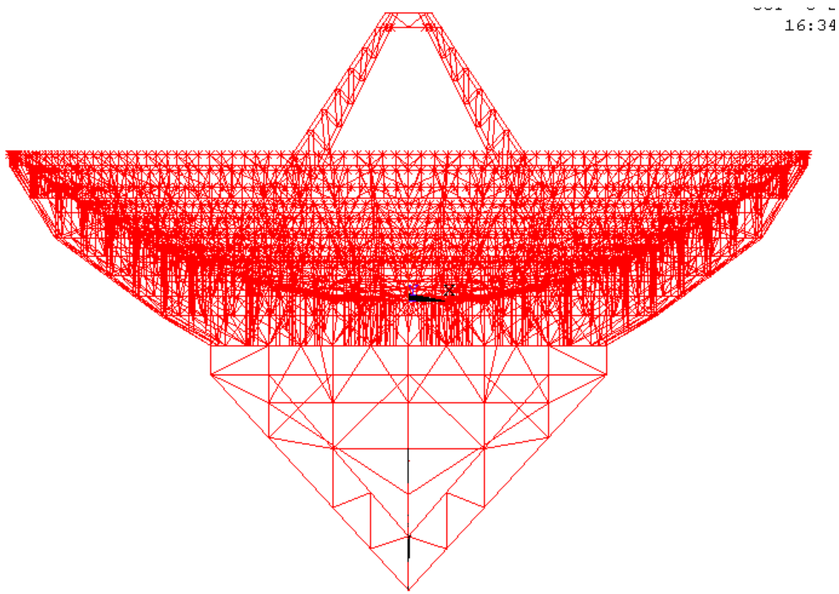


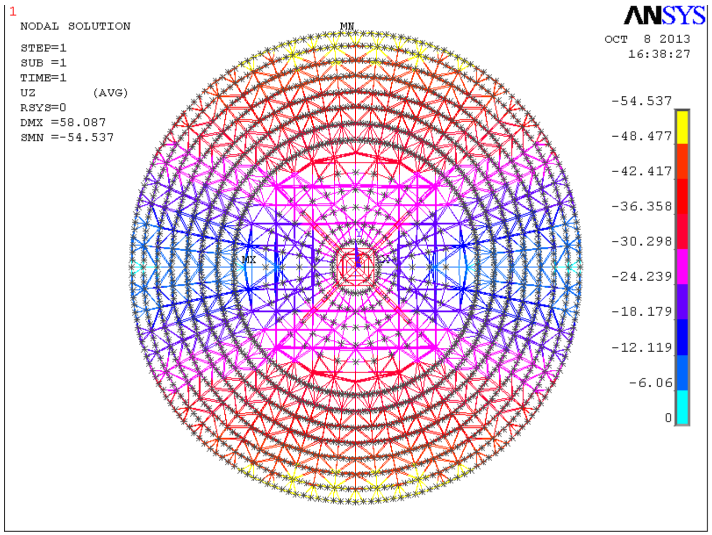


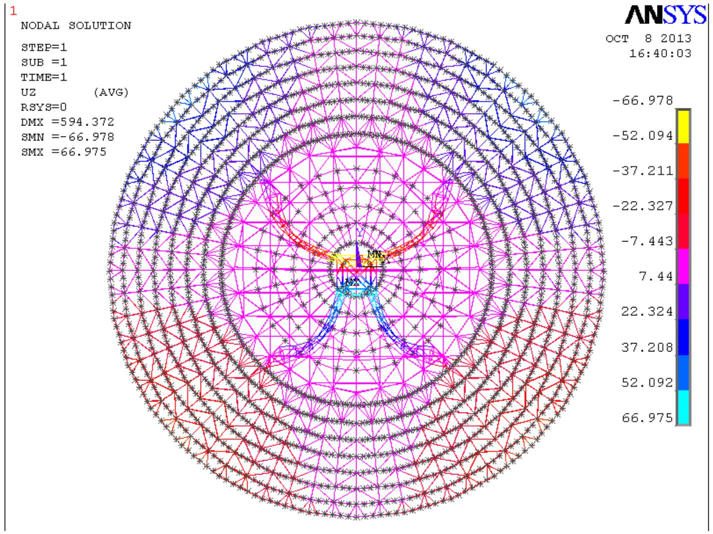
Challenge for reflector panel accuracy

- Reflector and alidade connecting

space truss scheme



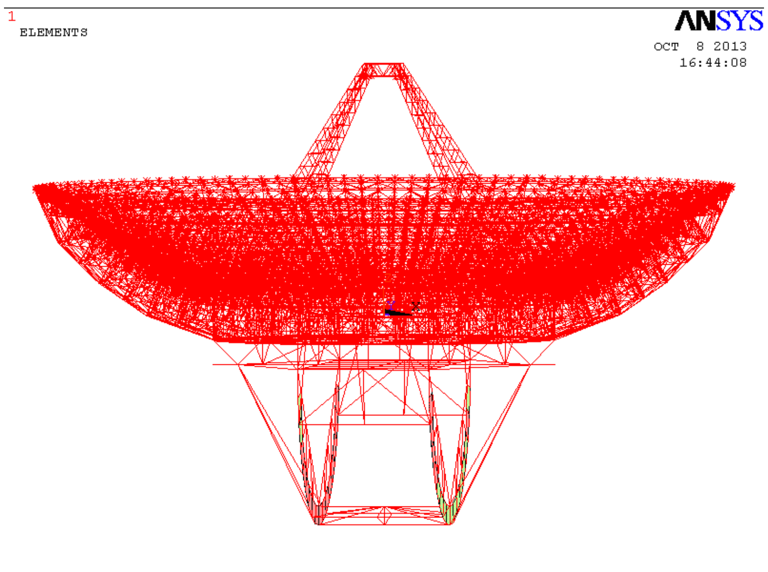


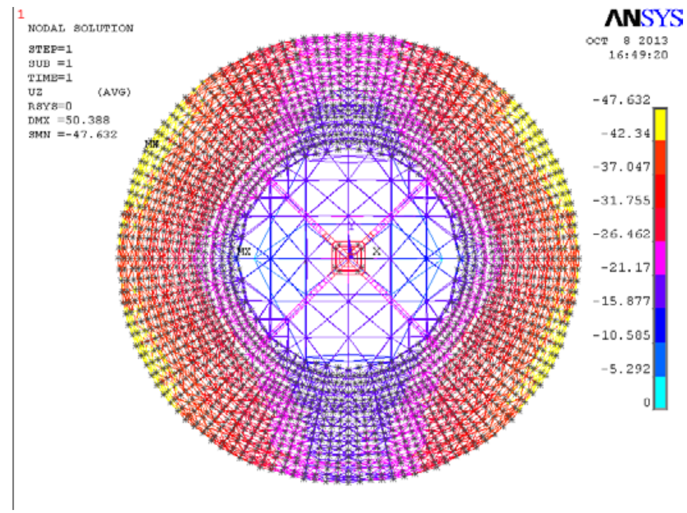


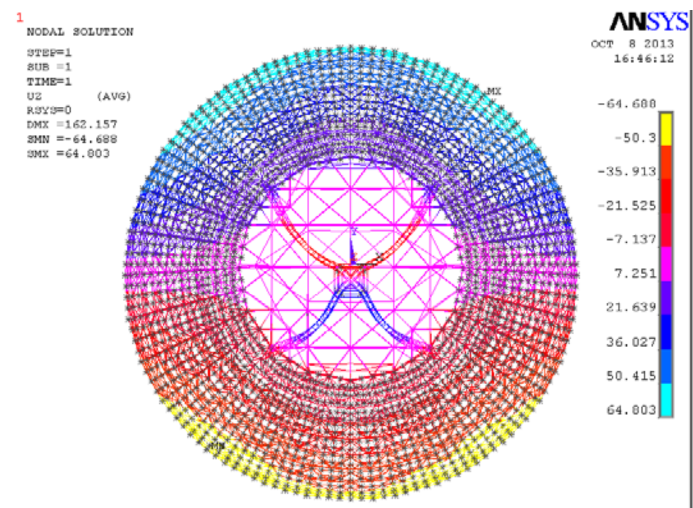
Challenge for reflector panel accuracy

- Reflector and alidade connecting

Dual gear scheme







results for connecting schemes

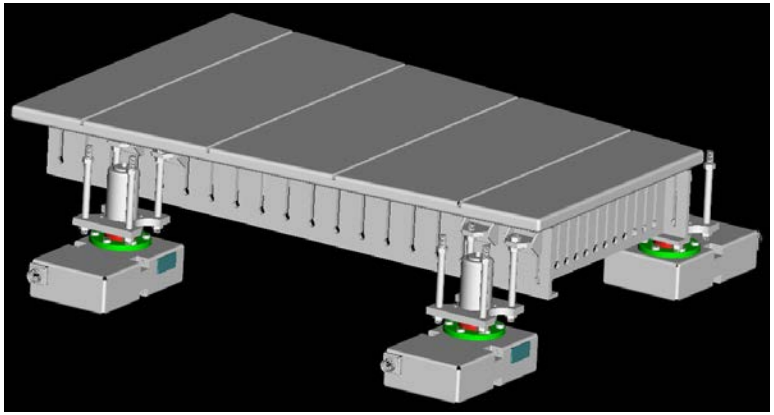
Connecting types	Central body diameter D(mm)	Elevation gear R(mm)	Subreflector supporting legs layout	Vertical(vertex) deformation Z_{max}(mm)	Parallel deformation Z_{max}(mm)	Main reflector weight（t）	Total weight（t）
Umbrella 1	55000	30000	±45° 、±135° orthogonal	-62.836	±66.97	300	2249.1
Umbrella 2	55000	40000	±45° 、±135° orthogonal	-56.372	70.117 -71.464	300	2134.8
Umbrella 3	55000	40000	±90° 、0° 、180° orthogonal	-55.68	66.63 -66.36	300	2135.9
Space truss	55000	30000	±45° 、±135° orthogonal	-54.53	±66.97	300	2280
Dual gear	55000	25500	±45° 、±135° orthogonal	-47.632	64.8 -64.688	300	2277.4

- only consideration gravity deformation
- only analysis vertical and parallel direction

Future ……….

Challenge for reflector panel accuracy

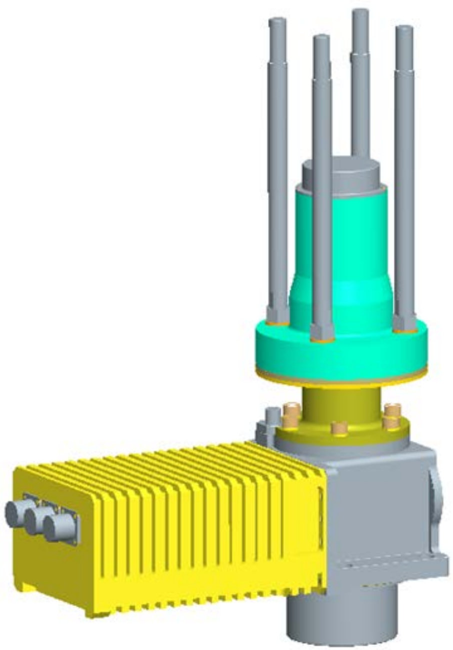
◆ actuator

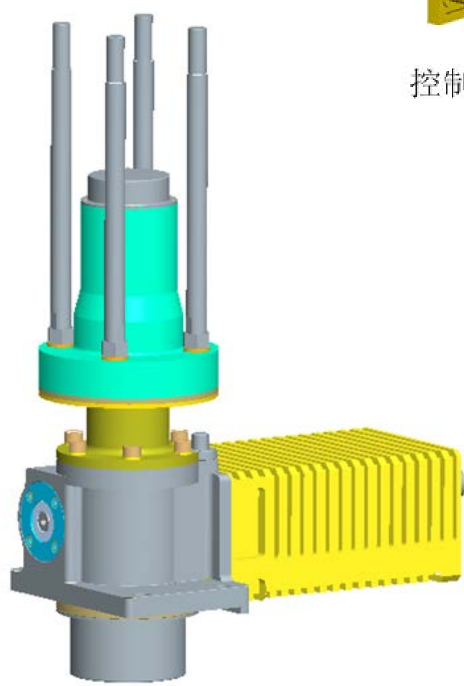


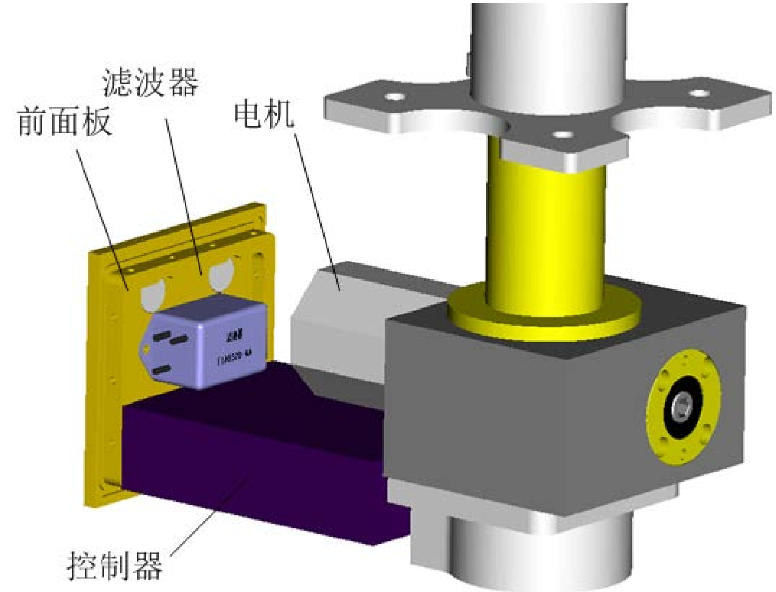
- EMC: GB/T 17618-1998
- Protection level: IP65 GB (prevent dust, water, etc)
- Working environments: -40℃ ~ +60℃

- Weight : < 13kg (include interface to antenna surface)
- Height : 330mm
- Stroke : > 50mm
- Positioning accuracy : < ±0.015mm
- Axial operating load : ≥ 300kg
- Radial operating load : ≥ 186kg
- Axial survival load : ≥ 1000kg
- Radial survival load : ≥ 700kg
- Velocity : ≥ 0.36mm/s
- Lifetime : > 20years

◆ actuator



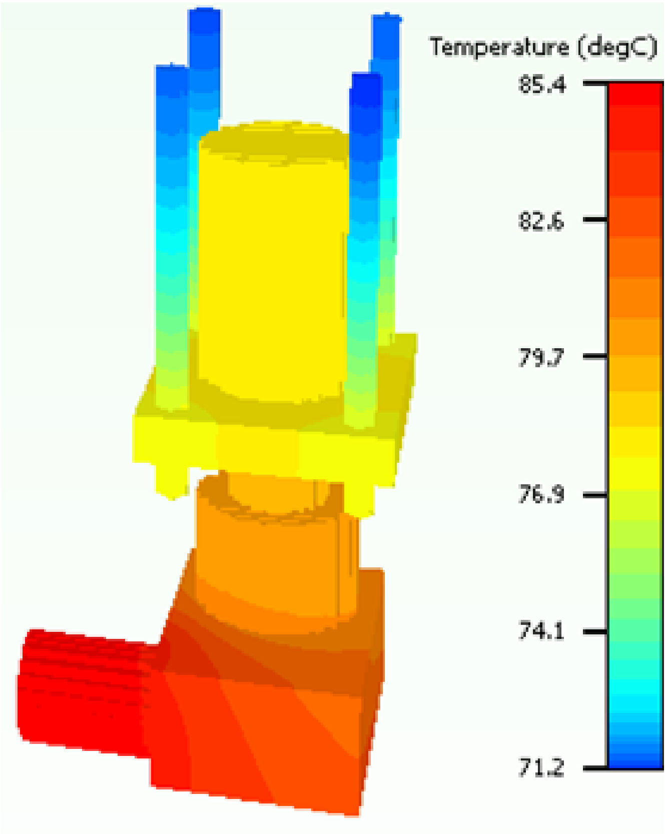




（b）控制器内部结构示意图

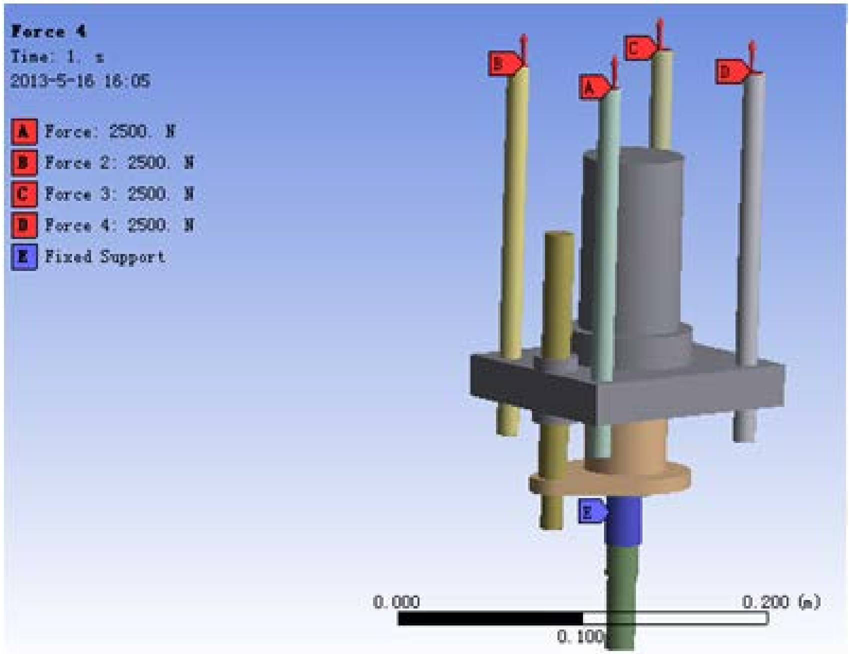
◆Thermal analysis

Maximum surface temperature:
motor 85.4℃(25℃↑)

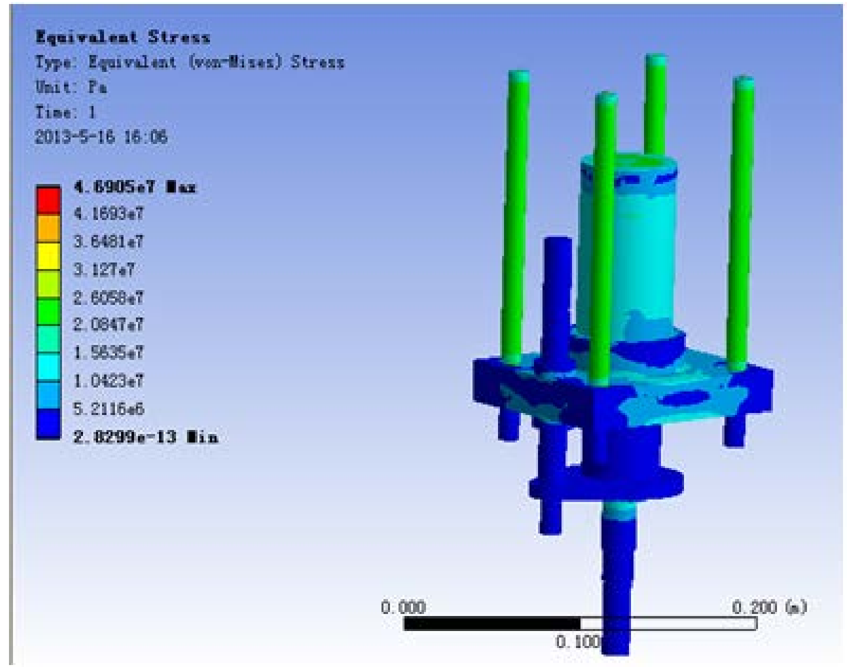


Surface temperature

◆ 有限元分析(力学)垂直方向最大载荷10KN

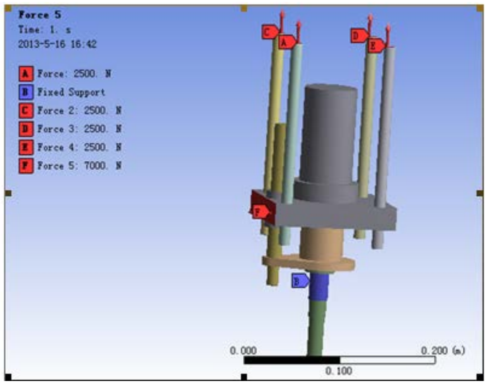


边界条件



等效应力

◆ 有限元分析(力学)垂直方向最大载荷10KN,径向载荷7KN



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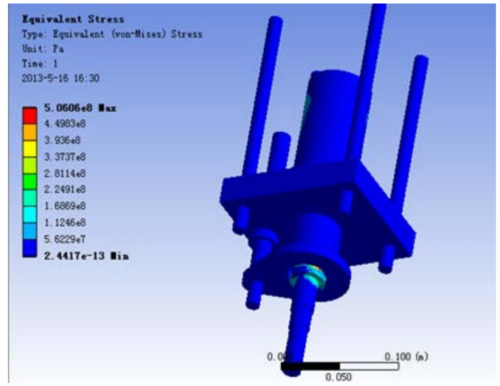
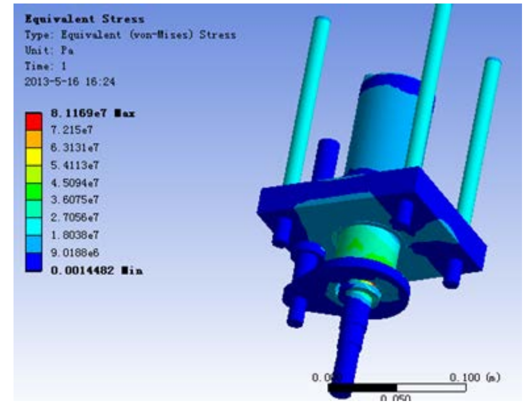
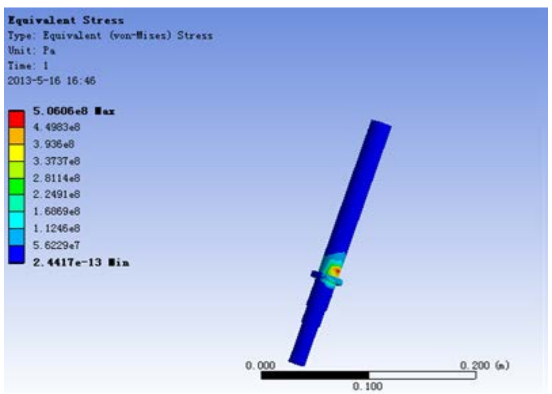


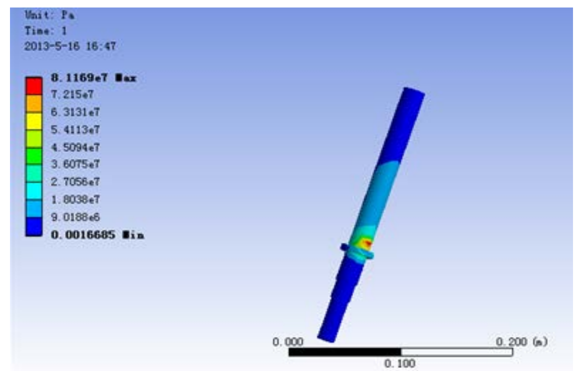
无直线轴承支撑



具有直线轴承支撑

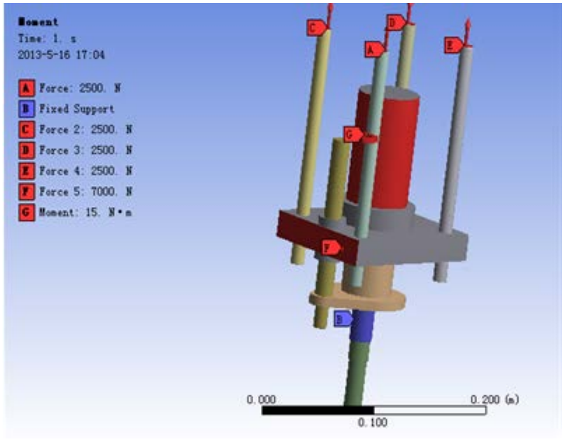


无直线轴承支撑

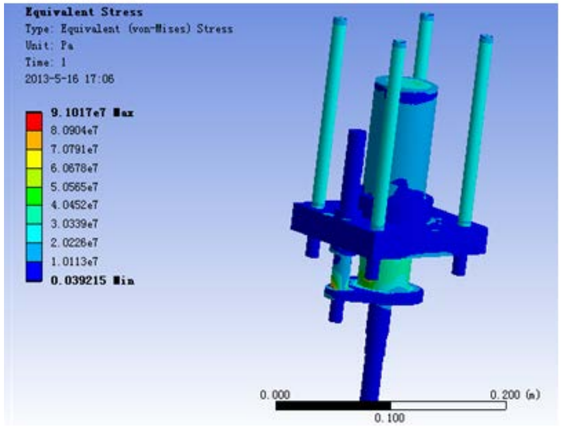


具有直线轴承支撑

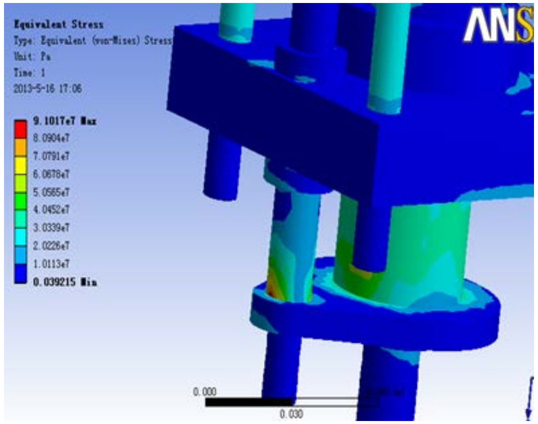
◆有限元分析(防转机构)



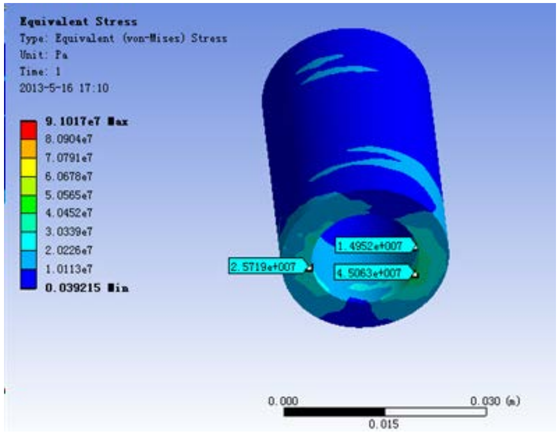
边界条件



等效应力



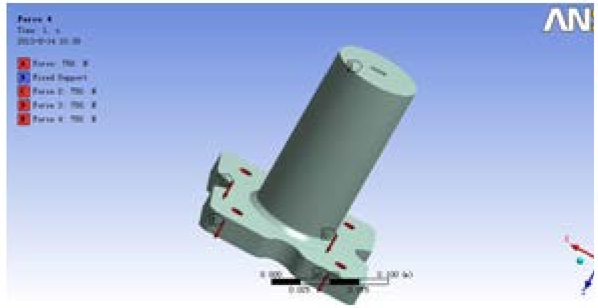
防转力矩引起的应力变化



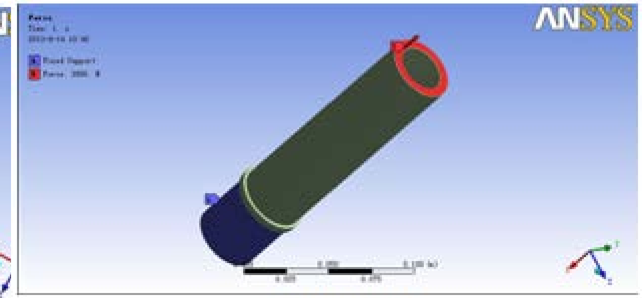
直线轴承的等效应力

◆ 有限元分析(丝杆，推杆，螺母)

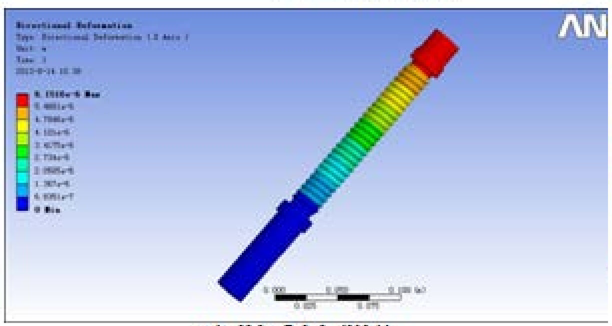
（a）丝杠力加载情况



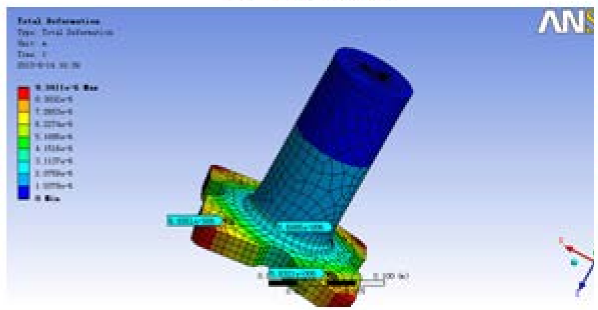
（a） 推杆加载情况



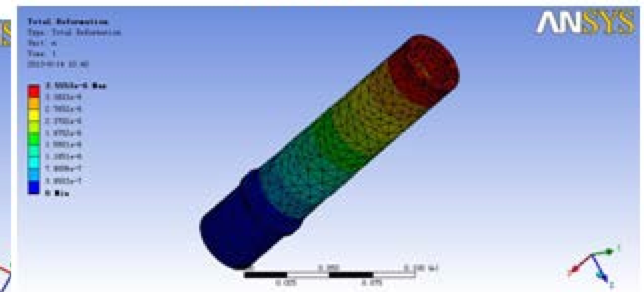
（a） 螺母加载情况



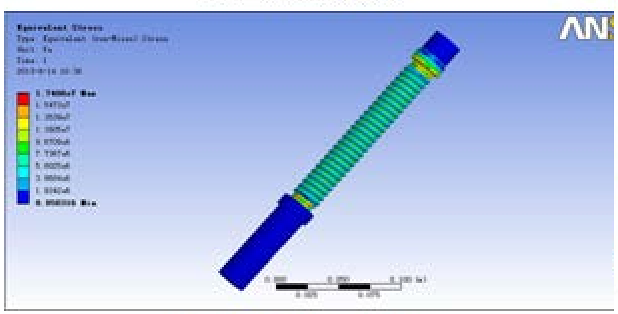
（b）丝杠受力变形情况



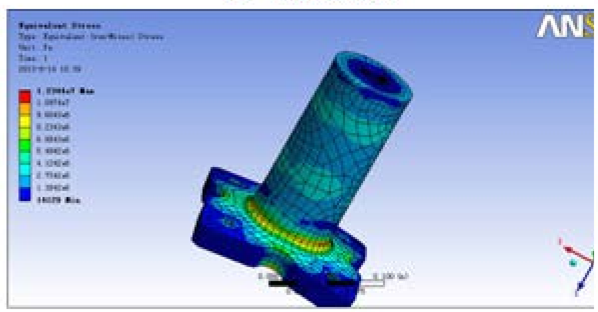
（b） 推杆变形情况



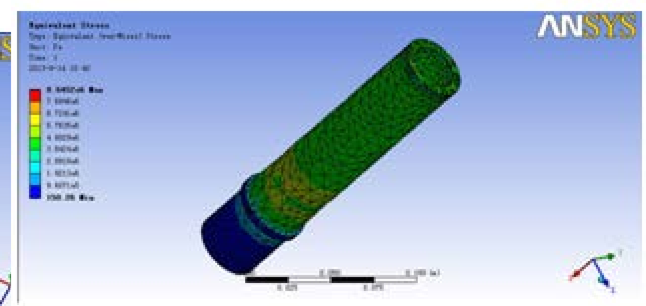
（b）螺母变形情况



（c）丝杠 von-Mises 应力



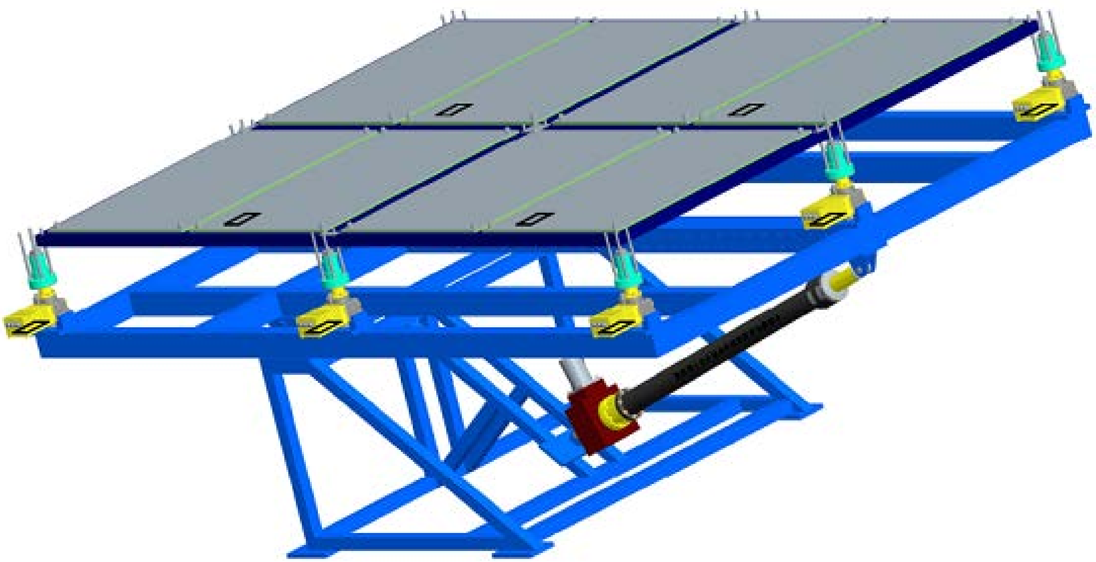
（c） 推杆 von-Mises 应力

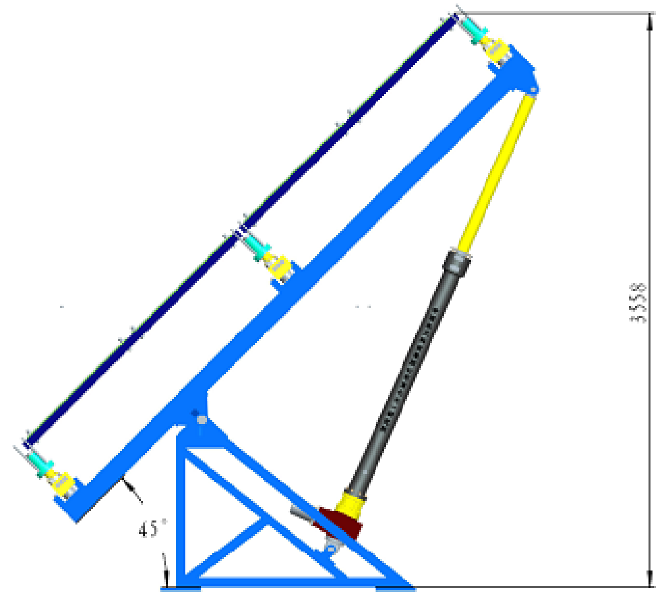


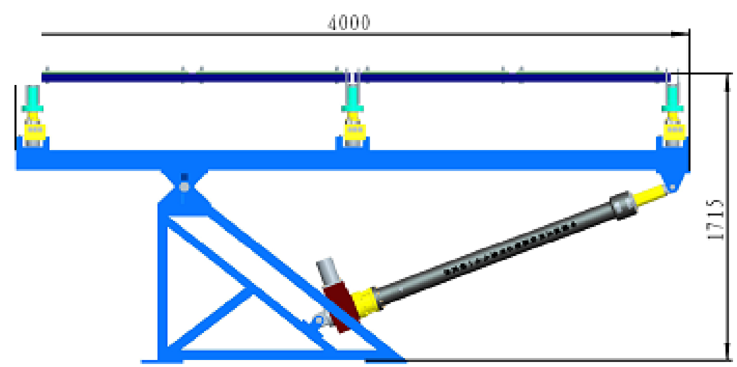
（c）螺母 von-Mises 应力

actuator

◆ testing system



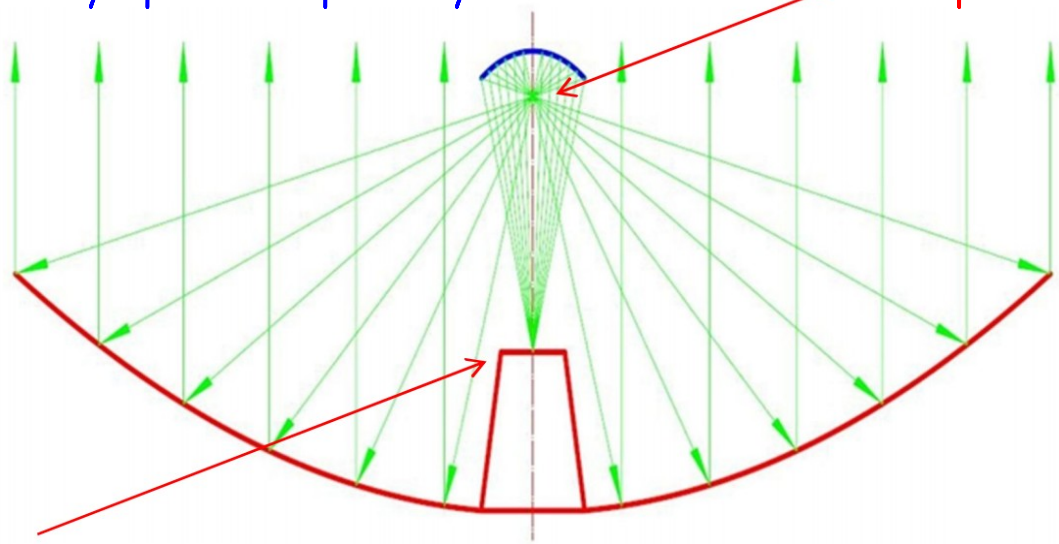




- mechanical (temperature -40℃~60℃)
- EMC

QTT Focal Positions

- Gregorian telescope
- Primary surface should be figured to a parabolic surface
- For low frequency operation primary surface should be a shaped configuration



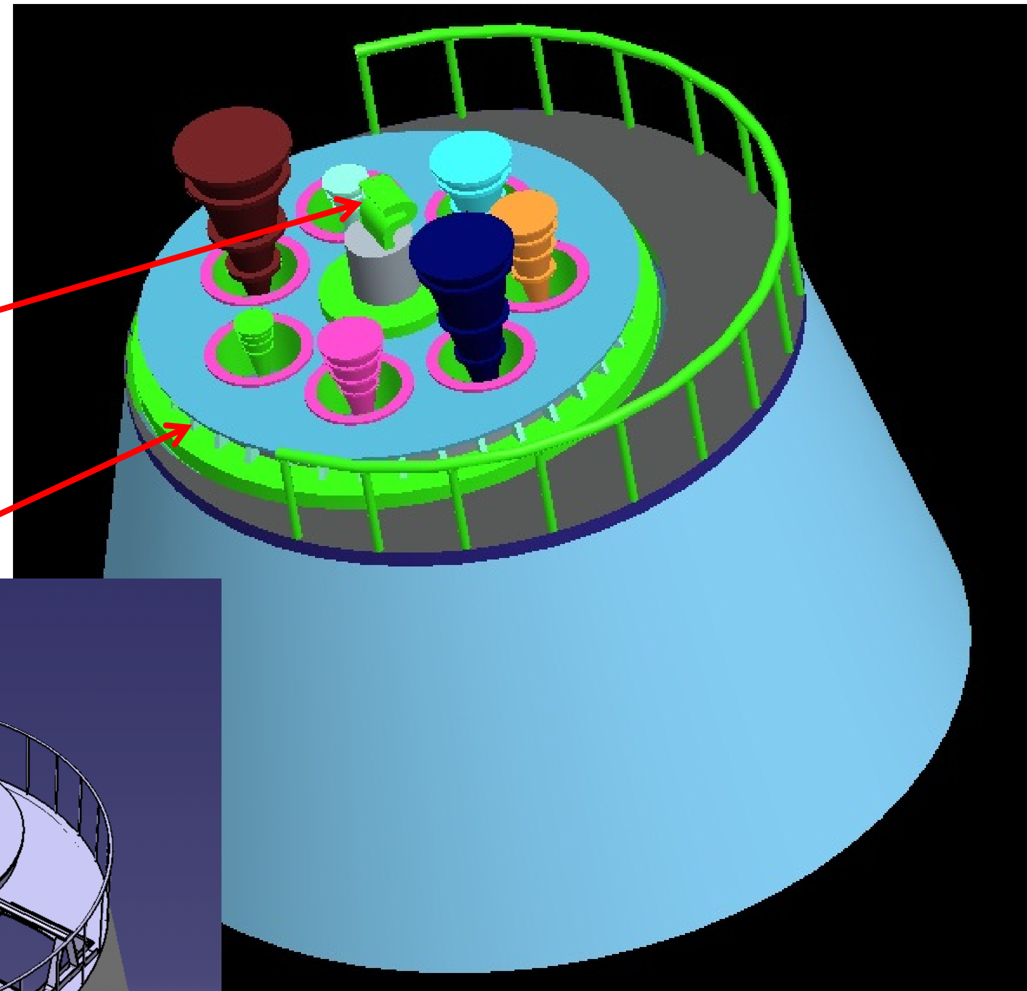
- The primary focus (100cm,30cm,and 15cm PAF)
- The Gregorian focus (5cm,1cm,0.6cm,0,3cm,13/3.6cm,3.6/0.9cm,0.3cm multi-beam)

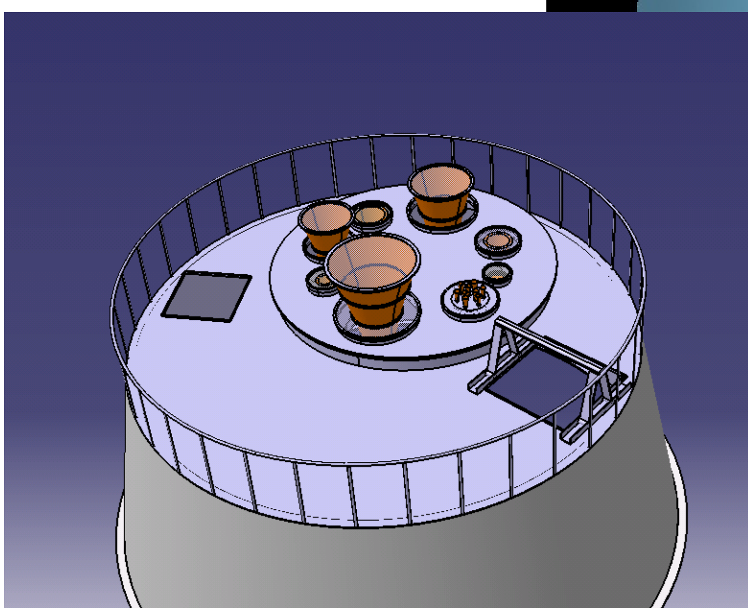
Feeds change schemes

- Primary reflector cabin

Blower system
dry the horn
cover after rain

Rotating turret



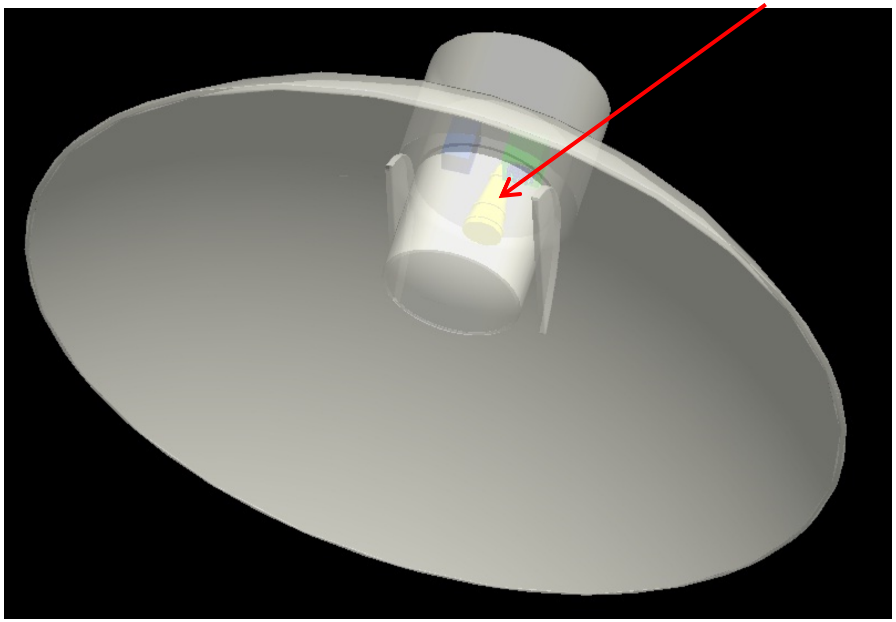


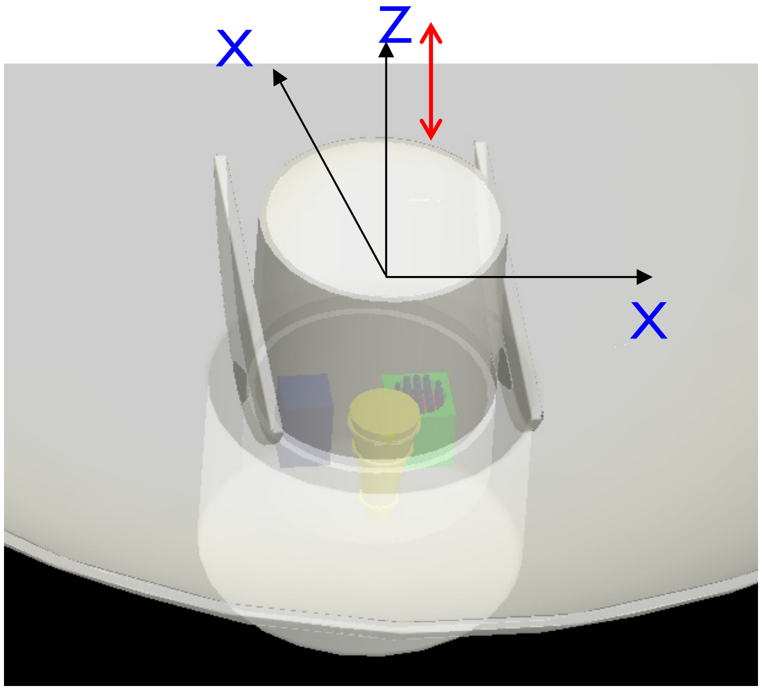
Challenge for sub-reflector

- Subreflector feed switching scheme

Feed {
100cm Kildal
30cm Horn
15cm PAF

- Feeds mounted on a rotating turret in a box
- The turret can move along Z axis
- The box can also move along Z axis

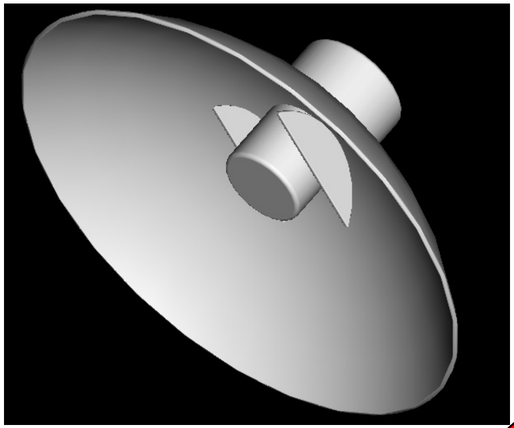


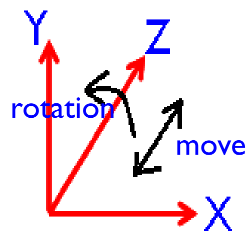


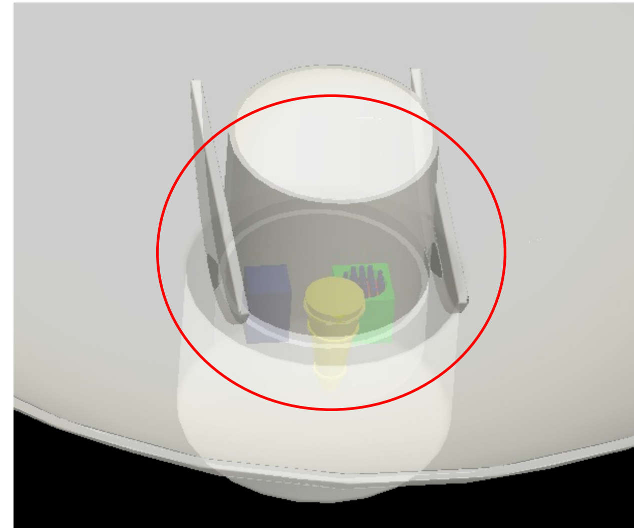
Primary focus:
100 cm Kildal, 30 cm Horn, 15 cm PAF
Gregorian focus:
5 cm, 1cm, 6 mm, 3 mm, 13/3.6 cm, 3.6/0.9 cm, 3 mm multi-beam

Challenge for sub-reflector

- Subreflector feed switching scheme





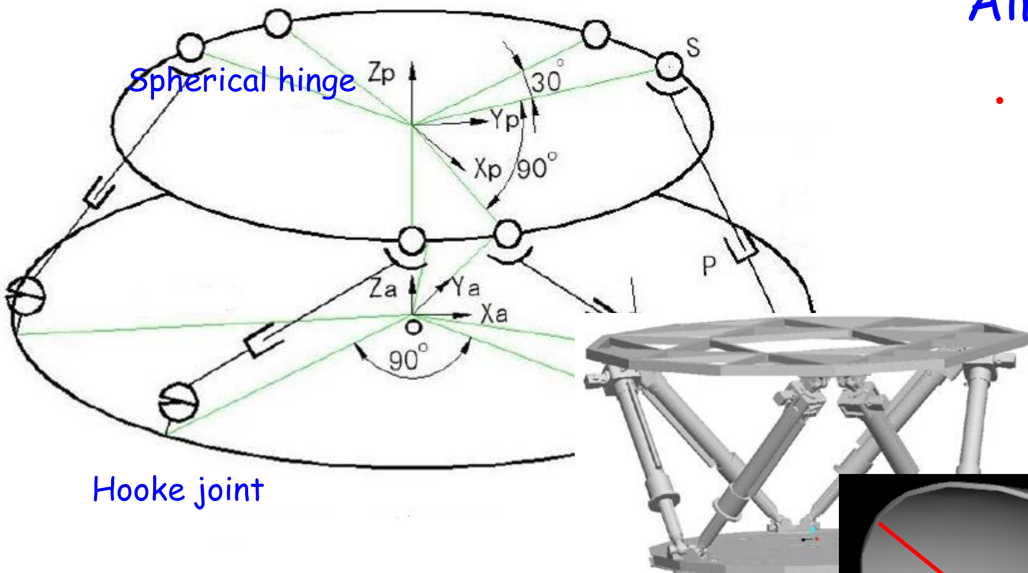


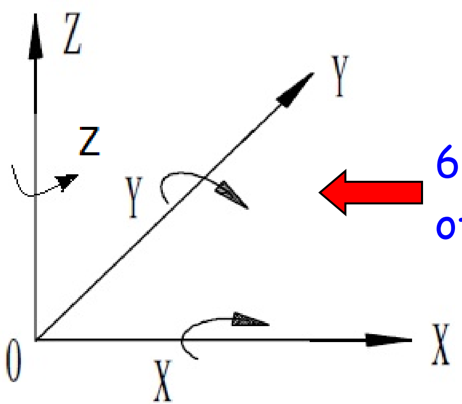
- So for secondary focus operations the prime focus box is removed and the hole closed

- Problem is that the area must provided large enough (large hole) to contain the three receivers for prime focus

Challenge for sub-reflector

- Subreflector hexapod support adjustment system

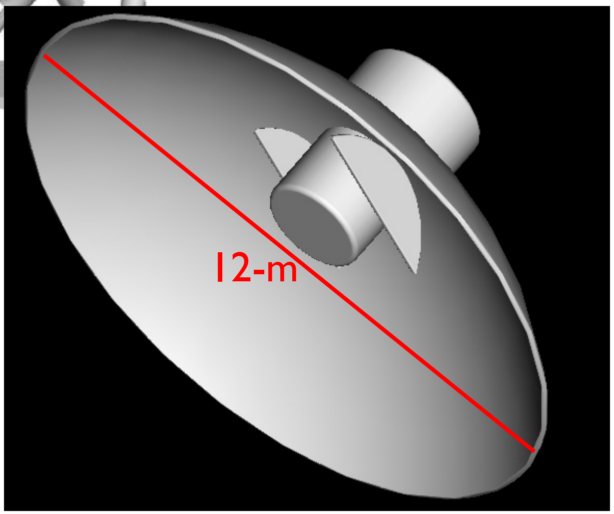


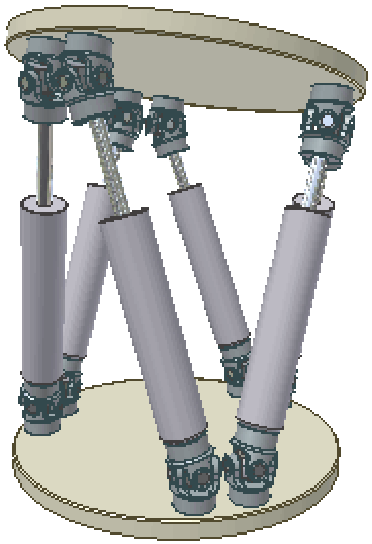


6 Degree of Freedom

Aims:

- Compensate the antenna performance and pointing change caused by gravity deformation





Servo control strategy

- Controller

	PI	FF	LQG	LQG+FF
Tracking error(max , mdeg)	28.6	0.7	3.6	0.1
Random disturbance error(max,mdeg)	3.2	3.6	0.4	0.5
Measurement error (max, mdeg)	28.7	3.67	3.7	1.5

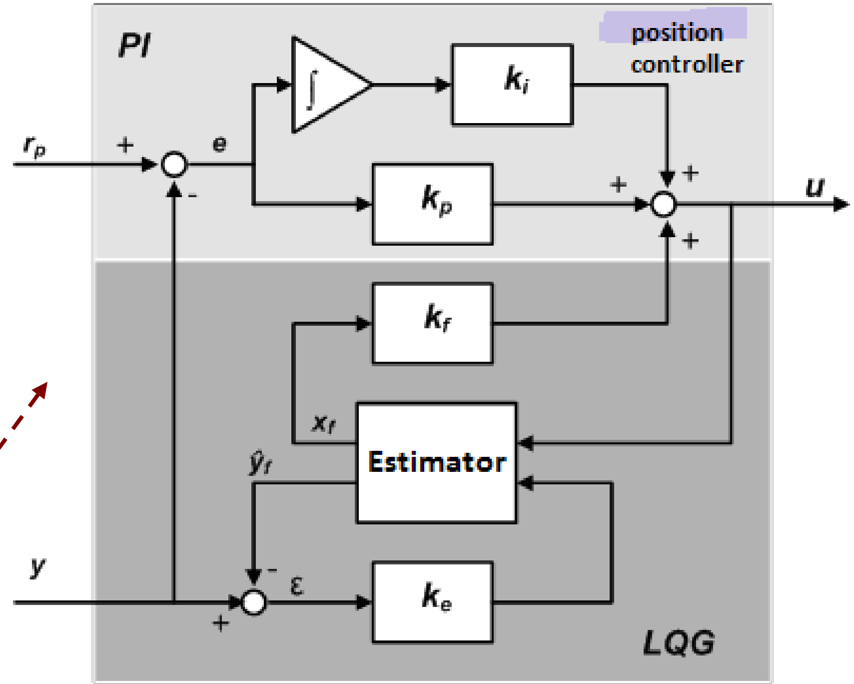
- Compare to PI, LQG+FF ->tracking error reduce to under 1/100 (1%)
- Compare to PI, LQG+FF ->random disturbance error reduce to under 1/5 (20%)
- Compare to PI, LQG+FF ->measurement error reduce to under 1/20 (5%)

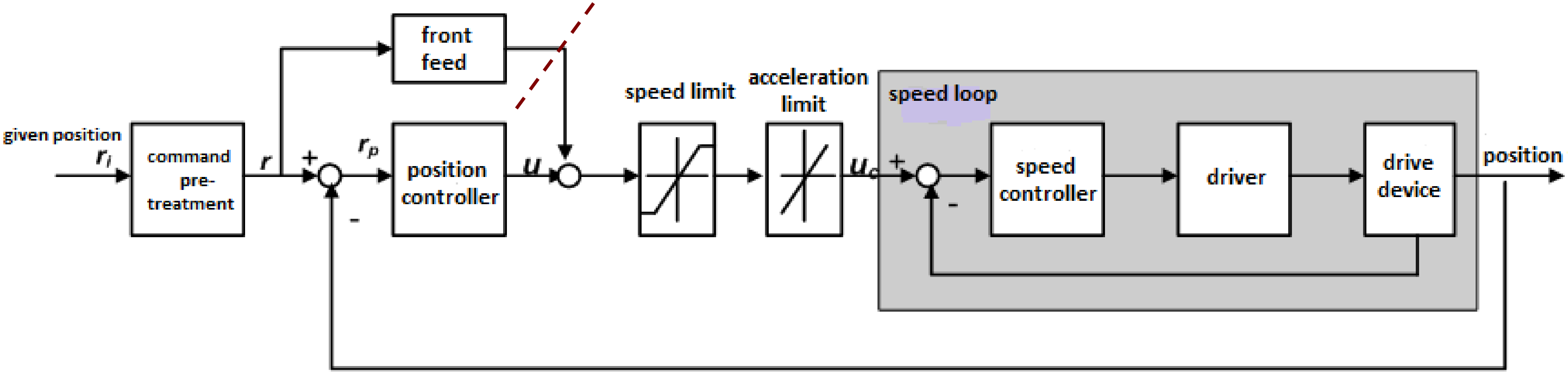
Servo control strategy

- Composite controller

Future: PI+LQG+FF

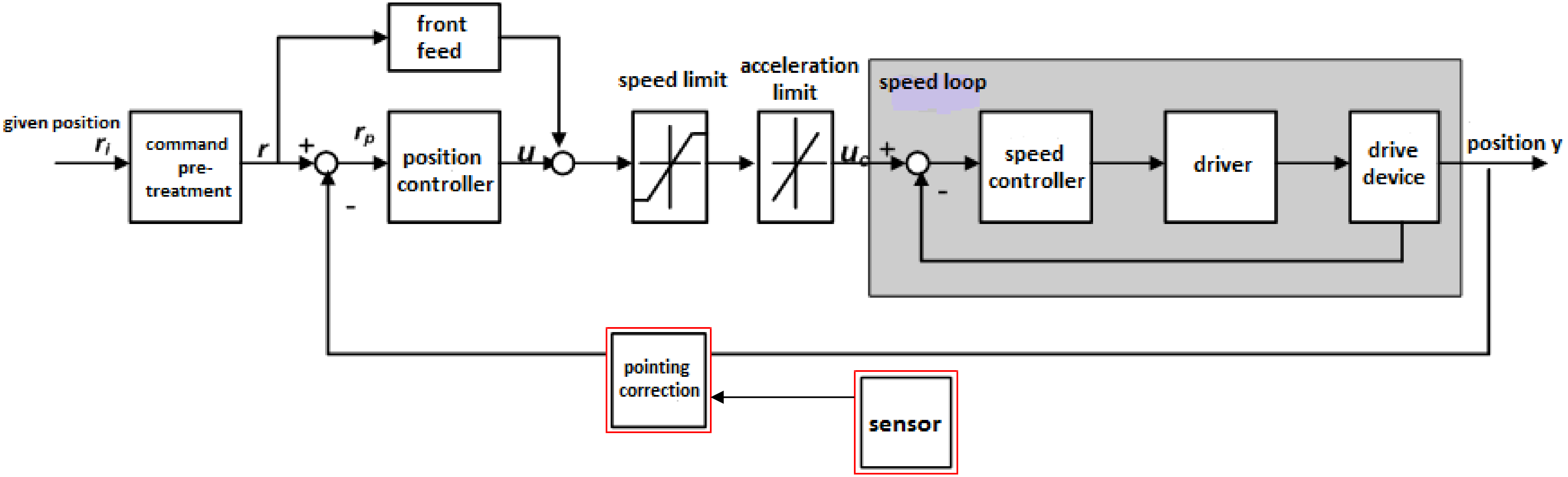
- PI and FF use to maintenance tracking motion
- LQG use to restrain the antenna disturbance





Sensor use

- Pointing correction

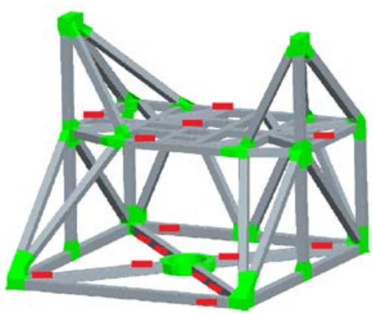


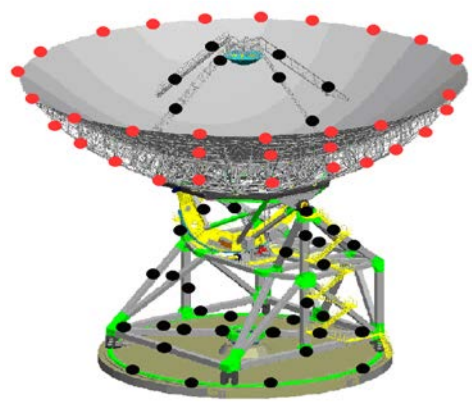
Sensor use

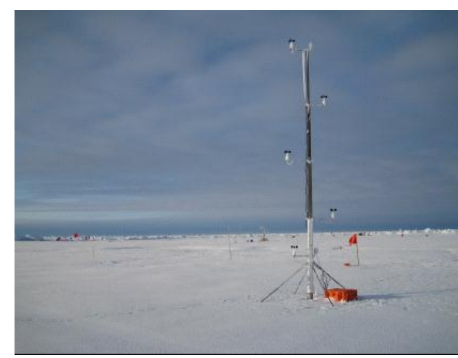
- Pointing correction ----- Error classification
  - Structure error
  - Servo error
  - Error caused by environment
    - Gravity deformation
    - Thermal deformation
    - Wind load influence

Sensor use

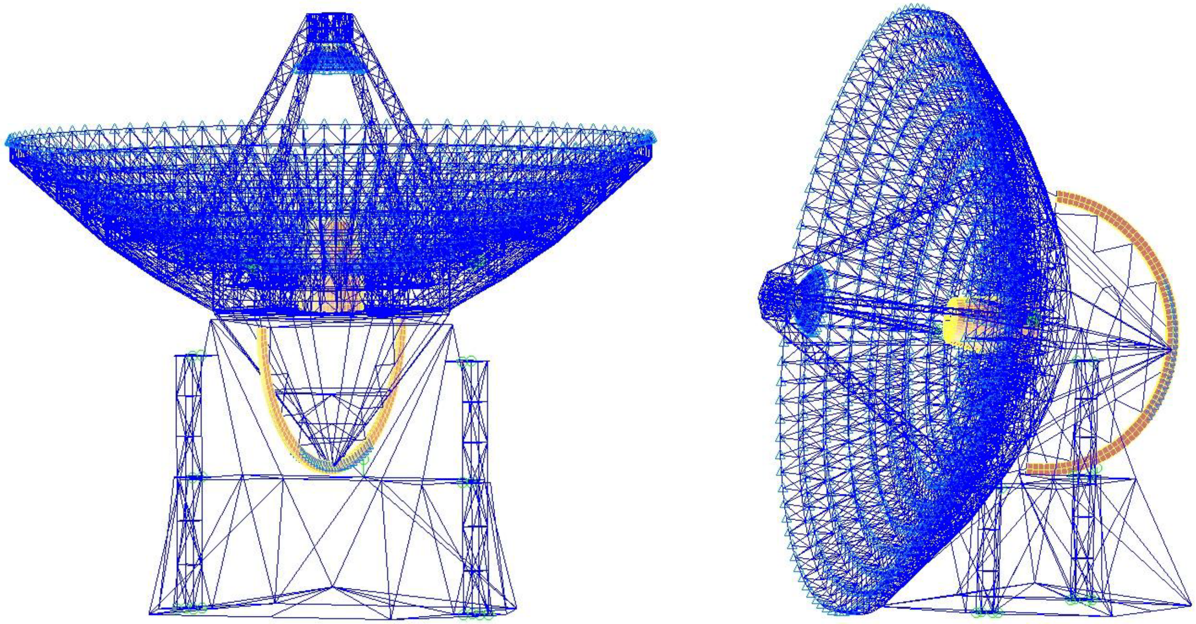
- Clinometer ---- track flatness, alidade deformation
- automatic weather station --- wind, temperature(built)
- Thermal sensor --- structure temperature nonuniform
- Star tracking telescope --- pointing correction, evaluation







Last-> Weight



The FE (finite element) calculations show a 30% higher weight(5850 tons), but the structural optimization was not finished at this time


Thank you!