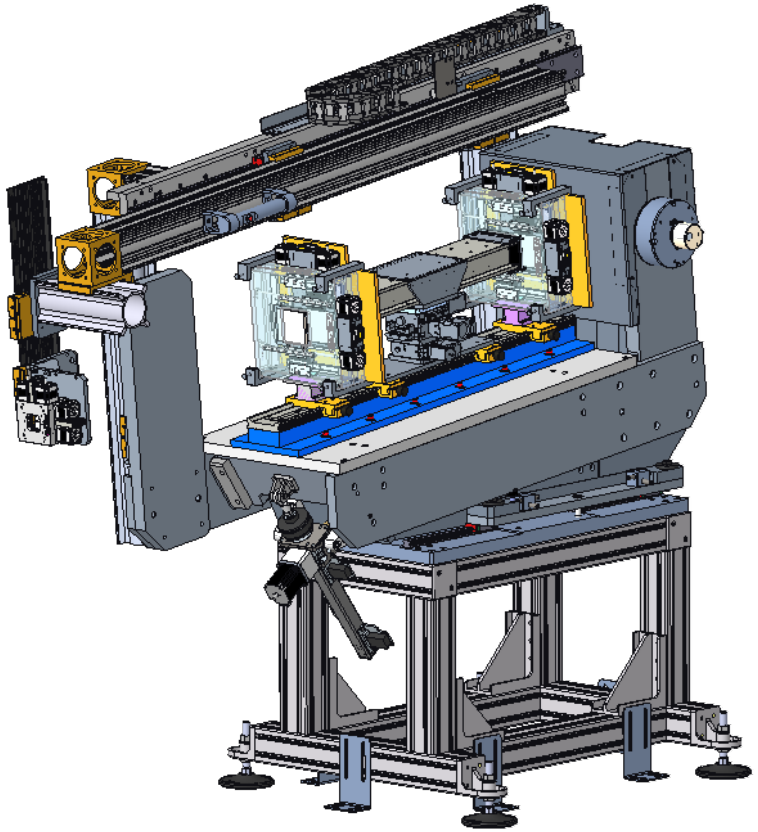
Preliminary QIKR Motion Design Review
Incident Table Details

Rudy Thermer, Motion Engineer

November 06, 2024

Outline

- Incident Table Requirements
- Design Details
- DACs



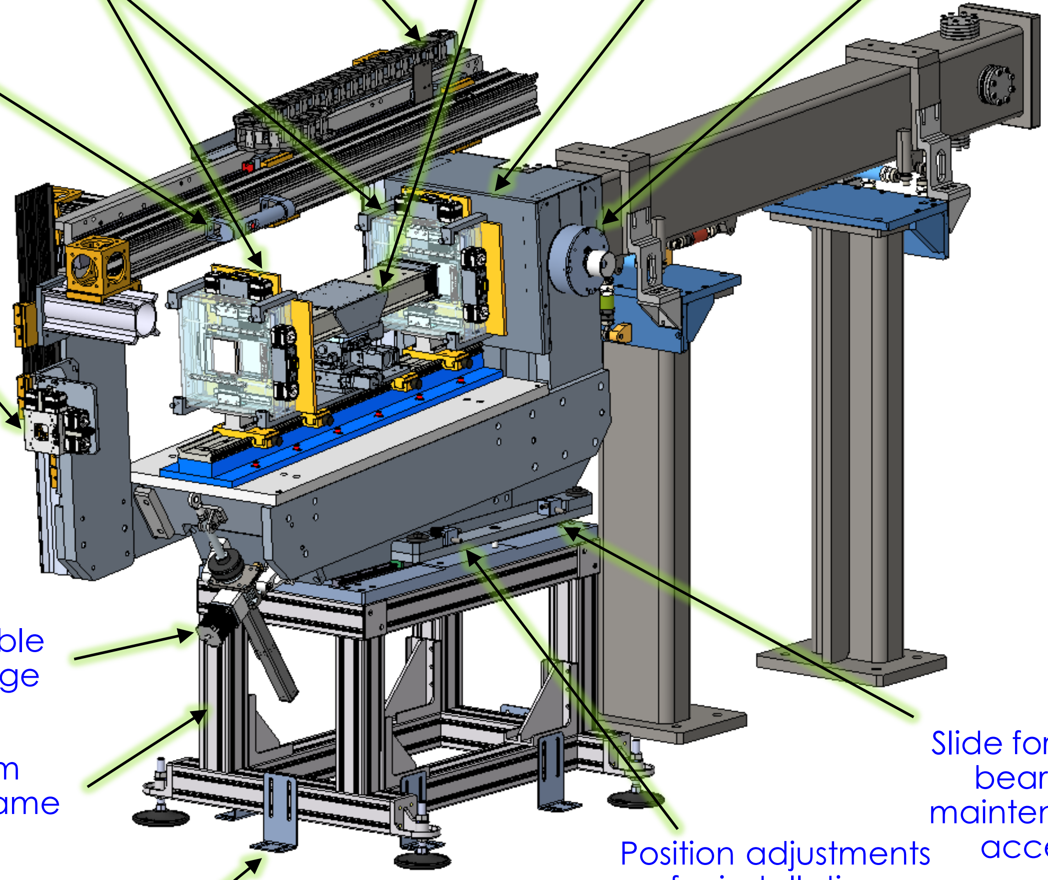
Incident Table, Slits, and FOM Requirements

- S.04.08.06-R100 – End station assemblies in contact with the cave floor must be tied to the floor to prevent accidental shifting of assemblies after initial alignment.
  - Done
- S.04.08.06-R101 – End Station components weighing more than 181.4kg (400lbs) or having a center of gravity greater than 1.2m (4ft) must be secured against motion during a seismic event per S04010000-TDO10000.
  - Tiedowns will be designed for seismic restraint at FD (total table weight is estimated to be ~500lbs)
- S.04.08.06.R102 – End station assemblies and components must not be permanently located within the sample environment keep-out zone around the nominal sample position.
  - The third slit is designed to move into and out of this zone. All other components are permanently located outside of it.
- S.04.08.06-R104 – Incident table must have a footprint in the x-dir of $\leq$ 765 mm.
  - Table is 720mm wide

Incident Table, Slits, and FOM Requirements

- S.04.08.06-R105 – Incident table must support $\geq$90.7kg (200lbs) in addition to its own weight.
  - Table can safely support 1000N (100kg) of extra weight in addition to the existing components (slits, FOM, etc.)
- S.04.08.06-R110 – The third slit must be movable along the z direction to within a range of $\leq$10mm and $\geq$500mm from the nominal sample center, motion resolution of $\leq$0.5mm
  - Currently can only move 342mm away from sample center. Solution has been identified for FD.
    Motion is manual, a scale in millimeters printed on the third slits sliding arm will provide position information to within $\pm$0.5mm
- S.04.08.06-R114 – The incident table must remotely and collectively rotate all slits and the frame overlap mirror about an x axis drawn through the center of the guide glass end to within a range of $\pm$5° and with a resolution of 0.0005°. *Note: angle measured from horizontal.*
  - Motion range is $\pm$6° from horizontal, motion resolution is 6.5 $(10)^{-5}$ degrees.

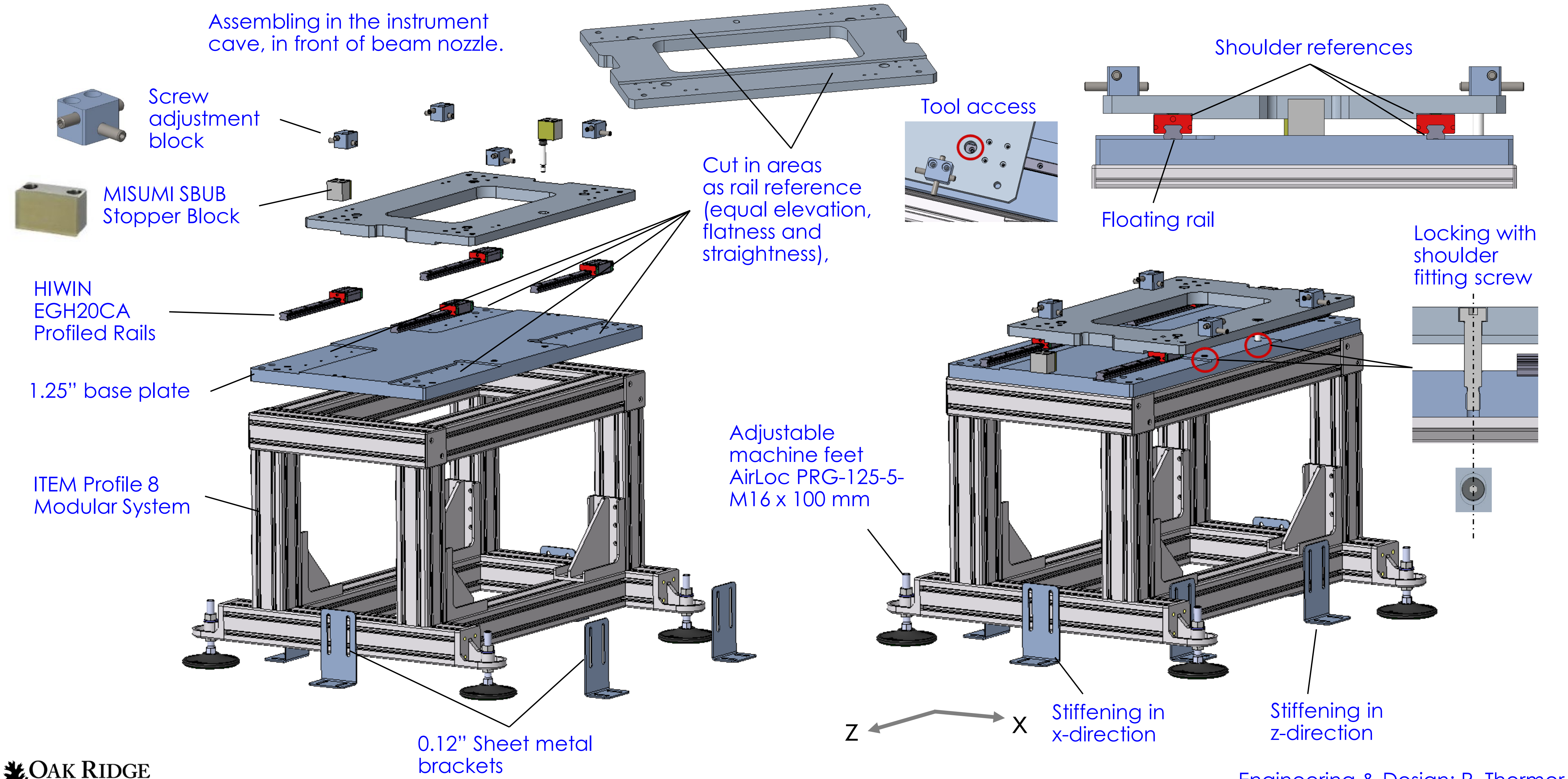
Incident Table – Overview



- The Incident Table positions three slits and a frame overlap mirror to select one of three possible beam angles
- The angle pivot is located at the guide end, which is the same location at which the beam angles diverge
  - This eliminates the need for vertical adjustment during angle changes
- Slit motion along the z-axis is manual, slit actuation is motorized
- 3rd slit is manually positioned close to the sample, locked in place with a mechanically pretensioned latch
- Initial table position is adjusted manually during installation
  - Feet on the frame provide vertical adjustment
  - Features on the table mount plate allow manual x-z positioning
- Table can slide forward on frame to allow maintenance access to pivot bearing

Engineering & Design: R. Thermer

Incident Table – Installation Sequence Support



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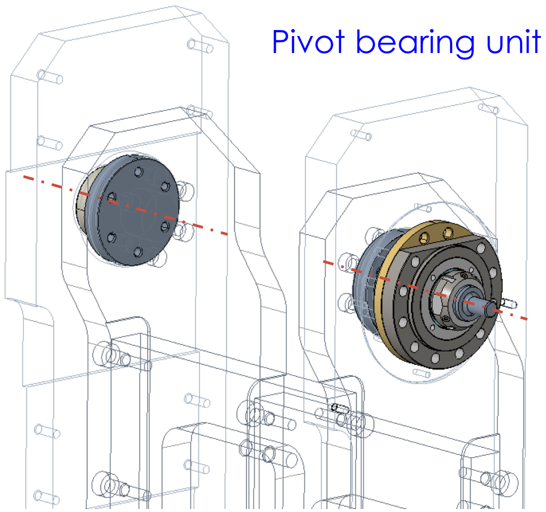
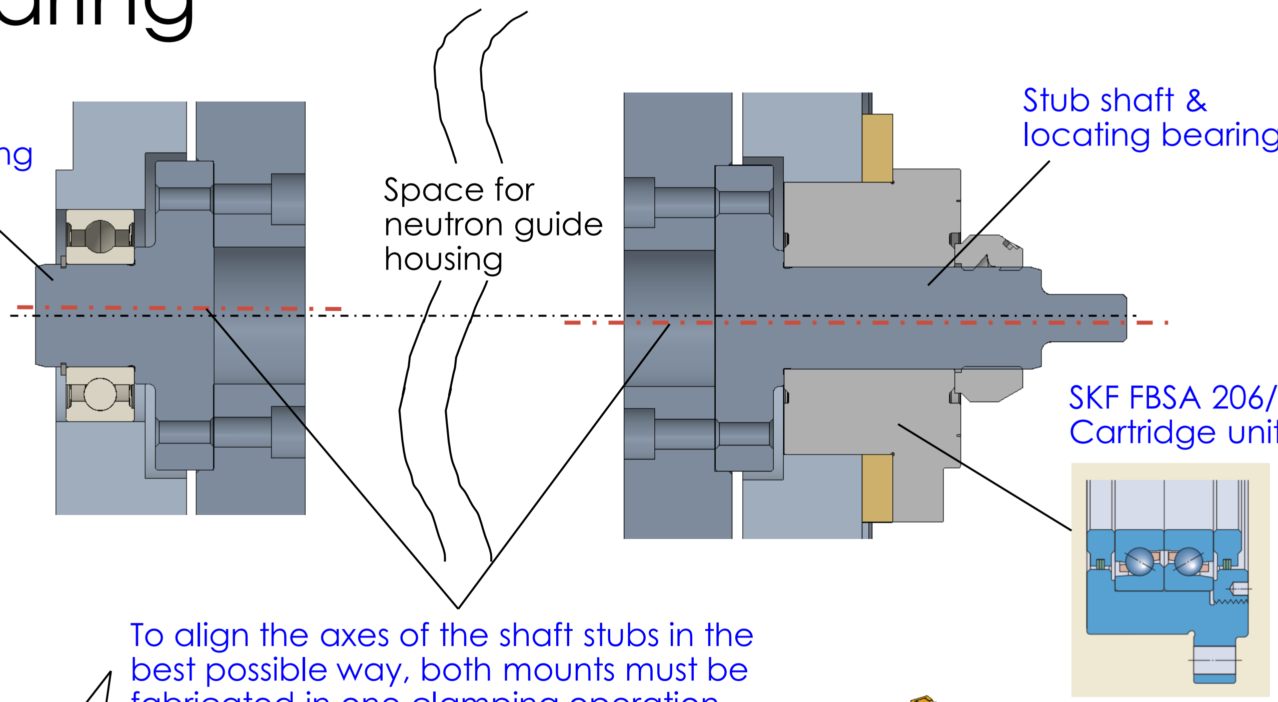
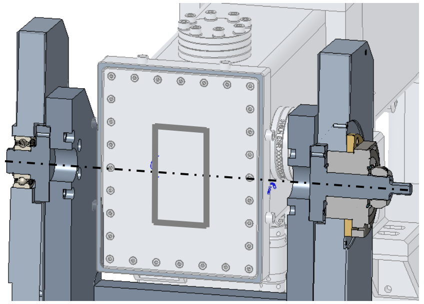
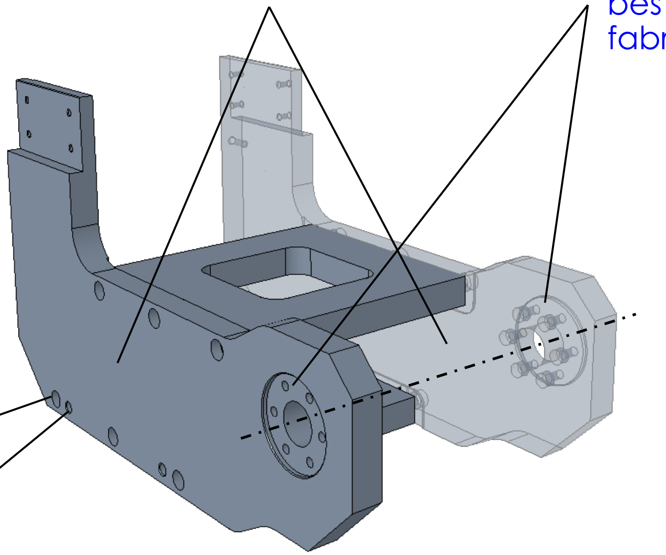
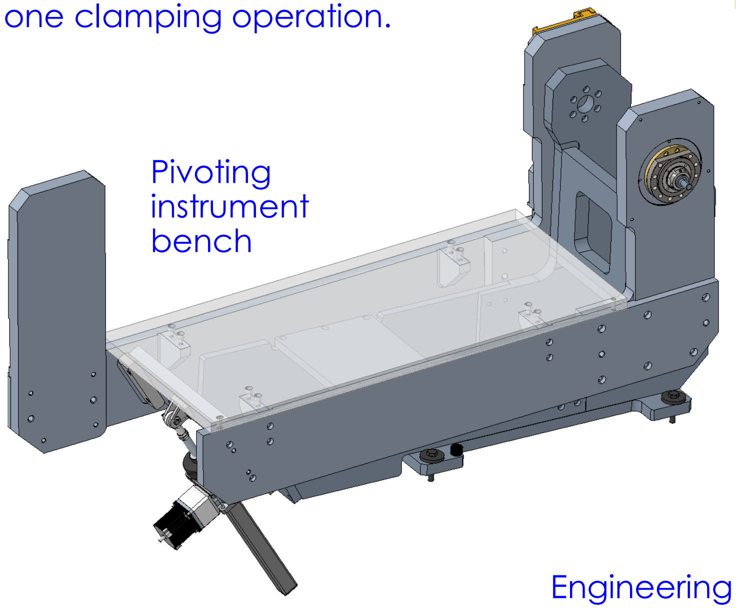
Incident Table – Pivot Bearing











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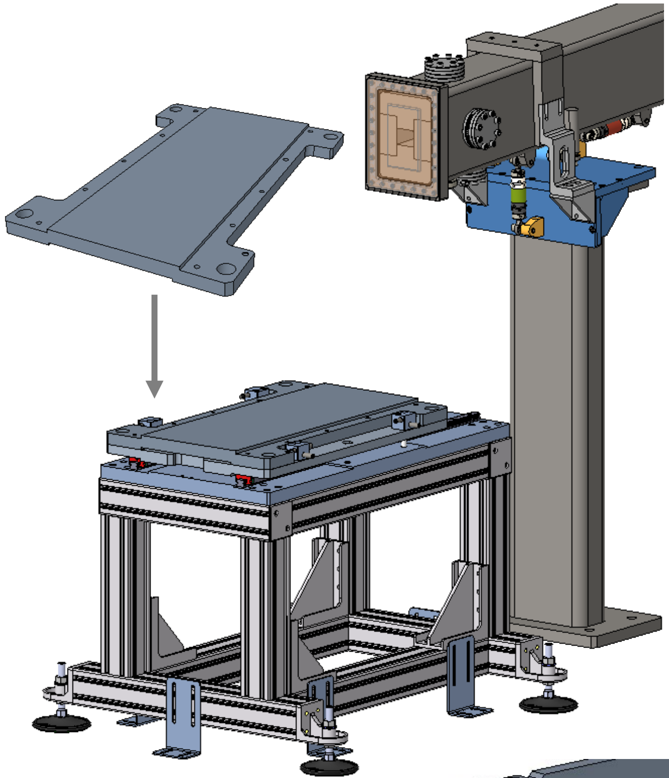
Incident Table – Installation Sequence Base

Assembling in the instrument cave, in front of beam nozzle.



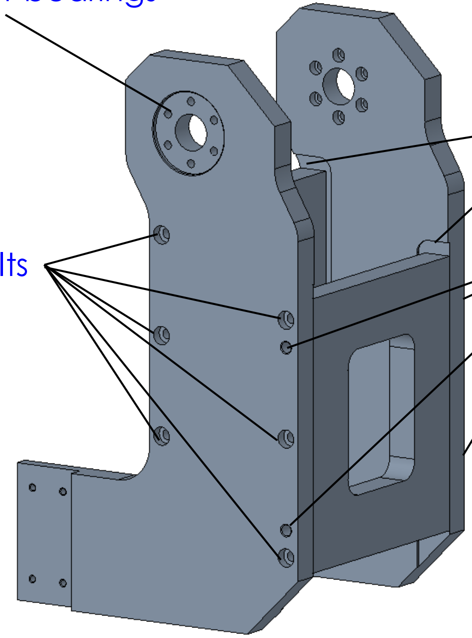
Post-processed mount for bearings

Weight: 31 kg (68.3 lbs)

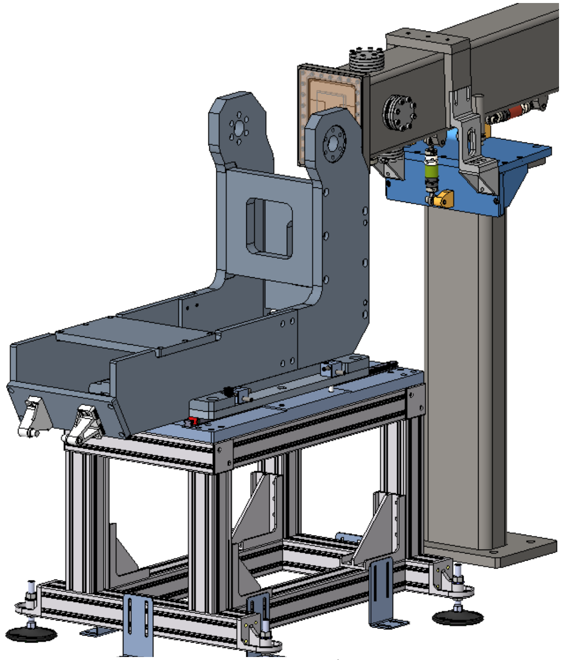
Cut in areas as mounting faces (parallelism, Perpendicularity, flatness)

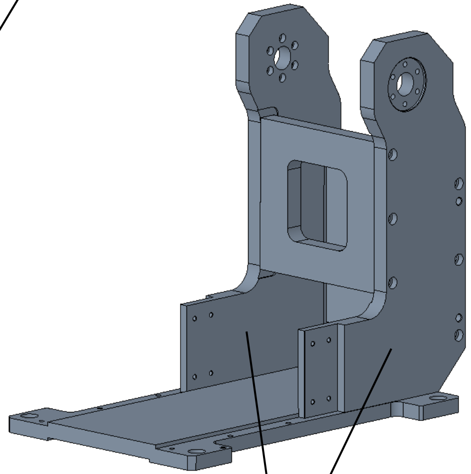
Bolts

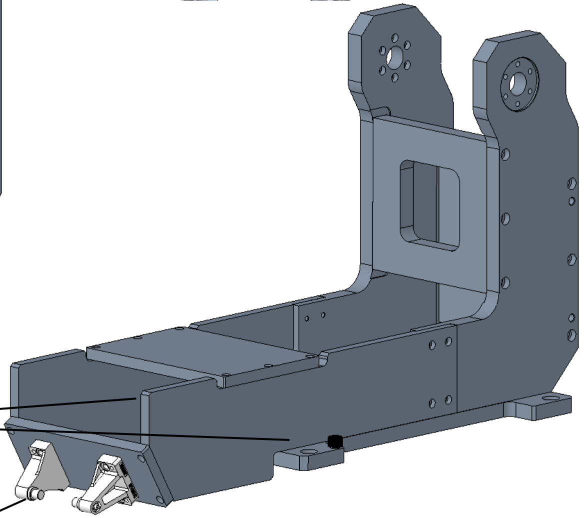
Pins



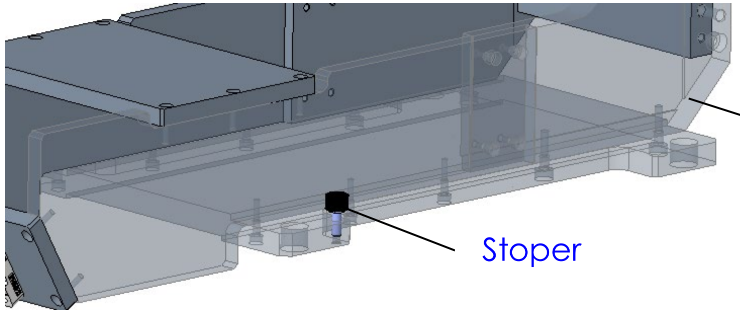
The sub-assembly is to be lifted by crane into the instrument cave (31 kg).







Panels are screwed To the base plate from below



Stoper

ZIMM Pivot Bracket Z-5/10-B

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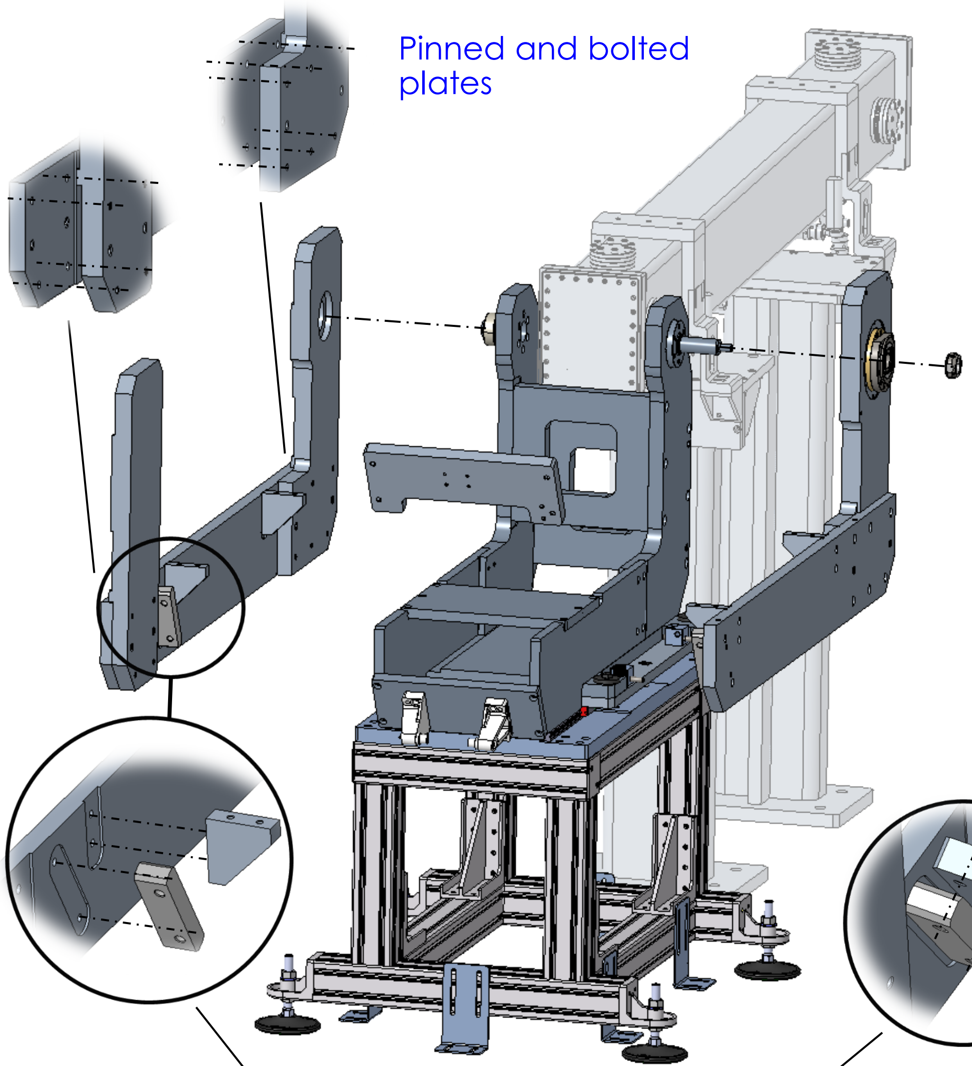
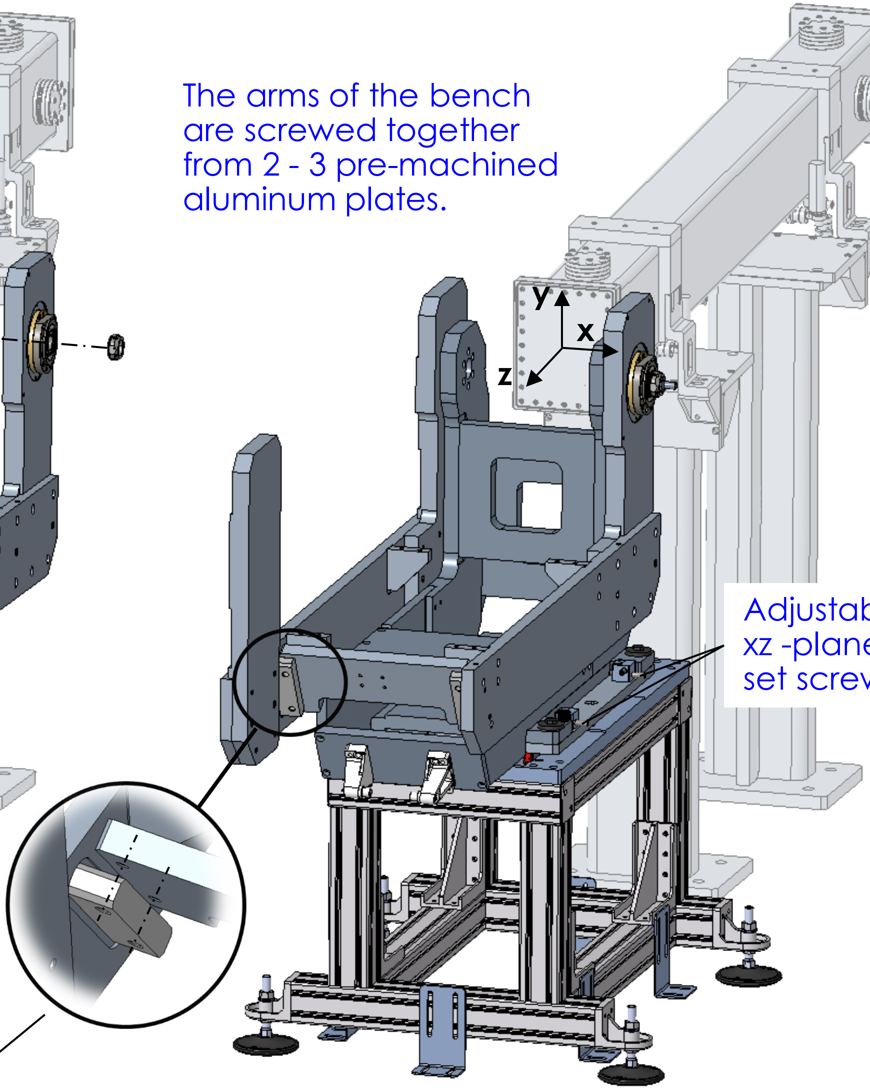
Incident Table – Installation Sequence Bench

Pinned and bolted plates



The arms of the bench are screwed together from 2 - 3 pre-machined aluminum plates.



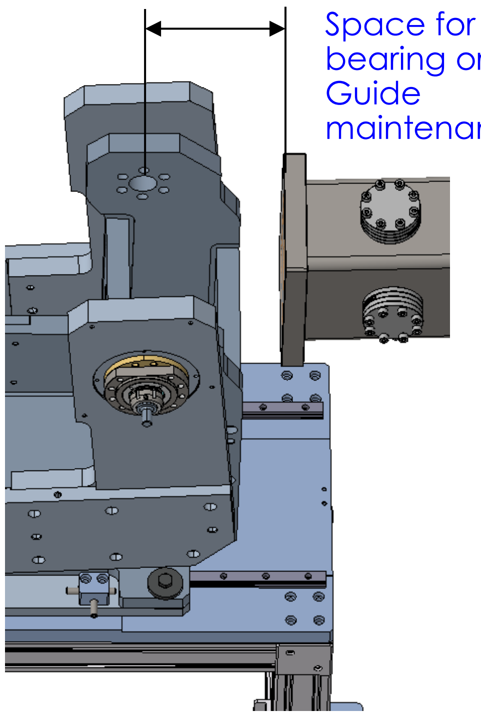
Adjustability in xz -plane with set screws

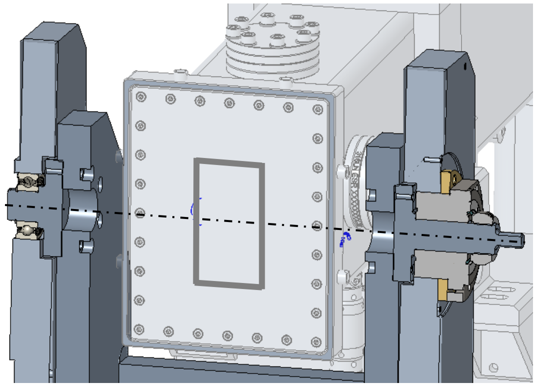
Appropriate connectors ensure a tension-free connection of the arms.

Vertical adjustability With machine feet

Stroke 200 mm

Space for bearing or Guide maintenance





Angle pivot is located at the guide end

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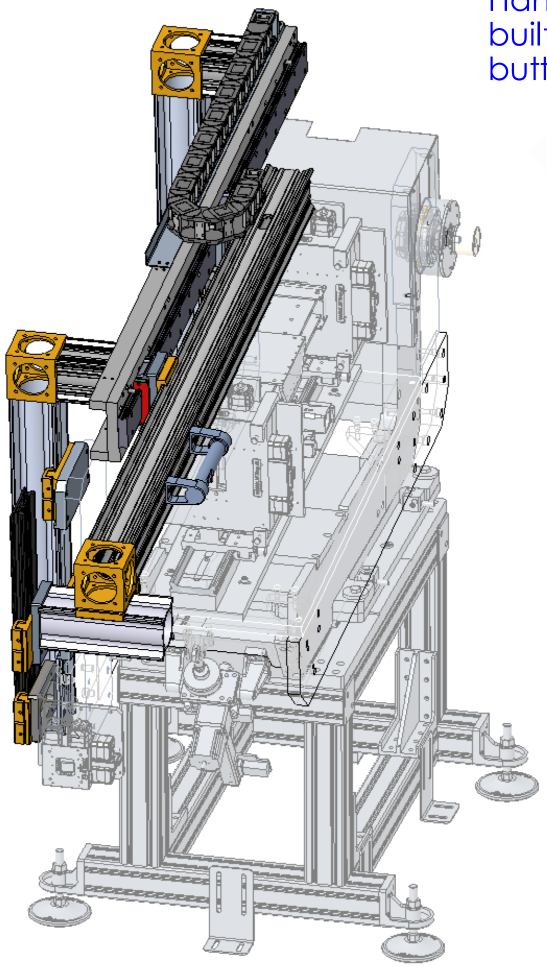
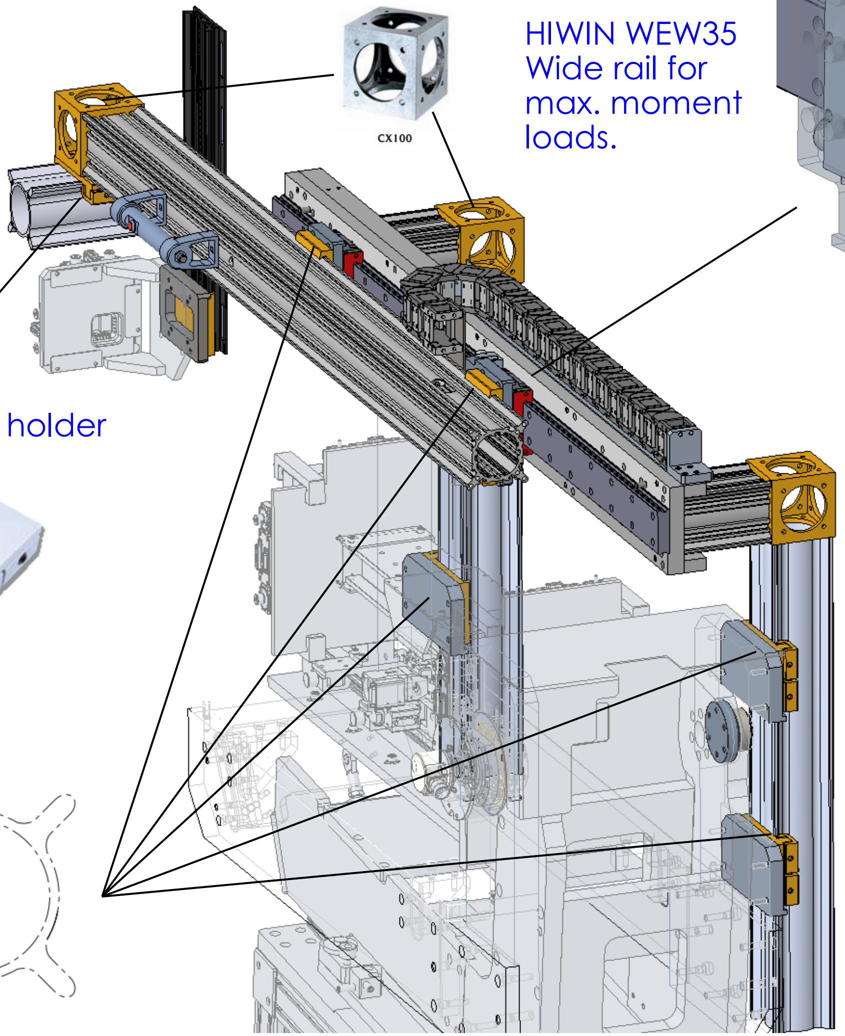
Incident Table – 3rd Slit Extension Arm

The X-95 structural rails are well suited for the entire structure of the slotted boom, as they offer maximal and cost-effective flexibility in adjustability as well as expansion or conversion.

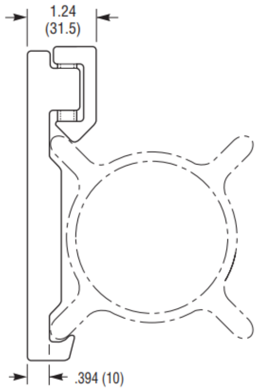


Handle with built-in push button

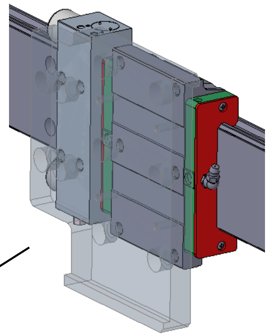
Structural cube



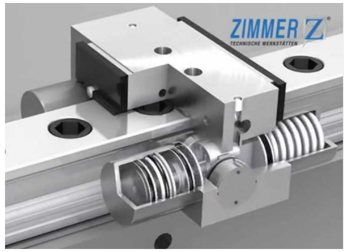
Profile Clamp holder



HIWIN WEW35 Wide rail for max. moment loads.



ZIMM MKS3501B Mechanically pretensioned brake releases with compressed air when the button is pushed and held.



X95 Frame design example

Cross coupling

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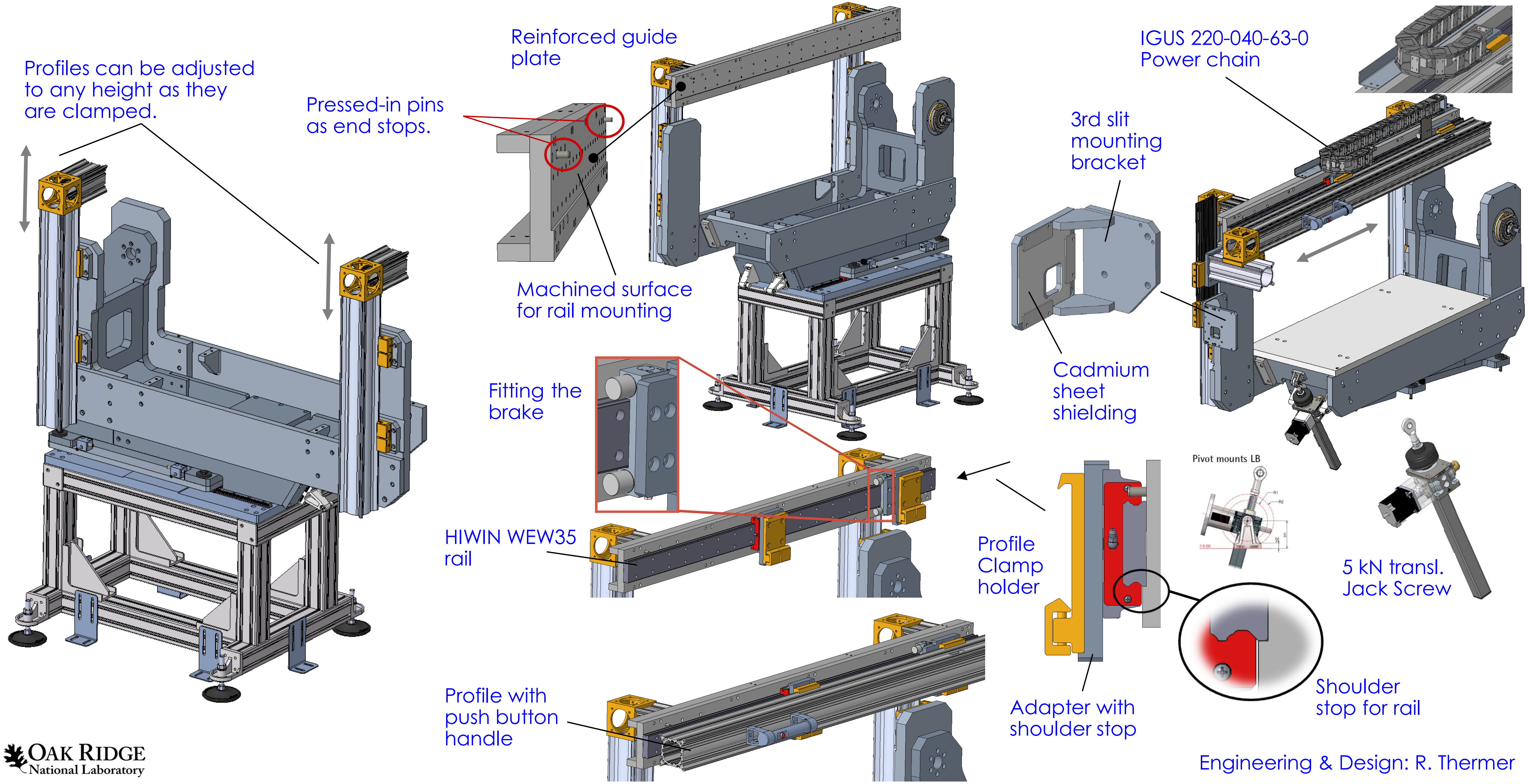
Incident Table – Installation Sequence Extension Arm



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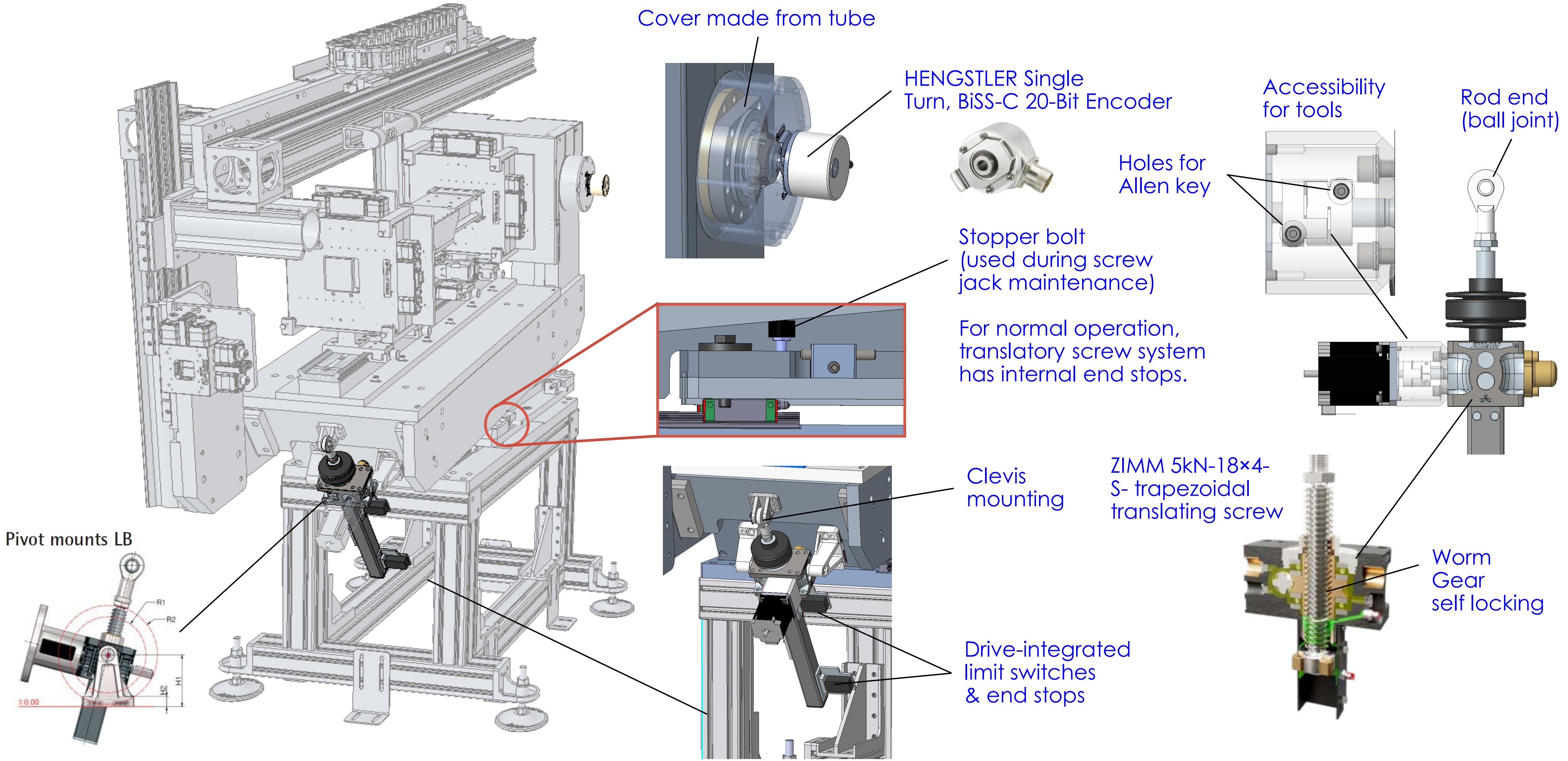
Incident Table – Motor, Encoder, End Stops, Limit Switches



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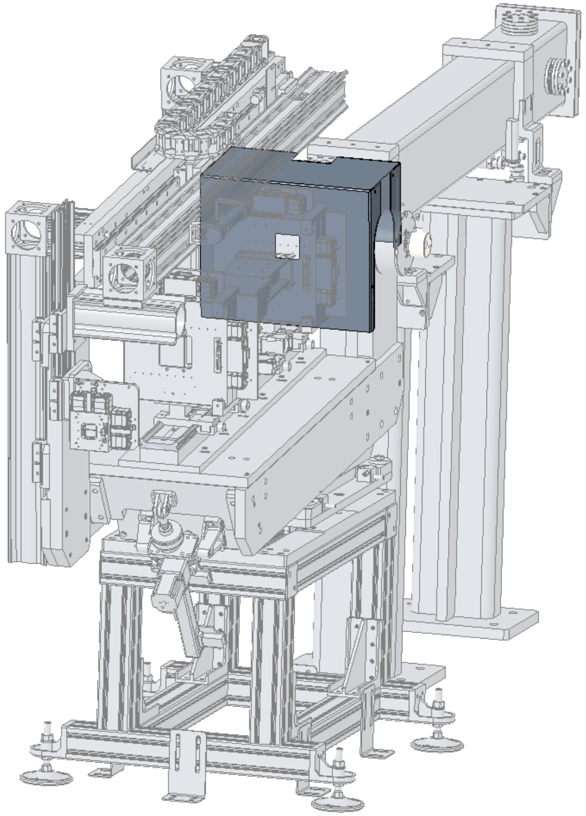
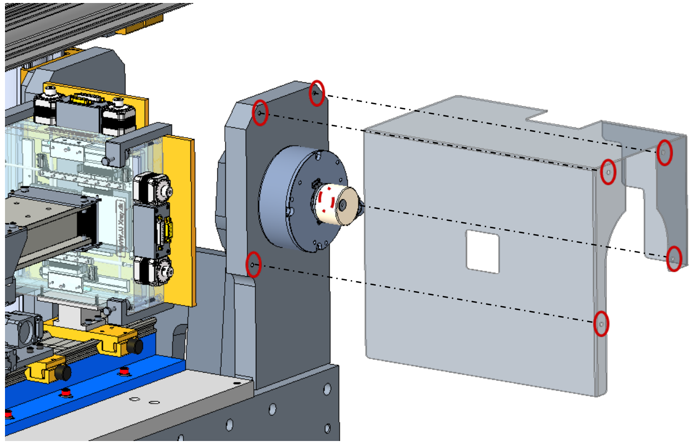
Incident Table – Installation Sequence

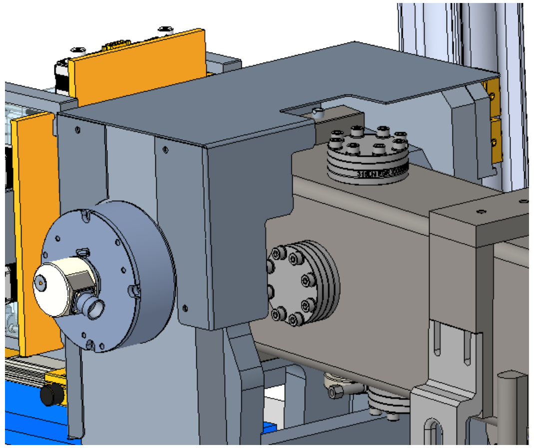
The hood is intended to prevent objects (for example, tools) from being left in the neutron path close to the guide end. This eliminates an accident scenario that can cause high radiation dose rates in the neighboring QIKR cave.



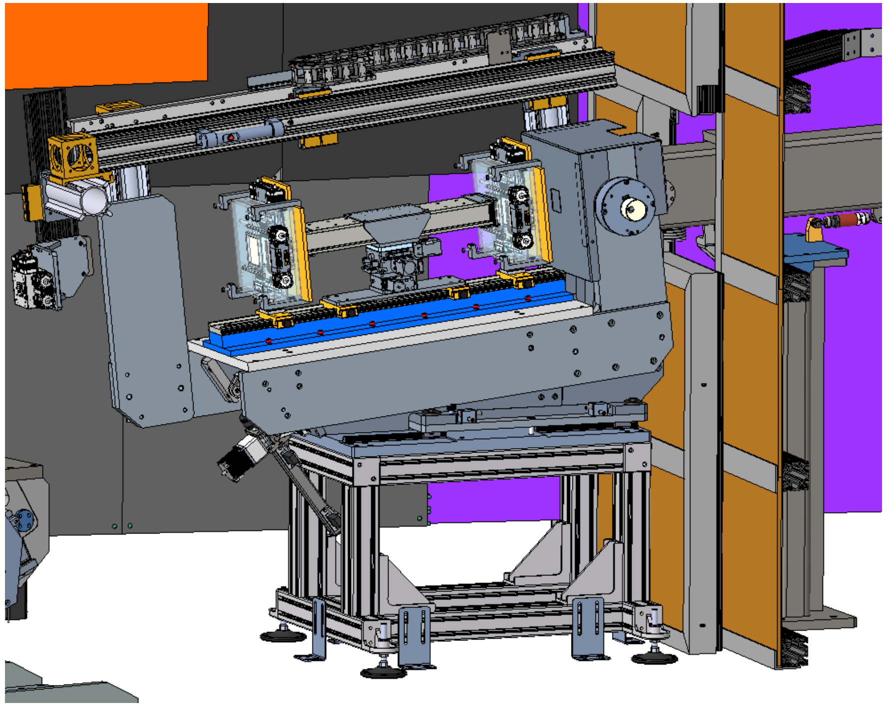
To attach the protective hood, four screw holes are required.



The cut out must allow sufficient freedom for the swivel motion of the instrument bench.



Limited space between the shielding wall and the hood makes it more difficult to place objects in the prohibited zone.



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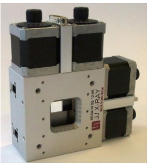
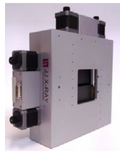
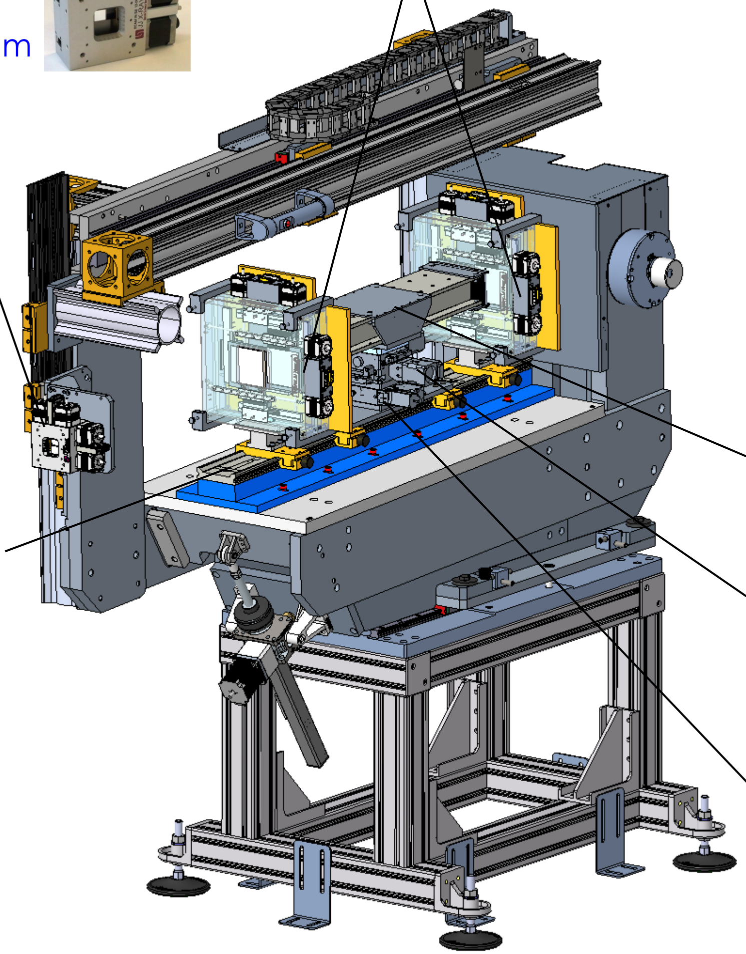
Incident Table – Optics Installation

JJ X-Ray
IB-C30-AIR Slits
Aperture size
30 mm x 30 mm

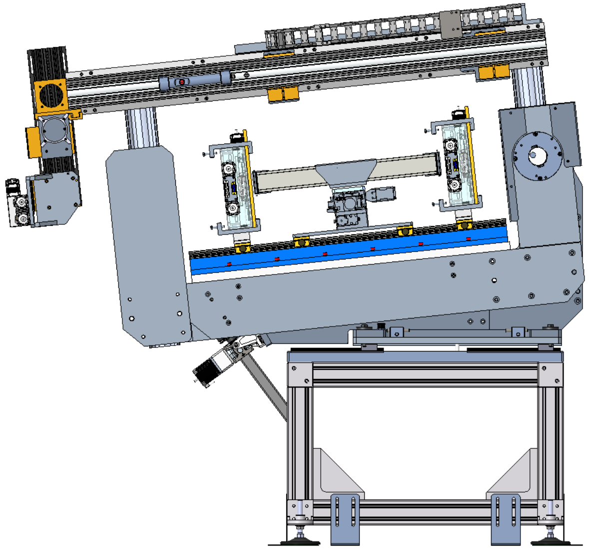


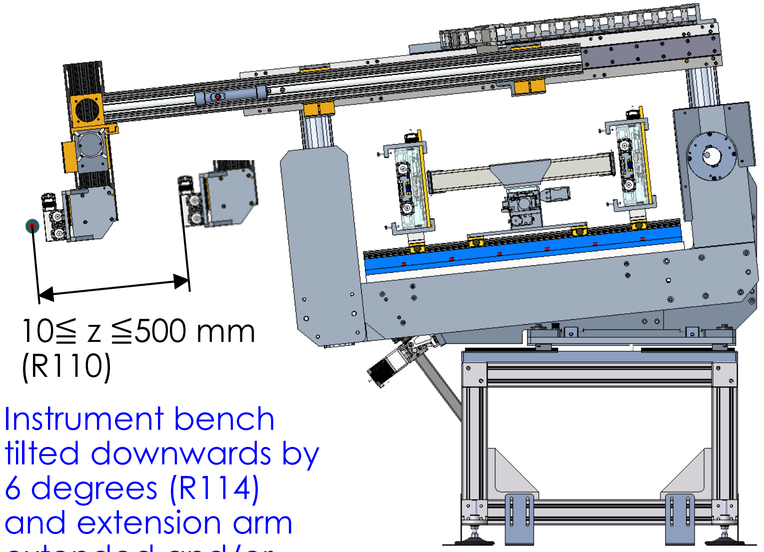
JJ X-Ray
IB-C80-AIR Slits
Aperture size
80 mm x 80 mm





X95 optic rail

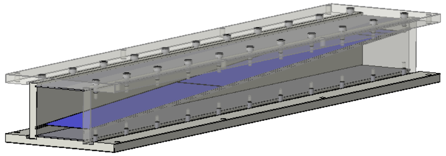




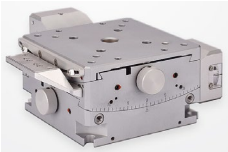
10≦ z ≦500 mm
(R110)

Instrument bench tilted downwards by 6 degrees (R114) and extension arm extended and/or retracted.

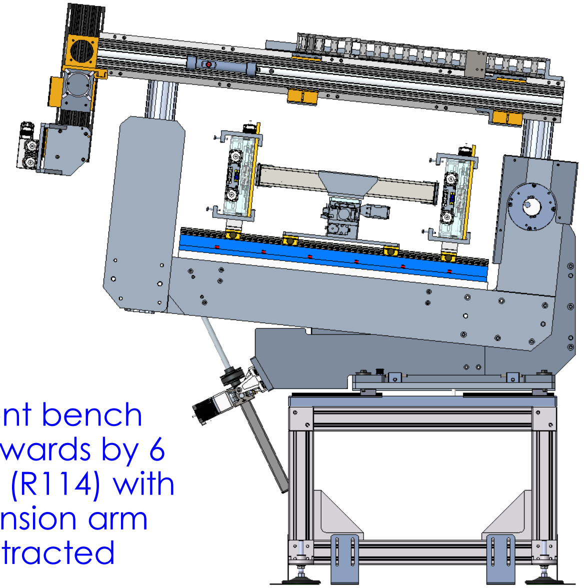
Frame overlap mirror



2-axis goniometer
Huber X-Ray
"2-Circle Segment 5203.10-150"



Vertical stage
Huber X-Ray
"Z-Stage 5103.A10"



Instrument bench tilted upwards by 6 degrees (R114) with the extension arm being retracted

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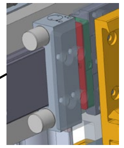
Incident Table – COST Component Details

- All components are from internationally well-established companies which are well represented in the US.
- Multiple vendors exist for some of the HIWIN, ITEM, FESTO, SKF products.

Huber X-Ray
“2-Circle Segment 5203.10-150” &
“Vertical stage Z-Stage 5103.A10”

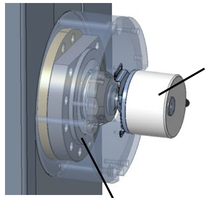
IGUS 220-040-63-0
Power chain



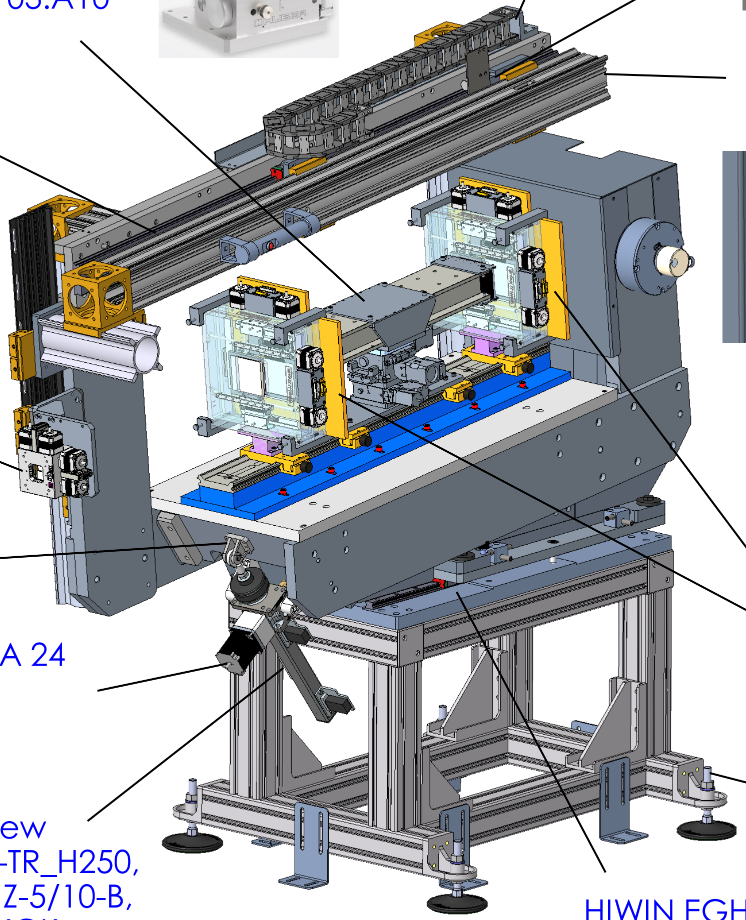
Zimmer Group
MKS3501B
Brake

MKS/Newport
X-95 structural rails

HIWIN WEW35
Wide rail for max. moment loads.



HENGSTLER
Single Turn,
BiSS-C 20-Bit
Encoder



JJ X-Ray
IB-C30-AIR Slits
Aperture size
30 mm x 30 mm

SKF Fixed Bearing
Package FBSA 206/DB

FESTO Clevis
Foot LBG-40

JJ X-Ray
IB-C80-AIR Slits
Aperture size
80 mm x 80 mm

NANOTEC NEMA 24
Stepper Motor
ST6018K2008-B

ITEM Profile 8
Modular System

ZIMM Jack Screw
System ZE-5-SL-TR_H250,
Pivot Brackets Z-5/10-B,
Rod end ZE-5-KGK

HIWIN EGH20CA
Profiled Rails

HENGSTLER Encoder
https://www.dynapar.com/

MKS/Newport Photonics Tech.
https://www.newport.com/

Zimmer Group
https://www.zimmer-group.com/en-us/about-us

FESTO, Automation
https://www.festo.com/us/en/e/about-festo/company-id_3688/

HIWIN, precision motion control and system technology.
https://hiwin.com/

ITEM Ind. Technology GmbH, machinery and equipment construction.
https://www.item24us.shop/contact/

JJ X-Ray, scientific x-ray and neutron instrumentation.
https://www.jjxray.dk/about-us/

Huber Diffraction and Positioning Equipment
https://www.xhuber.com/en/

Nanotec Motors & Drives
https://www.xhuber.com/en/

IGUS motion plastics
https://www.igus.com/

SKF Bearings
https://daltonbearing.com/

Incident Table – Actuator Calculations

Critical buckling force of the screws

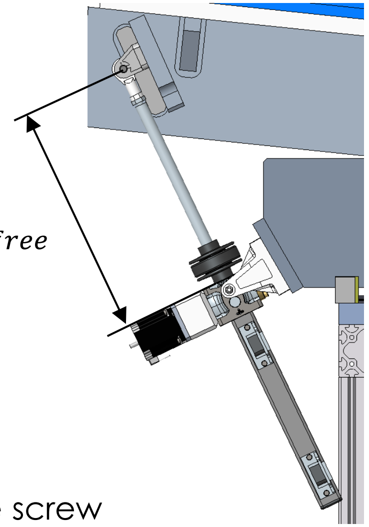
$F_{DW,IB} = 1715\ N, l_{1,IB} = 700mm$ Dead weight instrument bench.
$F_{PL,IB} = 1000\ N, l_{2,IB} = 1112\ mm$ Payload instrument bench. (R105: ≧ 90.7 kg)
$F_{SCR,\ IB} = ?, l_{SCR,\ IB} = 1105\ mm$ Reaction force screw jack

Force F_{IT} acting on the actuator's spindle:

$$F_{PL,IB} \cdot l_{2,\ IB} + F_{DW,\ IB} \cdot l_{1,\ IB} = F_{SCR,\ IB} \cdot l_{SCR,\ IB}$$

$$F_{SCR,\ IB} = \frac{F_{PL,IB} \cdot l_{2,\ IB} + F_{DW,\ IB} \cdot l_{1,\ IB}}{l_{IT}}$$

$$= \frac{1000\ N \cdot 1.112\ m + 1715\ N \ \cdot 0.7\ m}{1.105\ m} \cong 2.1\ kN$$



$F_{SCR,\ IB} = 2.1\ kN$ Reaction force screw jack
$l_{free} = 353\ mm$ Free screw length
$E = 210000\ N/mm^4$ E – modulus
$I = ?$ 2nd moment of area in mm^4
$v = 3$ Safety factor
$d = ?$ Minimum core diameter of the screw

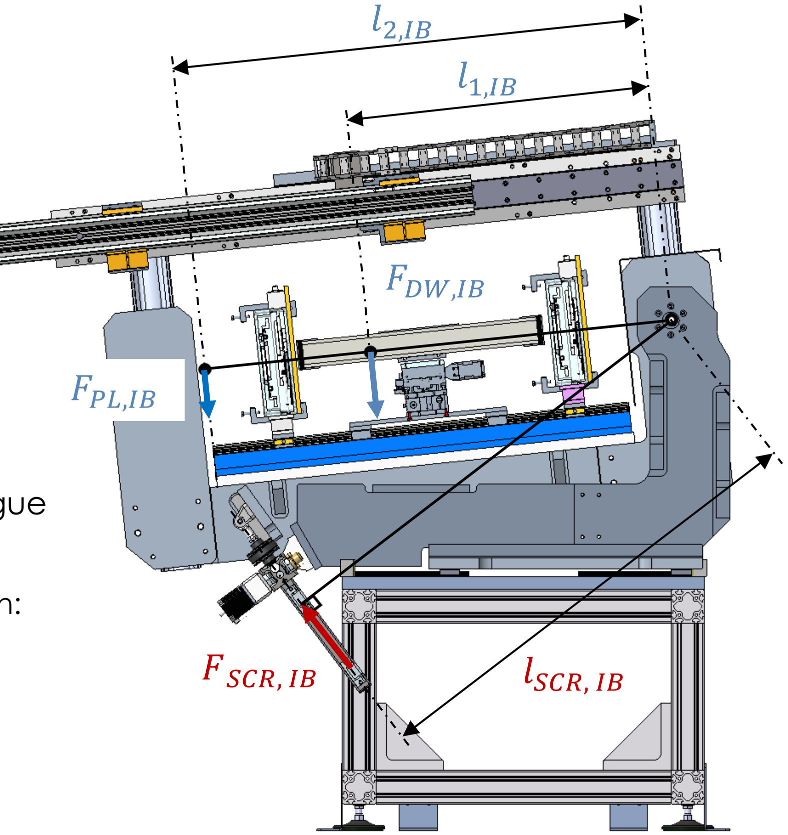
Thus, we obtain for the 2nd moment of inertia

$$I = \frac{F_{SCR,\ IB} \cdot v \cdot 4 \cdot {l_{IT,scr}}^2}{\pi^2 \cdot E} = \frac{2100\ N \cdot 3 \cdot 4\ (353\ mm)^2}{\pi^2 \cdot E} = 1515\ mm^4$$

and the minimum core diameter of the screw

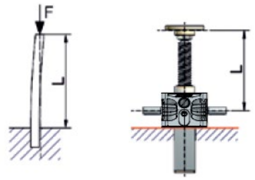
$$d = \sqrt[4]{\frac{I \cdot 64}{\pi}} = \sqrt[4]{\frac{1515\ mm^4 \cdot 64}{\pi}} = 13.3\ mm$$

Position of the CG evaluated for the extended downstream slit.



ZIMM Product Catalogue 2021 p.162

Conservative assumption: unguided case



$$I = \frac{F \times v \times (L \times 2)^2}{\pi^2 \times E} \quad \text{then } d = \sqrt[4]{\frac{I \times 64}{\pi}}$$

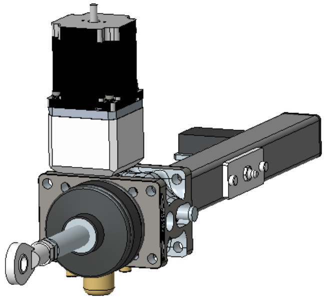
Screw Jack Series	GSZ-2	ZE-5	ZE-10	ZE-25	ZE-35/50
Trapezoidal screw Tr	16x4	18x4	20x4	30x6	40x7
Core-Ø in mm (minimum)	10,9	12,9	14,9	22,1	31
Ball screw KGT Ømm	16	16	25	32	40
Core-Ø in mm (minimum*)	12,9	12,9	21,5	27,3	34,1

Side note pivot bearings:
The static load rating of the floating bearing 62206-2RS1 is 11.2 kN and of the fixed bearing is 28.5 kN FBSA 206/DBB

Incident Table – Actuator Calculations

ZIMM jack screw systems

5kN-18×4-S-Trapezoidal Screw



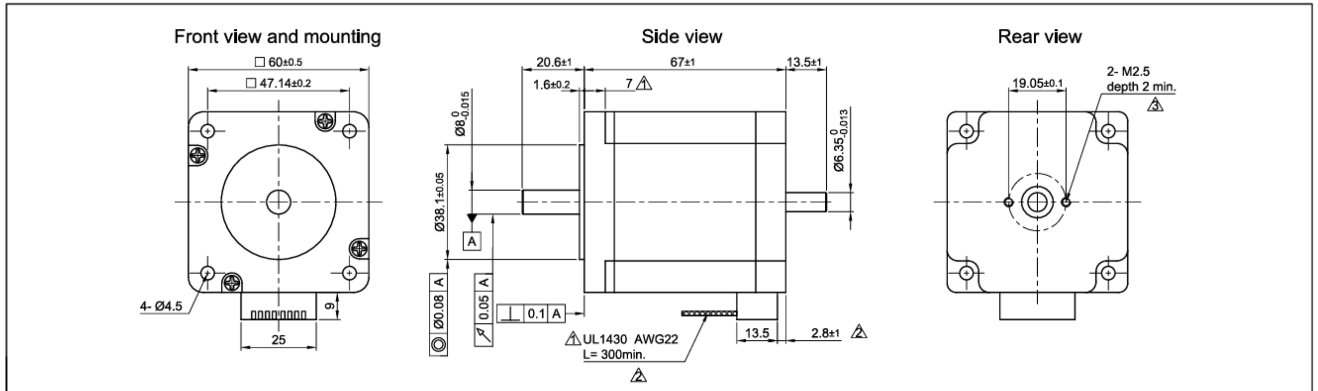
Size:	5 kN
Nominal speed:	1500 rpm
Max. drive shaft speed:	3000 rpm
Screw size standard:	18x4
Housing material:	Aluminium, corrosion-resistant
Worm shaft:	Steel, case-hardened, ground
Weight of screw jack body:	12 kg
Weight of screw/m:	158 kg
Gearbox lubrication:	Synthetic fluid grease
Screw lubrication:	Grease lubrication
Gearbox operating temperature:	max. 60°, higher on request
Moment of inertia:	N: 0.132 kg cm² / L: 0.091 kg cm²
Input torque (at 1500 rpm):	max. 4.7 Nm (N) / max. 1.5 Nm (L)
Drive-through torque:	max. 39 Nm
Screw:	Translating (S)

Standard configuration

Code	Gearbox (series)	Size	Version (variant)	Ratio	Screw	Stroke per drive shaft rotation
ZE-5-SN	ZE	5	S (translating screw)	N (normal) 4:1	Tr 18x4	1,00 mm
ZE-5-SL				L (low) 16:1		0,25 mm

Nanotec hybrid stepper motor

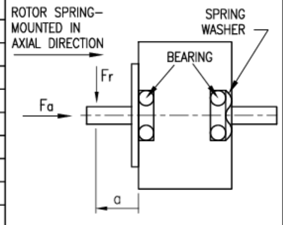
ST6018K2008-B – STEPPER MOTOR – NEMA 34



SPECIFICATION \ CONNECTION	UNIPOLAR OR BIPOLAR–1 WINDING	BIPOLAR SERIAL	BIPOLAR PARALLEL
VOLTAGE (VDC)	4.8		
AMPS/PHASE	2.0	1.41	2.82
RESISTANCE/PHASE (Ohms)@25°C	2.4±15%	4.8±15%	1.2±15%
INDUCTANCE/PHASE (mH) @1KHz	4.6±20%	18.4±20%	4.6±20%
HOLDING TORQUE (Nm) [lb–in]	1.5 [13.28]	2.12 [18.76]	2.12 [18.76]
DETENT TORQUE (Nm) [lb–in]	0.045 [0.398]		
STEP ANGLE (°)	1.8		
STEP ACCURACY (NON–ACCUM)	±5%		
ROTOR INERTIA (Kg–m²) [lb–in²]	5.7x10⁻⁵ [0.195]		
WEIGHT (Kg) [lb]	1.2 [2.65]		

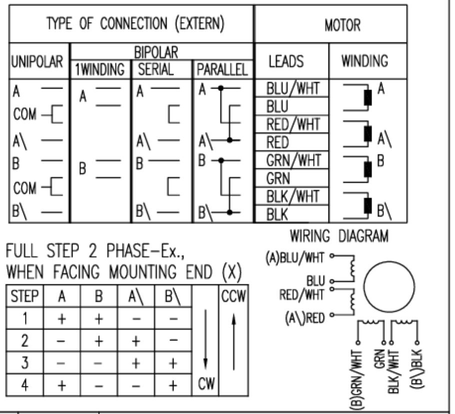
TEMPERATURE RISE: MAX.80°C (MOTOR STANDSTILL; FOR 2 PHASE ENERGIZED)
AMBIENT TEMPERATURE –10°~ 50°C [14°F ~ 122°F]
INSULATION RESISTANCE 100 MOhm (UNDER NORMAL TEMPERATURE AND HUMIDITY)
INSULATION CLASS B 130° [266°F]
DIELECTRIC STRENGTH 500VAC FOR 1 MIN. (BETWEEN THE MOTOR COILS AND THE MOTOR CASE)
AMBIENT HUMIDITY MAX. 85% (NO CONDENSATION)

PERMISSIBLE RADIAL+AXIAL FORCE



AXIAL–FORCE Fa (N)	Fa=14			
DISTANCE a (mm)	5	10	15	20
RADIAL–FORCE Fr (N)	163	112	85	63

	AXIAL	RADIAL
SHAFT PLAY (mm)	0.075	0.025
AT LOAD MAX: (N)	10	5.0



FULL STEP 2 PHASE–Ex., WHEN FACING MOUNTING END (X)

STEP	A	B	A\	B\
1	+	+	–	–
2	–	+	+	–
3	–	–	+	+
4	+	–	–	+

CCW / CW

REV	DESCRIPTION	DATE	DRN
3	change tolerance	08.11.16	A.S.
2	change tol. cable/rework draw	09.03.16	A.S.
1	LENGTH+UL NO.	04.08.09	J.W.

Nanotec® PLUG & DRIVE

Surface specification DIN ISO 1302 | General tolerances DIN ISO 2768- cH | Work piece edge DIN ISO 13715

	SIGNATURE	DATE
APVD	S.Ha.	16.01.07
CHKD		
DRN	J.W.	13.07.06

STEPPING MOTOR

DWG.NO ST6018K2008–B

Incident Table – Actuator Calculations

Necessary drive torque

ZIMM 5kN-18×4-S-Trapezoidal Screw

$F_{SCR,IB} = 2.1\ kN$	Force acting on the spindle
$p = 4\ mm$	Screw pitch
$\eta_{gear} = 0.53$	Gearbox efficiency (worm gear screw jack)
$\eta_{screw} = 0.42$	Screw efficiency
$i = 16$	Gearbox ratio
$M_{G,5} = ?$	Necessary drive torque

$$M_{G,5} = \frac{F_{SCR,IB} \cdot p}{2 \cdot \pi \cdot \eta_{gear} \cdot \eta_{screw} \cdot i} = \frac{2100\ N\ \cdot 0.004\ m}{2 \cdot \pi \cdot 0.53 \cdot 0.42 \cdot 16} = \underline{0.4\ Nm}$$

Efficiencies of the screw jack $\eta_{Gearbox}$ (without screw)

i	rpm	GSZ-2	ZE-5	ZE-10	ZE-25	ZE-35
N	3000	0,87	0,81	0,83	0,87	-
N	1500	0,87	0,82	0,84	0,87	0,87
N	1000	0,86	0,82	0,82	0,86	0,87
N	750	0,86	0,82	0,84	0,85	0,86
N	500	0,85	0,82	0,84	0,83	0,85
N	100	0,74	0,77	0,79	0,78	0,78
L	3000	0,78	0,74	0,78	0,76	-
L	1500	0,77	0,70	0,74	0,72	0,64
L	1000	0,75	0,67	0,72	0,7	0,64
L	750	0,74	0,65	0,7	0,68	0,64
L	500	0,71	0,62	0,67	0,65	0,63
L	100	0,54	0,53	0,59	0,54	0,52

Efficiencies of the screws η_{Screw}

Tr-screw, single-pitch	16x4	18x4	20x4	30x6	40x7	50x8	55x9
Efficiency	0,45	0,42	0,39	0,39	0,35	0,33	0,34
Tr-screw, double-pitch	**16x8P4**	**18x8P4**	**20x8P4**	**30x12P6**	**40x14P7**	**50x16P8**	**55x18P9**
Efficiency	0,62	0,59	0,56	0,56	0,53	0,50	0,51

Motor torque, resolution and speed

Nanotec ST6018K2008-B

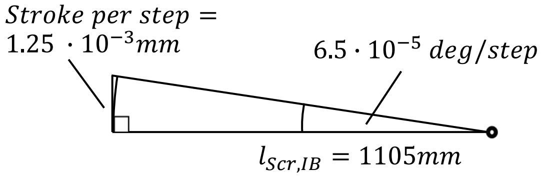
Selection: $Stepper\ motor\ with\ 1.6\ Nm\ torque\ at\ 200\ rpm\ (4 \cdot M_{G,5})$

Resolution: $Stroke\ per\ drive\ shaft\ rotation = 0.25\ mm$

$$Stroke\ per\ step\ (1.8°) = \frac{0.25\ mm}{200} = 0.00125\ mm$$

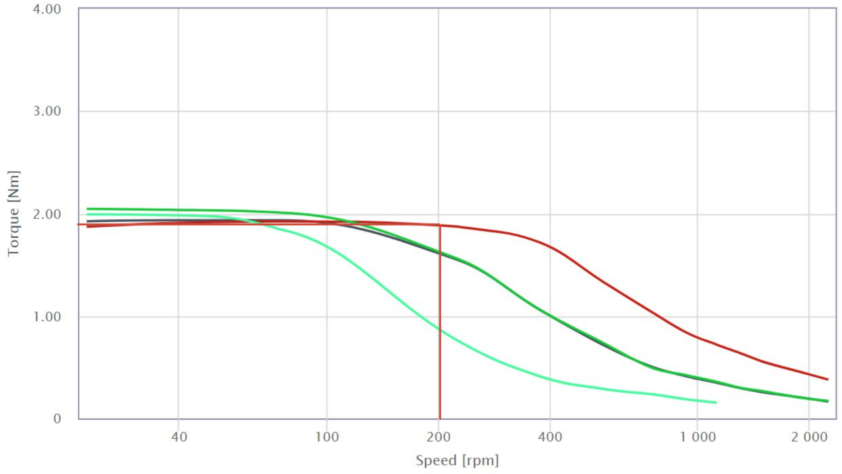
$$Angular\ Resolution \approx \text{asin} \frac{1.25 \cdot 10^{-3} mm}{1105 mm} = \underline{6.5 \cdot 10^{-5}\ deg}$$

Speed: $Duration\ for\ the\ whole\ stroke = \frac{250\ mm}{200\ rpm \cdot 0.25\ mm} = \underline{5\ min}$



$$\frac{specified\ ang.resolution}{angle\ per\ step} = \frac{5 \cdot 10^{-4}}{6.5 \cdot 10^{-5}} = 7.7$$ (R114)

Torque curve ST6018K2008-B



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Engineering & Design: R. Thermer

Incident Table – Encoder Calculation

Rotary resolution and pulses per revolution (ppr)

The required number of **pulses per revolution** is

$$Rotary\ Resolution\ (ppr) = \frac{360\ Mechanical\ Degrees\ (°)}{Min\ Required\ Offset\ (°)} = \frac{360°}{(5 \cdot 10^{-4})°} = 720000\ ppr$$

HENGSTLER Single Turn, BiSS-C 20-Bit Encoder

Part Number	AC58/0020AF.49BED-P0-D
Type	AC58 - Absolute Encoder
Resolution	0020 - 20 Bit ST
Supply Voltage	A - DC 5 V
Flange, Protection, Shaft	F.49 - Spring tether, IP64 , hubshaft 14 mm, mounting with front clamping ring
Interface	BE - BiSS-C
Connection	D - M23 Conin, 12 Pole Radial, CW
Cable Length	P0=15 m
Connector at Cable End	D - M23 Coupling, 12 Pin, CCW

Encoder ppr selection:

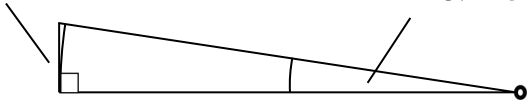
$19\ Bit\ ST$: $2^{19} = 524288$ ppr

$20\ Bit\ ST$: $2^{20} = 1048576$ ppr

$22\ Bit\ ST$: $2^{22} = 4194304$ ppr

Drive resolution vs. encoder resolution

$$\frac{Encoder\ resolution}{Drive\ resolution} = \frac{360°/1048576}{6.5 \cdot 10^{-5}} = 5.3$$



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Questions?