LMECA2840 – Technical Presentation III

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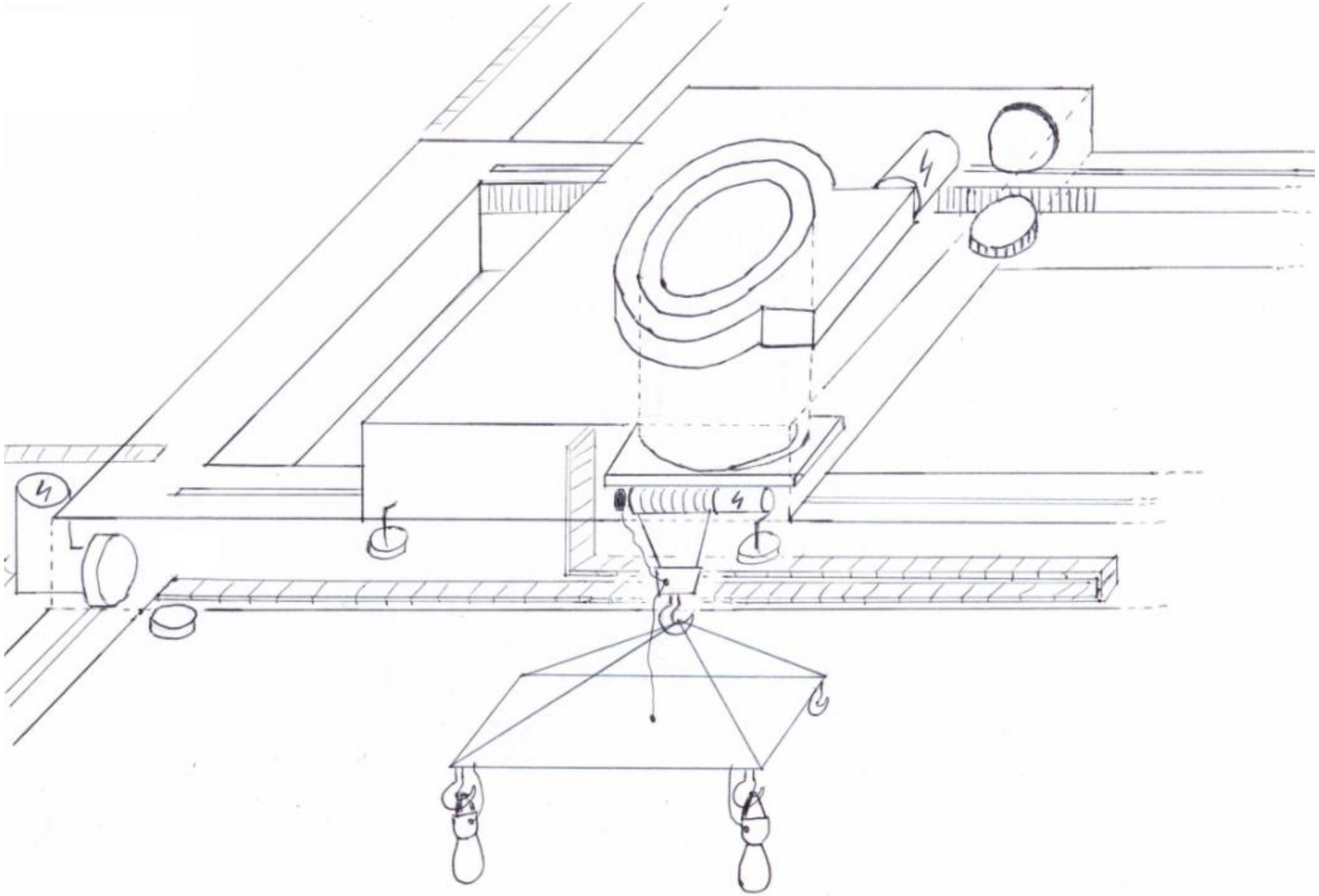
Group A5

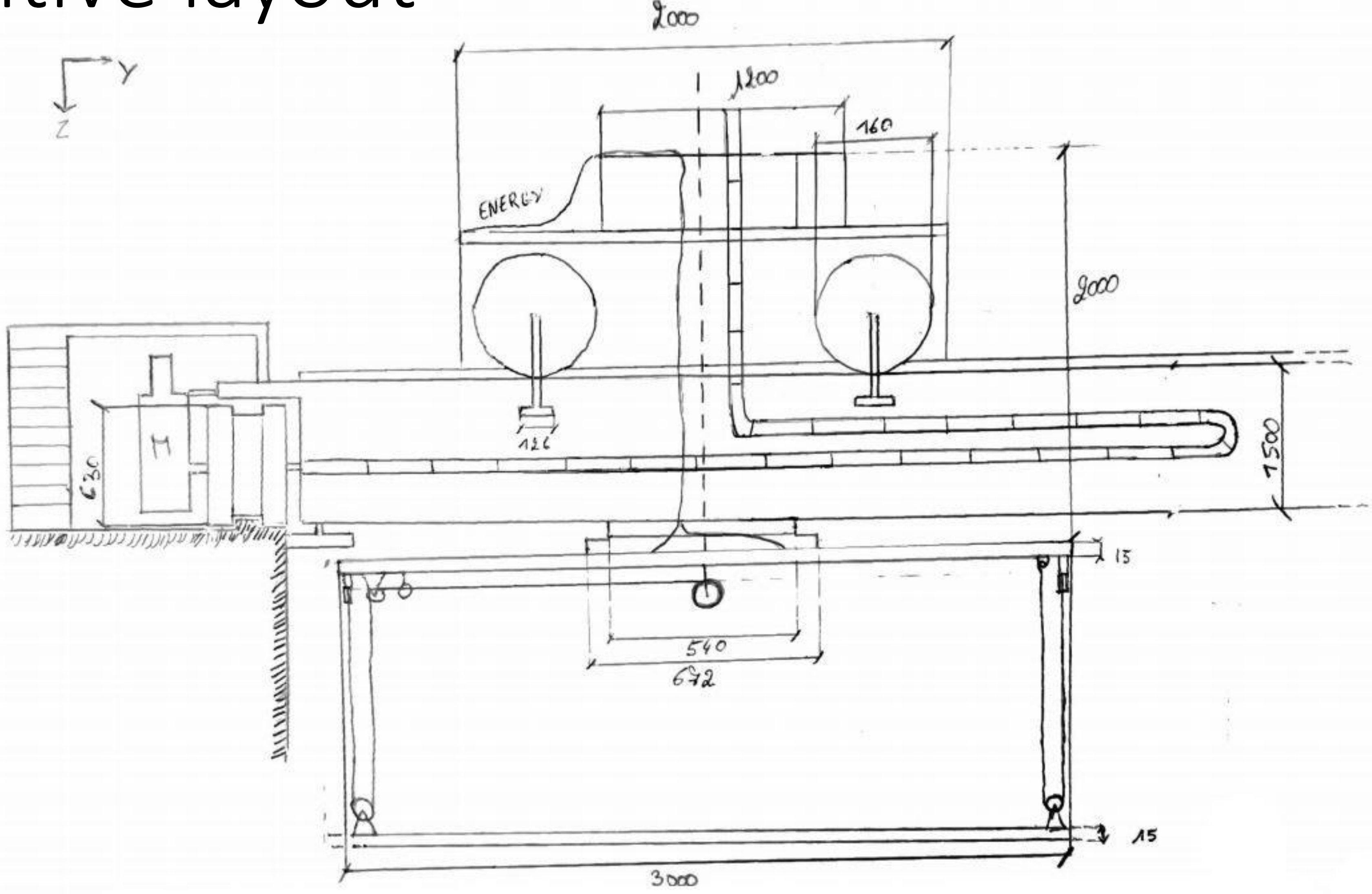
SUMMARY

- Introduction of the project
  - Preliminary VS Current design
- Dimensioning
  - Platform
  - Cables
  - Vertical column + Sewing ring
  - Trolley
  - Main beams
  - Shaft, bearings, motor, rollers
- Sensors

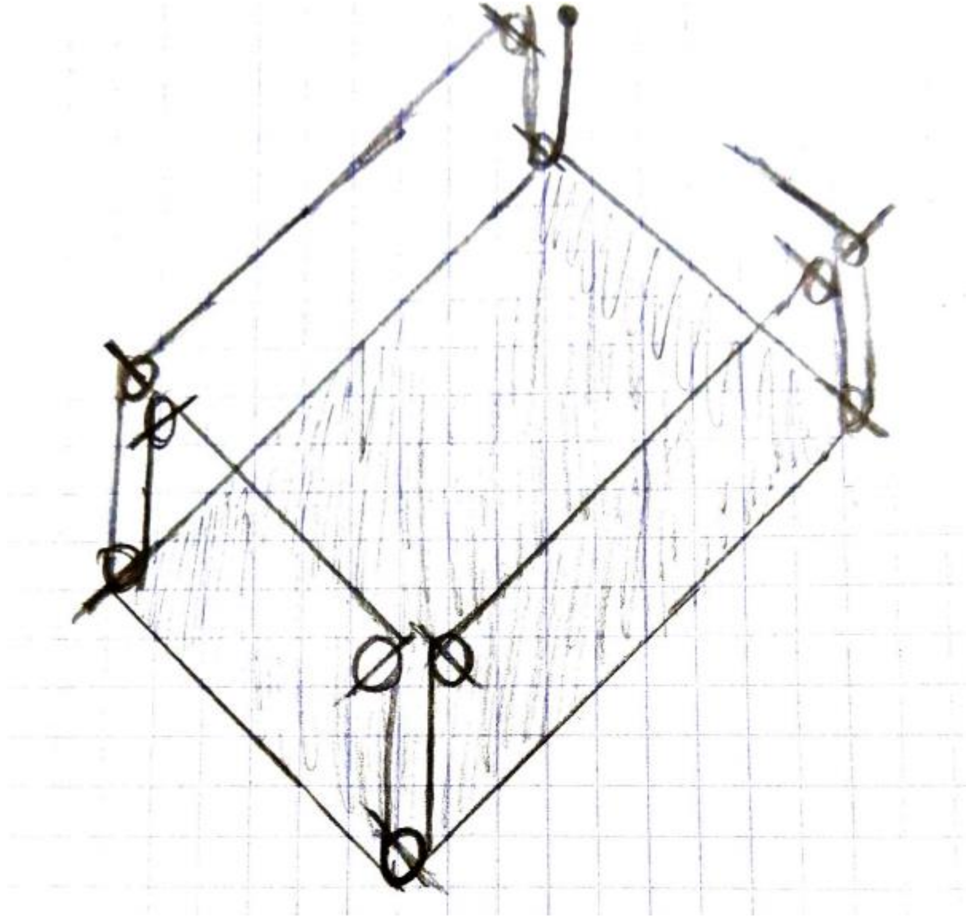
Preliminary layout

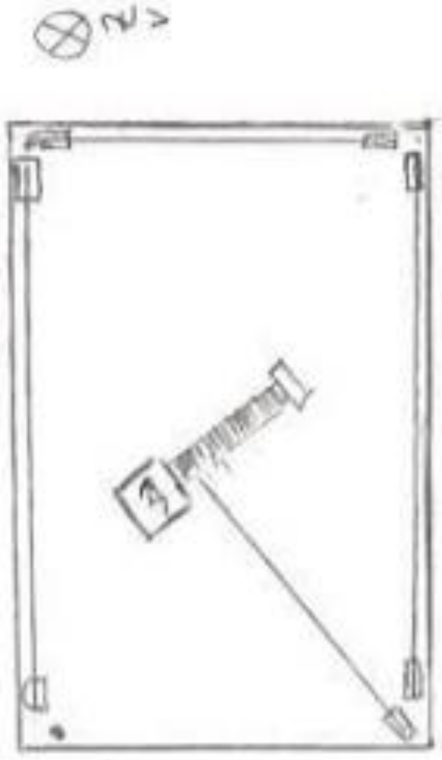


Definitive layout

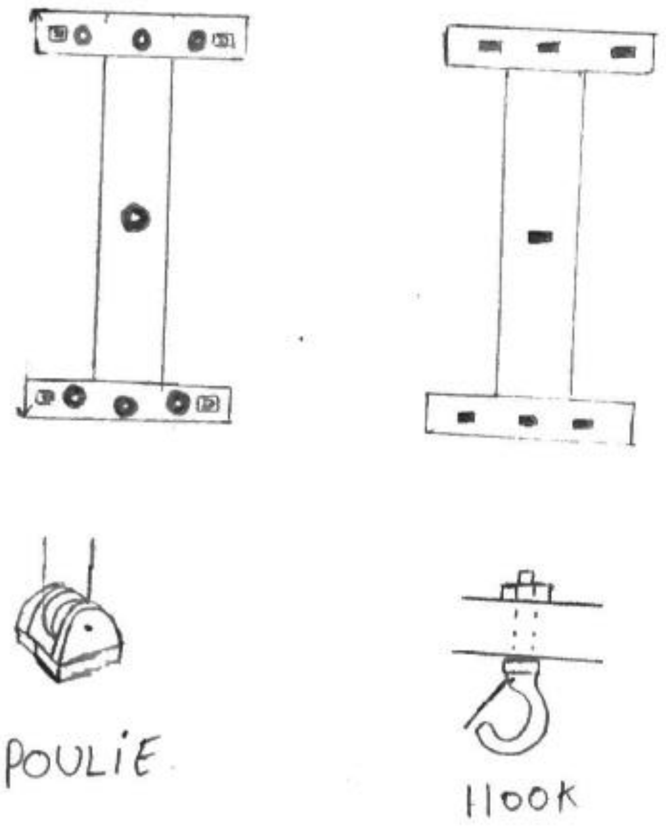


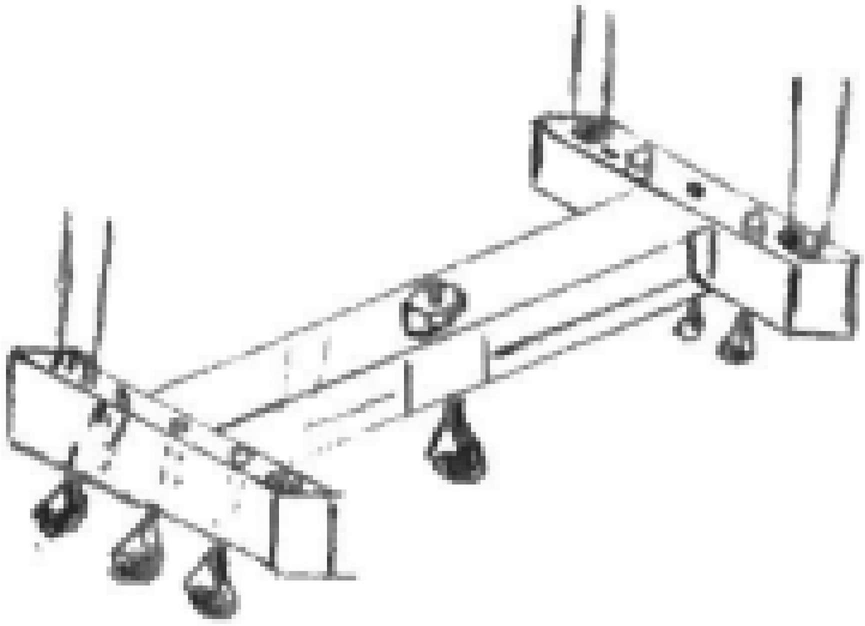
Modifications



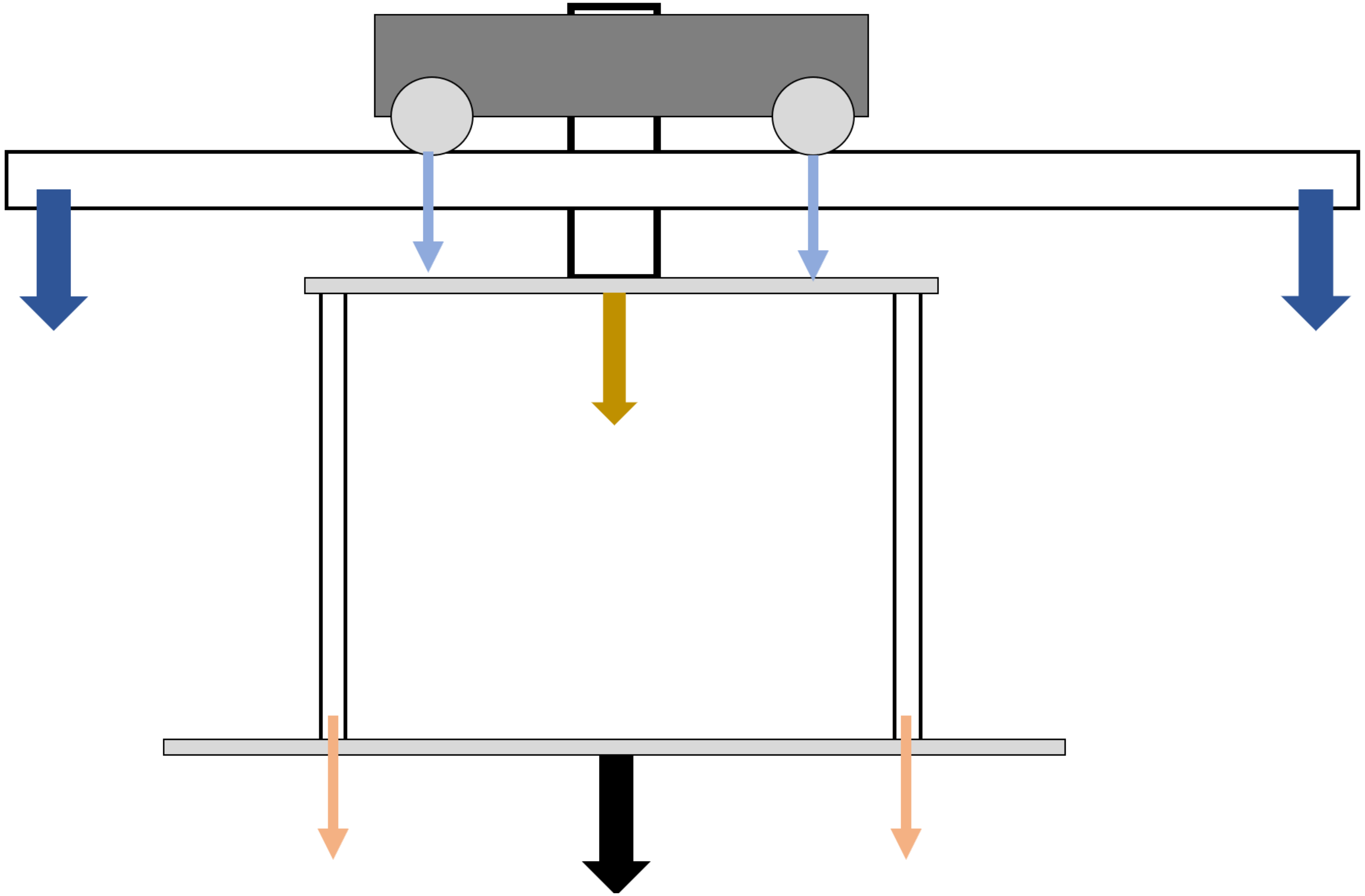


Modifications





DIMENSIONING – Force Analysis



DIMENSIONING - Platform

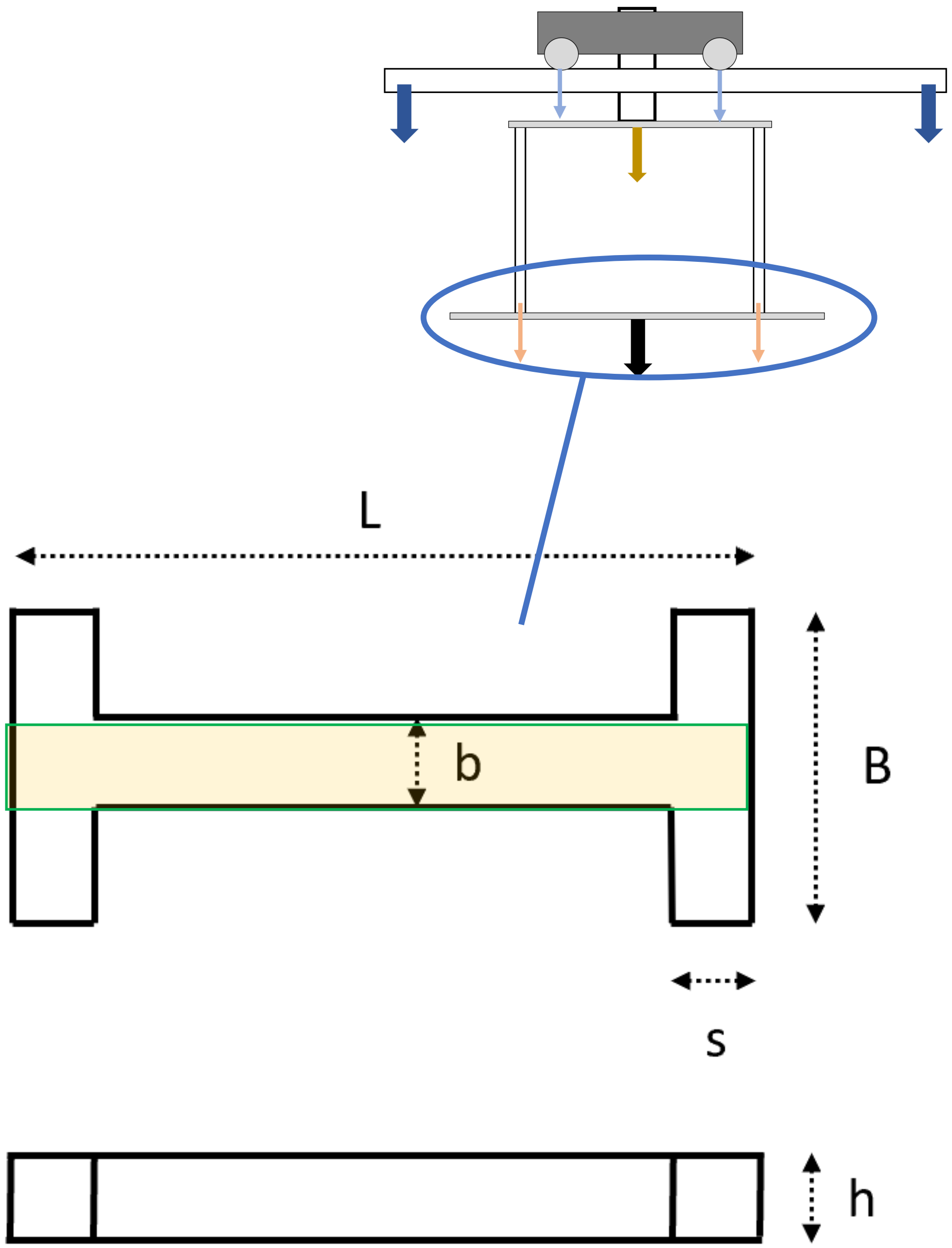
Assumptions

- Security factor : $\gamma = 2$
- Material : A36 steel

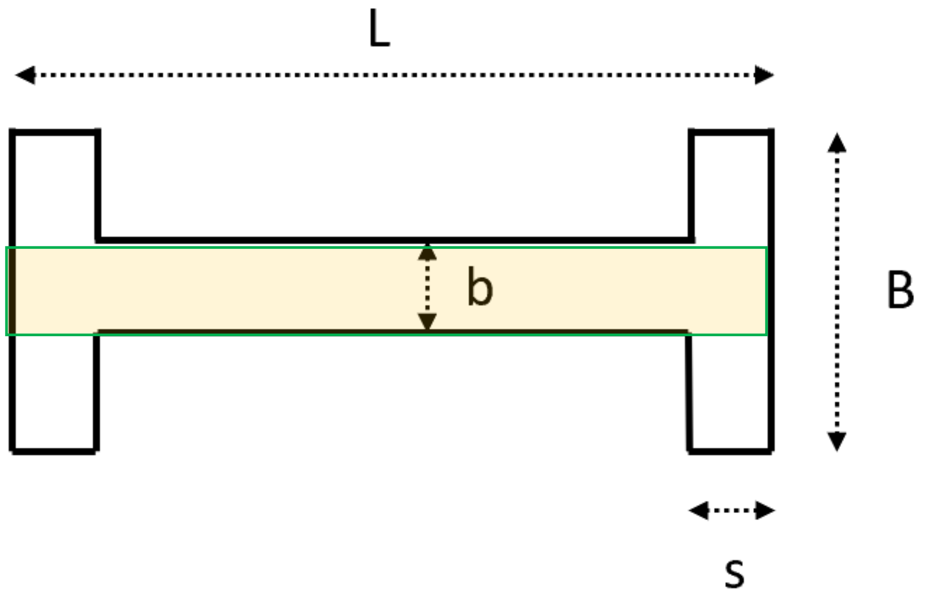
  $\rho =$ 7800 [kg/m³]

  $\sigma_y = 250$ [MPa]
- No shear/axial stress
- Shape → Rectangular section

  → $I = bh^3/12$
- Loading → 15 tons in the middle



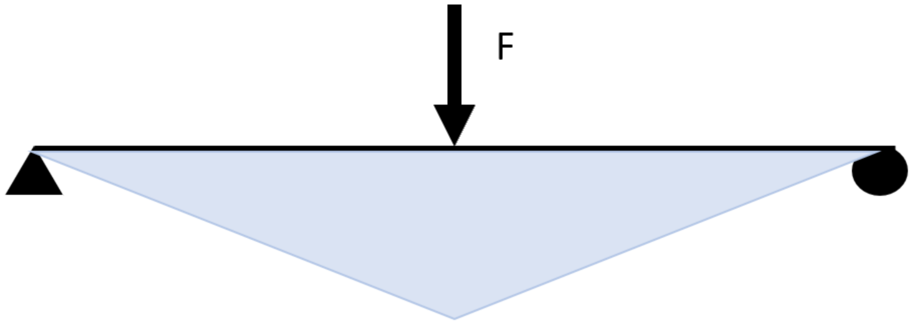
DIMENSIONING - Platform



$$\boxed{\sigma_{max} = \frac{M_{max} \cdot h/2}{I}}$$

$$\boxed{\sigma_y > \gamma \sigma_{max}}$$

$$h > \sqrt{\frac{3\gamma F L}{2b\sigma_y}}$$



$M_{max} = FL/4$

- L = 3 m
- b = 0.3 m
- B = 1.5 m
- s = 0.2 m

$$\boxed{\begin{array}{l} h = 15\ \text{cm} \\ W_{platform} = 1650\ \text{kg} \end{array}}$$

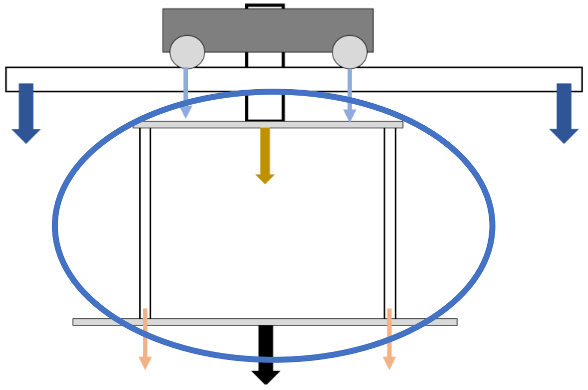
DIMENSIONING - Cable

Assumptions

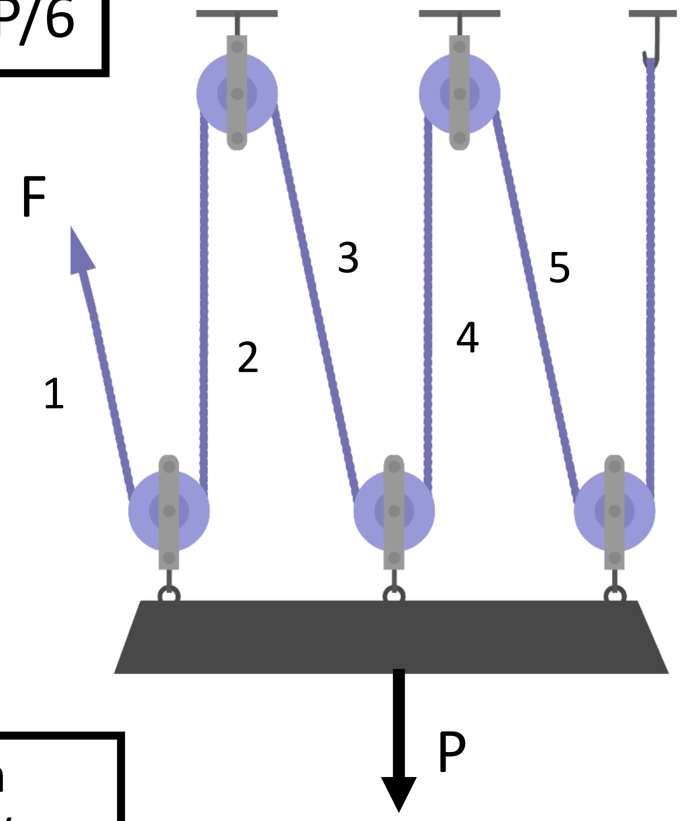
- Safety factor : γ = 8
- Tension only
- Material :

  W_L depends on diameter [kg/m]

  σ_y = 1700 [MPa]
- L_{tot} = 150m
- Weight uniformly divided by 8



$\boxed{F = P/6}$



$$\boxed{\sigma_{max} = \frac{F}{A}}$$

$$\boxed{\sigma_y > \gamma \sigma_{max}}$$

$$D_{min} = \sqrt{\gamma \frac{4F}{\pi \sigma_y}}$$

$$\text{where } F = \frac{W_{piece} + W_{platform}}{8}$$

D_{min} = 13 mm
W_L = 0.63 kg/m
W_{cables} = 95 kg

DIMENSIONING – Vertical column and slewing ring

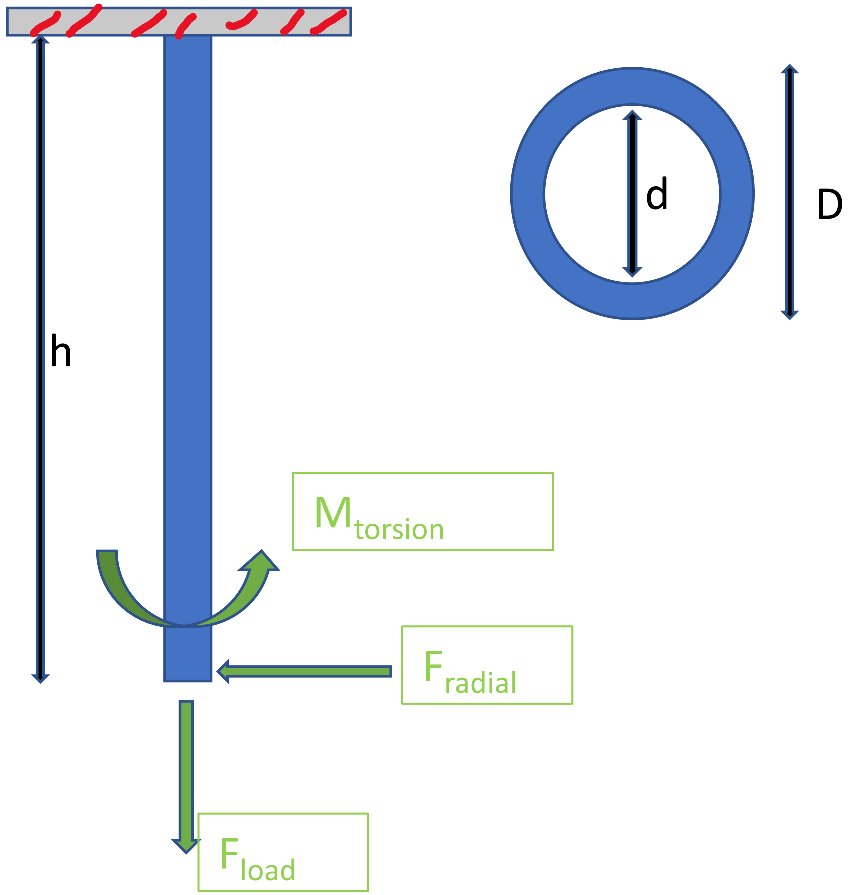
Assumptions

- Material : A36 steel
  - ρ = 7800 [kg/m³]
  - σ_y = 250 [MPa]
  - Tau_y = 144 [Mpa]
- Tension due to the weight of the platform and the piece
- Torsion due to moment of inertia of the components
- Bending due to x-y displacement
- Shape → Hollow cylinder with ratio D/d = 1.2 … 1.5
- Built-in beam at the slewing ring

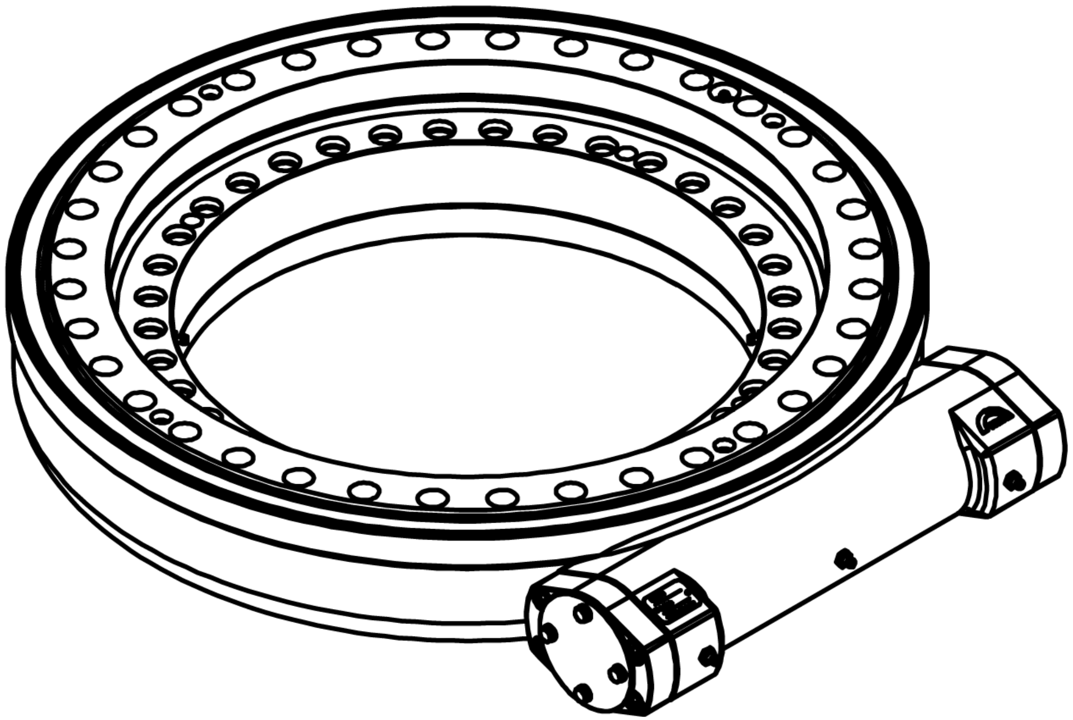
$$\sigma_y \geq \frac{F_{load}}{A}$$

$$\tau_y \geq \frac{M_{torsion} \cdot r}{J}$$

$$\sigma_y \geq \frac{F_{radial} \cdot h \cdot y}{I}$$



DIMENSIONING – Vertical column and slewing ring



- F_{Load} = 174 [kN]
- $M_{torsion}$ = 14.3 [kNm]
- $M_{bending}$ = 6 [kNm]

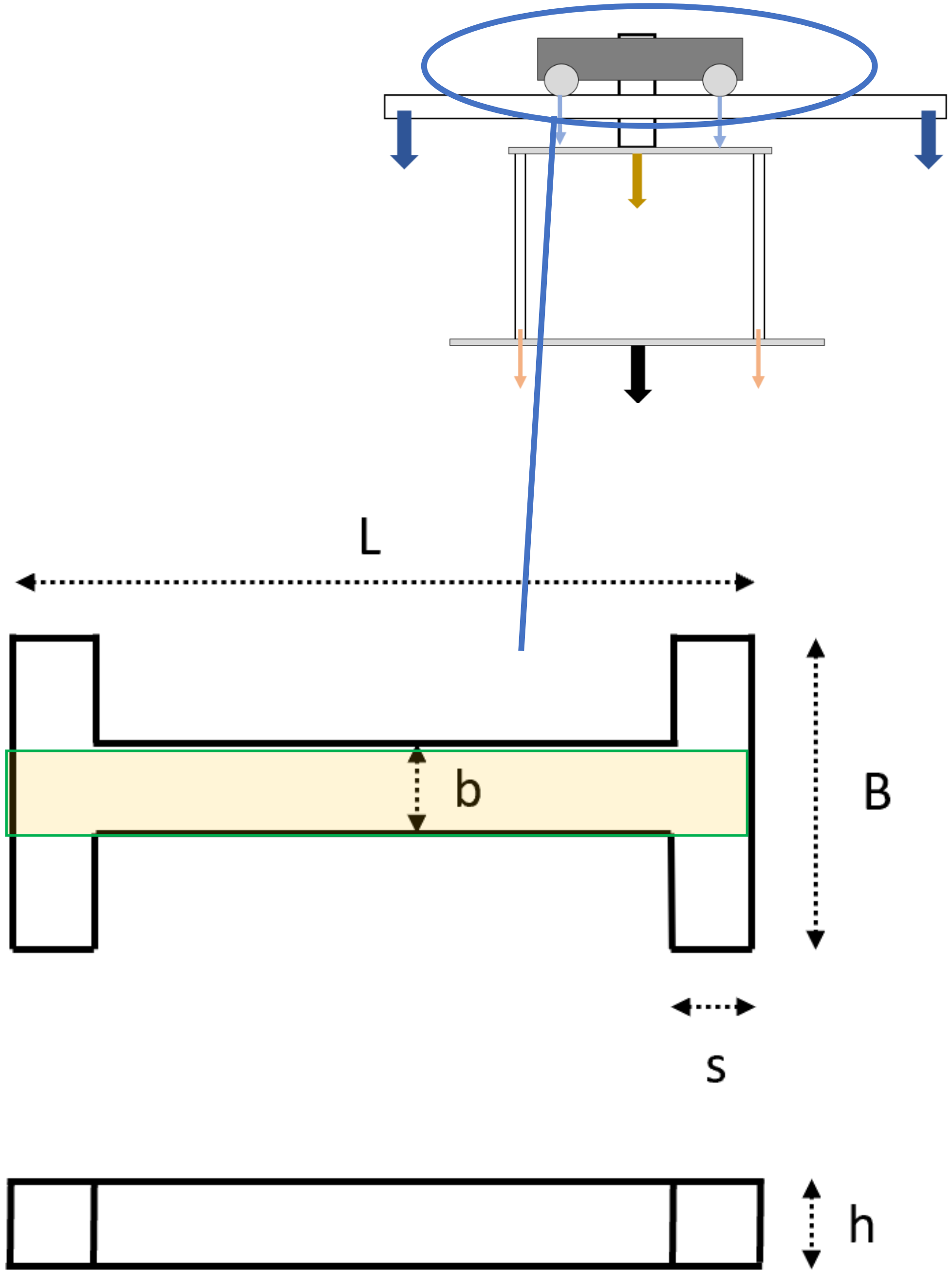
- Slewing ring outer diameter : 67.2 [cm]
- Vertical column outer diameter : 54 [cm]
- Vertical column height: 2 [m]

- Mass (column + ring) : 1200 [kg]

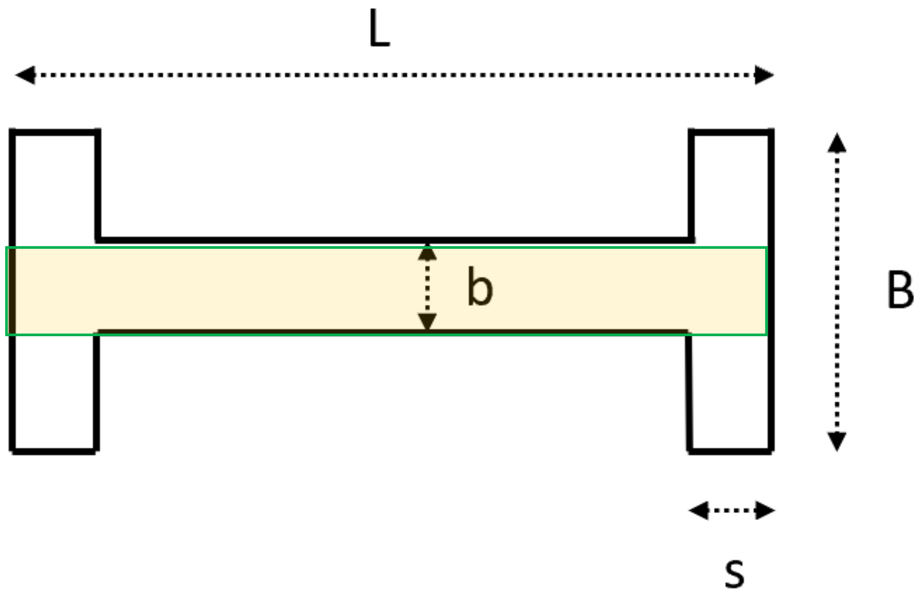
DIMENSIONING – Trolley

Assumptions

- Security factor : $\gamma = 2$
- Material : A36 steel
  - $\rho =$ 7800 [kg/m³]
  - $\sigma_y = 250$ [MPa]
- No shear/axial stress
- Shape → Rectangular section
  → $I = bh^3/12$
- Loading → 19 tons



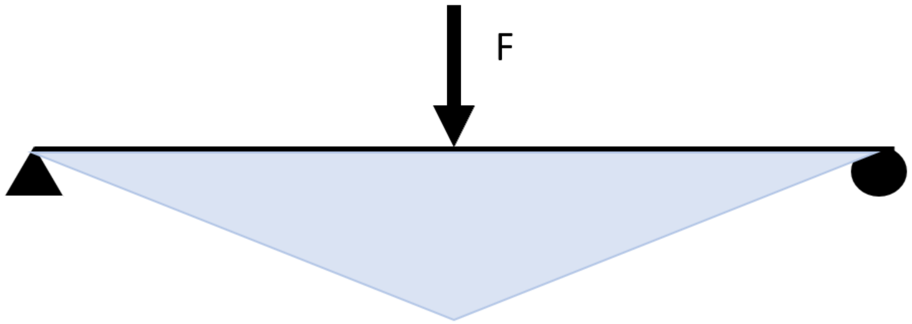
DIMENSIONING - Trolley



$$\sigma_{max} = \frac{M_{max} \cdot h/2}{I}$$

$$\sigma_y > \gamma \sigma_{max}$$

$$h > \sqrt{\frac{3\gamma F L}{2 b \sigma_y}}$$



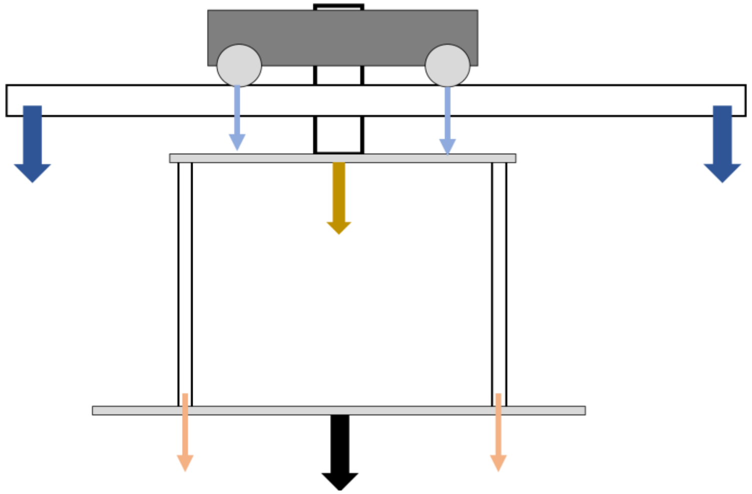
$M_{max} = FL/4$

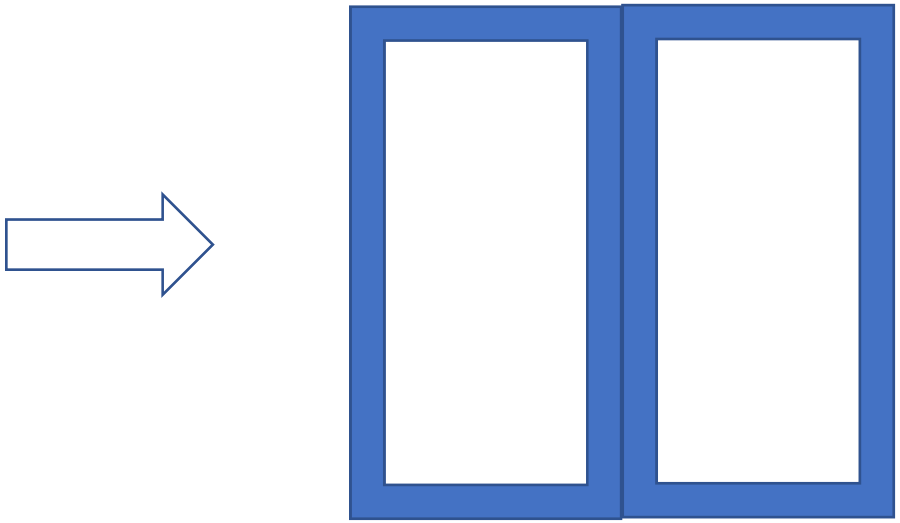
- L = 2 m
- b = 1 m
- B = 3 m
- s = 0.3 m

Motor, gear, rack&pinion, …

h = 7 cm
$W_{trolley}$ = (1750 + 1400) kg
= 3,2 tons

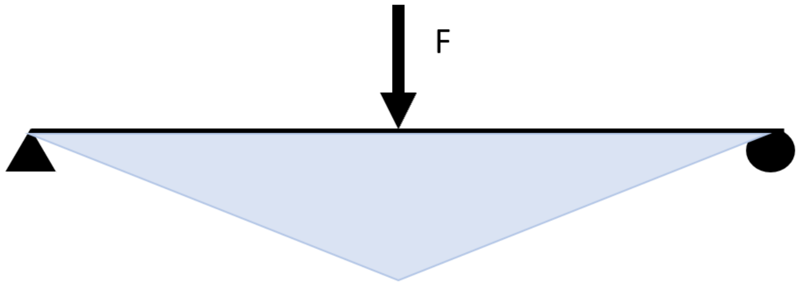
DIMENSIONING – Main beams





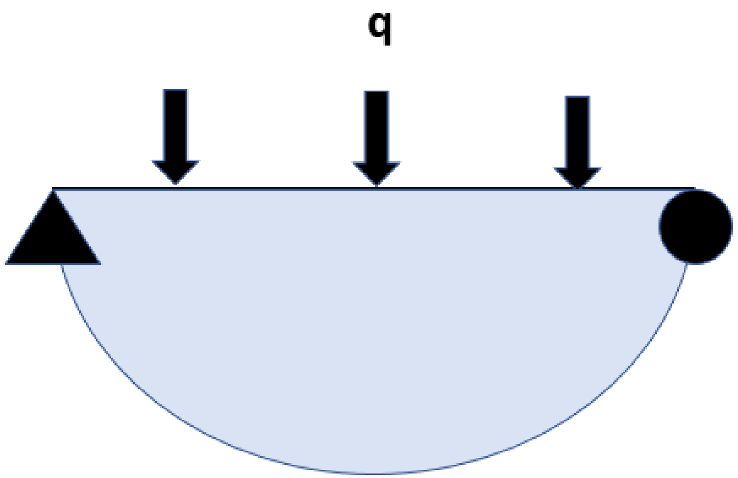
Main beams, two loadings

1



$M_{max} = FL/4$

2



$M_{max} = qL^2/8$

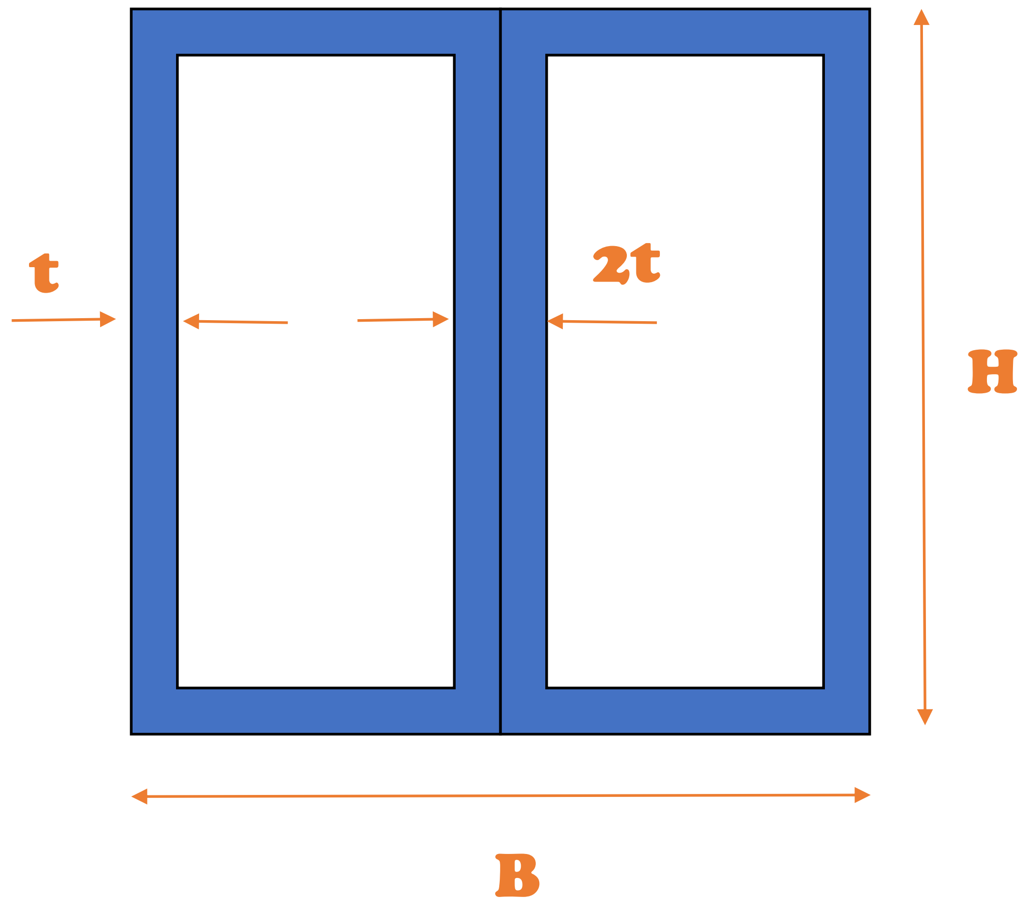
Assumptions

- Trolley's width negligible VS beam's width
- Total deformation = sum of two deformations
- Beam's weigth not negligible
- Load uniformly distributed
- Problem is isostatique

Bending moments

$$\left.\begin{array}{l}\bullet\ F = 135\ \text{kN} \\ \bullet\ L = 50.25\ \text{m}\end{array}\right\} \quad \begin{array}{l}\bullet\ M_{max1} = 1695.94\ \text{kNm} \\ \bullet\ M_{max2} = ?\end{array}$$

Main beams, cross section



Main dimensions

- H = 150 cm
- B = 80 cm
- t = 2.5 cm

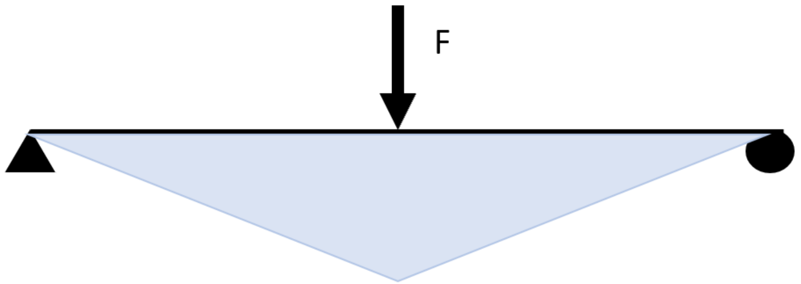
- A = 0.185 m²
- I = 0.04716 m4

Density of steel = ± 8000 [kg/m³]

- q = 14.8 [kN/m]
- M_max_2 = 4671.366 [kNm]

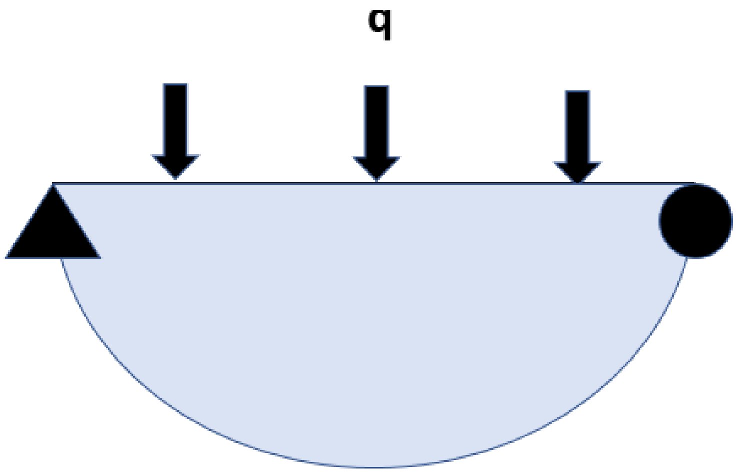
Main beams, two displacements

1



$M_{max} = FL/4$

2



$M_{max} = qL^2/8$

Displacements

- $f_1 = 0.03$ [m]
- $f_2 = 0.12$ [m]

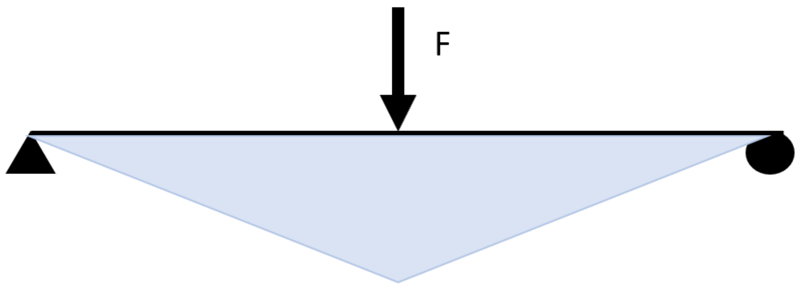
$f_{tot} = f_1 + f_2 = 0.15$ [m]

$f_{tot} = 0.3\%$ L

Ok for rack and pinion

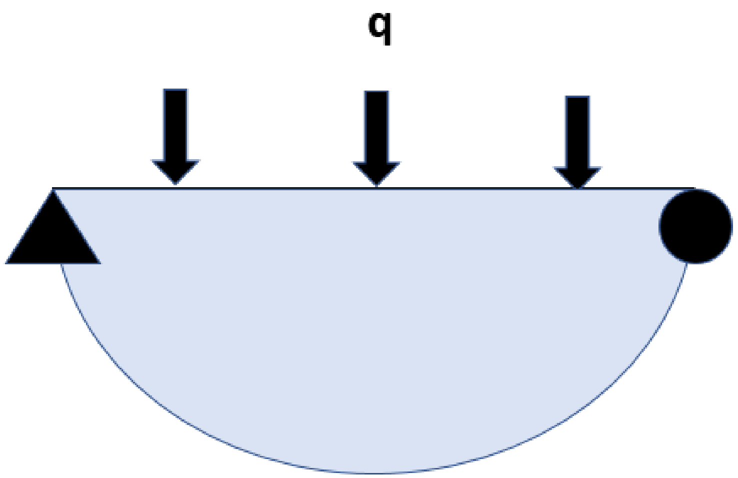
Main beams, check of the maximal stress

1



$M_{max} = FL/4$

2



$M_{max} = qL^2/8$

Stresses

- σ_1 = 19.73 [MPa]
- σ_2 = 63.42 [MPa]

σ_{tot} = 83.15[MPa]

$\sigma_{max} \ll \sigma_{yield}$

Rack and pinion selection

1. For the application : High Precision Rack
2. Compute the minimal feed force required

$$Fpermissible = \frac{F_{tab}}{K_S\, KA\, fn\, L}$$

$$F_{permissible} > Ftangential$$

$$F_{tangential} = m\,(g\,\mu + \mathrm{a})$$

ATLANTA ack and Pinion Drive – Calculation and Selection – Module 6 – Straight Tooth System

Rack		UHPR	HPR		BR			
Quality		4	6	7	9		10	
Rack	Material	C45	C45	C45	C45		C45	
	Heat Treatment	Ind. Hardened	Induction Hardened		Soft		Induction Hardened	
Pinion	Material	16MnCr5	16MnCr5	16MnCr5	16MnCr5	C45	16MnCr5	C45
	Heat Treatment	Case Hardened	Case Hardened	Case Hardened	Case Hardened	Soft	Case Hardened	Ind. Hardened
No. of Pinion Teeth [1]	Pitch Circle Dia.	Maximum Feed Force						
12	72 mm	27.5 kN	27.5 kN	27.5 kN	7.5 kN	3.0 kN	25.5 kN	15.0 kN
13	78 mm	33.5 kN	33.5 kN	33.5 kN	8.0 kN	3.5 kN	30.0 kN	17.5 kN
14	84 mm	41.5 kN	41.5 kN	41.5 kN	8.5 kN	4.0 kN	34.5 kN	20.0 kN
15	90 mm	46.0 kN	45.5 kN	45.5 kN	9.0 kN	4.5 kN	38.0 kN	22.5 kN
16	96 mm	50.5 kN	50.5 kN	50.5 kN	10.0 kN	5.0 kN	40.5 kN	25.0 kN
17	102 mm	56.5 kN	56.5 kN	56.5 kN	11.5 kN	6.0 kN	43.5 kN	27.5 kN
18	108 mm	61.0 kN	61.0 kN	61.0 kN	12.5 kN	7.0 kN	46.0 kN	30.0 kN
19	114 mm	64.5 kN	64.5 kN	64.5 kN	13.0 kN	7.5 kN	48.5 kN	32.5 kN
20	120 mm	68.0 kN	68.0 kN	68.0 kN	14.0 kN	8.0 kN	51.0 kN	34.5 kN
21	126 mm	71.5 kN	71.5 kN	71.5 kN	14.5 kN	8.5 kN	53.5 kN	37.0 kN
22	132 mm	75.5 kN	75.0 kN	75.0 kN	15.5 kN	9.0 kN	56.0 kN	39.5 kN
23	138 mm	79.0 kN	79.0 kN	78.5 kN	16.0 kN	9.5 kN	58.5 kN	42.0 kN
24	144 mm	82.5 kN	82.5 kN	82.5 kN	17.0 kN	10.5 kN	61.0 kN	44.0 kN
25	150 mm	86.0 kN	86.0 kN	86.0 kN	17.5 kN	11.0 kN	61.5 kN	46.5 kN
26	156 mm	87.5 kN	87.5 kN	87.5 kN	18.5 kN	11.5 kN	62.0 kN	49.0 kN
27	162 mm	88.0 kN	87.5 kN	87.5 kN	19.0 kN	12.0 kN	62.0 kN	50.0 kN
28	168 mm	88.5 kN	88.0 kN	88.0 kN	20.0 kN	12.5 kN	62.5 kN	50.0 kN
29	174 mm	88.5 kN	88.5 kN	88.5 kN	20.5 kN	13.0 kN	62.5 kN	50.5 kN
30	180 mm	89.0 kN	89.0 kN	89.0 kN	21.5 kN	13.5 kN	63.0 kN	50.5 kN

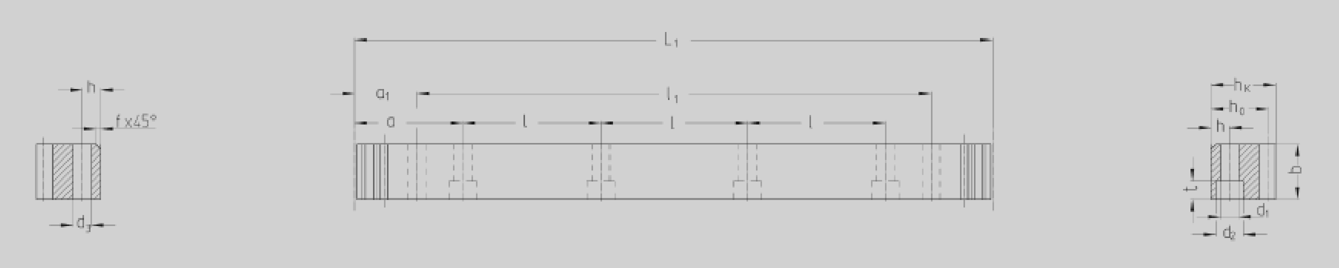
1) Check availability (chapter ZB)

Maximum permissible feed forces – description see page ZB-36

Once the minimal Feed Force is found : check the availability of both rack and pinion in catalogue → need to iterate

ATLANTA — **HPR Racks Module 2–8**

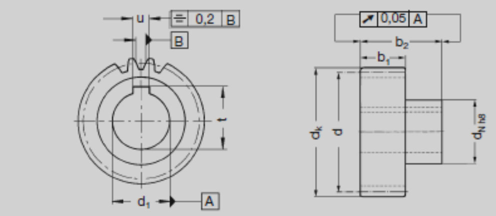
ATLANTA-Quality 7



Order Code	Module	L_1	N° of Teeth	b	h_k	h_0	f	a	l	N° of Holes	h	d_1	d_2	t	a_1	l_1	d_3	kg
28 20 107	2	1005.3	160	24	24	22	2	62.8	125.66	8	8	7	11	7	31.3	942.7	5.7	4.2
28 30 107	3	1017.9	108	29	29	26	2	63.6	127.23	8	9	10	15	9	34.4	949.1	7.7	6.0
28 40 107	4	1005.3	80	39	39	35	2	62.8	125.66	8	12	14	20	13	37.5	930.3	7.7	10.5
28 50 107	5	1005.3	64	49	39	34	2.5	62.8	125.66	8	12	14	20	13	30.1	945.0	11.7	13.4
28 60 107	6	1017.88	54	59	49	43	2.5	63.6	127.23	8	16	18	26	17	31.4	955.00	15.7	20.20
28 80 107	8	1005.30	40	79	79	71	2.5	62.8	125.66	8	25	22	33	21	26.6	952.00	19.7	44.76

ATLANTA — **Gearwheels with Ground Teeth – Module 5–10**

Straight Tooth System, with Bore ØH6 and Keyway acc. to DIN 6885



Keyway Middle of Tooth Gap

16MnCr5, 1.7131
Case-Hardened
Gearing Grade 6 e 25

Order Code	Fig.	N° of Teeth z	d	d_k	d_1^{H6}	d_N	b_1	b_2	u	t	kg	Shrink-Disk on Page GH-1
Module 5												
24 56 421		21	105	115	45	68	50	85.0	14	48.8	3.7	80 80 068
24 57 421		21	105	115	55	80	50	90.0	16	59.3	3.7	80 87 080
24 56 425		25	125	135	45	68	50	85.0	14	48.8	5.2	80 80 068
24 57 425		25	125	135	55	80	50	90.0	16	59.3	5.1	80 87 080
24 58 425		25	125	135	75	110	50	110.0	20	80.4	4.7	80 80 110
Module 6												
24 67 421		21	126	138	55	80	60	100.0	16	59.3	5.6	80 87 080
24 68 421		21	126	138	75	110	60	120.0	20	79.9	4.7	80 80 110
24 67 425		25	150	162	55	80	60	100.0	16	59.3	8.0	80 87 080
24 68 425		25	150	162	75	110	60	120.0	20	79.9	7.1	80 80 110
Module 8												
24 88 420*		20	160	176	75	110	80	140	20	79.9	12.0	80 80 110
24 89 420*		20	160	176	85	125	80	145	22	90.4	12.1	80 80 125
Module 10												
24 09 620*		20	200	220	85	125	100	165	22	90.4	23	80 80 125

* Gearing quality 5 f 23

Motor selection

1. Compute maximal torque for the maximal acceleration
2. Compute the maximal power required
3. Choose a motor matching those
4. Choose a reducer fitting motor speed and pinion speed

POWER REQUIRED

We calculate the power needed to move trolley at max velocity of 0.3m/s

Power = force * velocity = 2.3kw

From catalogue we select four pole motor running at 1500rpm to give a power of 3.0kw and a torque of 20Nm.

ELECTRICAL PERFORMANCE DATA 50Hz

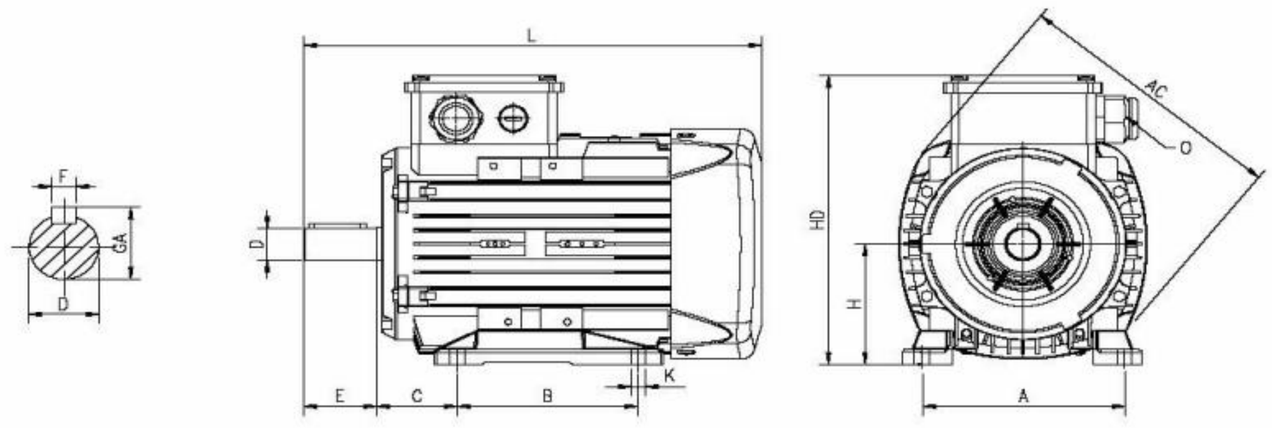
	MOTOR TYPE	HOUSING	NOMINAL VALUES					STARTING VALUES				Breakdown torque ratio	EFFICIENCY			Cos	J	Weight	Sound Level dBA
			Power		Speed	Current	Torque	Current (Ia/In)		Torque (Ma/Mn)			η %						
			kW	HP	rpm	A	Nm	Y	Δ	Y	Δ		4/4	3/4	2/4	4/4	kgm2	kg	
	4 pole 1500 rpm																		
220/380 V	Q2E71M4C *	aluminum	0,25	1/3	1415	0,7	1,7	4,4	-	2,3	-	3,4	68,5	68,8	68,8	0,74	0,00095	9	45
	Q2E71M4D *	aluminum	0,37	1/2	1415	1,1	2,5	4,4	-	2,3	-	3,4	72,7	73,1	72,0	0,75	0,00095	8,5	45
	Q2E80M4B *	aluminum	0,55	3/4	1415	1,5	3,7	4,8	-	2,8	-	3,2	77,1	77,6	76,4	0,76	0,00205	10,5	49
	Q2E80M4D	aluminum	0,75	1,0	1435	2	5,1	5,2	-	2,9	-	3,2	79,6	78,9	75,3	0,7	0,00268	12	49
	Q2E90L4C	aluminum	1,1	1,5	1430	2,5	7,4	6,7	-	2,9	-	3,3	81,4	80,8	78,1	0,81	0,00365	18	54
	Q2E90L4D	aluminum	1,5	2,0	1430	3,5	10,0	7,0	-	3,2	-	3,6	82,8	82,0	79,3	0,76	0,00365	18	55
	Q2E100L4C	aluminum	2,2	3,0	1430	5,0	14,6	7,1	-	3,9	-	4,2	84,3	83,8	81,2	0,77	0,00545	26	56
	Q2E100L4D	aluminum	3,0	4,0	1440	6,4	20,0	7,1	-	3,4	-	3,8	85,5	85,1	83,0	0,75	0,00581	26	56

Motor selected : Q2E100L4D

The output shaft diameter and lenght is of our interest because we need to find exact gear reducer according to the that.

Diameter of shaft : 28 mm
Lenght of shaft : 60mm

DIMENSIONS



B3-B6-B7-B8-V5-V6

			Main Dimensions			Foot Mounted Motors						Shaft				Bearing		Seal	
Power (kW)	Number of Poles	Motor Type	AC	L	O	B	A	H	HD	K	C	D(1)	E	GA	F(2)	Drive Side	Non drive Side	Drive Side	Non drive Side
3	2	Q2E 90L2DE	193	316.5	1*M25	125	140	90	222	10	56	24	50	27	8	6305-2Z	6205-2Z	25*40*7	25*40*7
	2	Q2E100L2C	217	352.0	1*M25	140	160	100	241	12	63	28	60	31	8	6306-2Z	6205-2Z	30*47*7	25*40*7
	4	Q2E100L4D	217	352.0	1*M25	140	160	100	241	12	63	28	60	31	8	6306-2Z	6205-2Z	30*47*7	25*40*7
	6	Q2E132M6A	279	475.5	2*M32	140	216	132	314	12	89	38	80	41	10	6208-2Z	6208-2Z	40*62*10	40*62*10

GEAR REDUCER

At Pinon(to have a max velocity of 0.3m/s**)**

Torque at pinon : 713Nm
Rpm at the pinon : 46 rpm
Dia of the pinon : 0.126m

At motor :

Power : 3kw
Rpm : 1500

At reducer :

1500 rpm $\longrightarrow$ 46 rpm
Reduction ratio = 33

		Stage	Ratio	PGL-42	PGL-60 / 60T	PGL-90 / 90T	PGL-115 / 115T	PGL-142 / 142T	PGL-180 / 180T	PGL-220 / 220T
Nominal Output Torque T_{2N}	N • m	2	15	13.8	44.2	95.2	283	482	1151	1670
			20	11.9	35.9	74.6	249	490	1055	1574
			25	13.8	43.0	95.2	283	473	1151	1670
			30	13.8	43.0	95.2	283	473	1151	1670
			35	13.8	43.0	95.2	283	473	1151	1670
			40	13.8	43.0	95.2	283	473	1151	1670
			45	13.8	43.0	95.2	283	473	1151	1670
			50	13.8	43.0	95.2	283	473	1151	1670
			60	12.5	39.4	90.9	266	436	1055	1574
			70	11.9	36.0	85.6	219	400	1055	1574
			80	10.9	32.4	85.0	216	363	860	1184
			90	9.8	28.7	80.0	210	320	764	1185
			100	10.1	25.0	75.0	210	320	763	1184
Emergency Stop Torque T_{2NOT}	N • m		(3.0 times of Nominal Output Torque) (* Max. Output Torque T_{2B} =60% of Emergency Stop Torque)							
Nominal Input Speed n_{1N}	rpm	1,2	3-100	3000	3000	3000	2500	2000	2000	2000
Max. Input Speed n_{1max}	rpm	1,2	3-100	6000	6000	6000	5000	4000	4000	4000
Micro Backlash P0	arcmin	1	3-10	-	-	-	≦3	≦3	≦3	≦3
		2	12-100	-	-	-	≦5	≦5	≦5	≦5

We select a planetary gear reducer for this application,

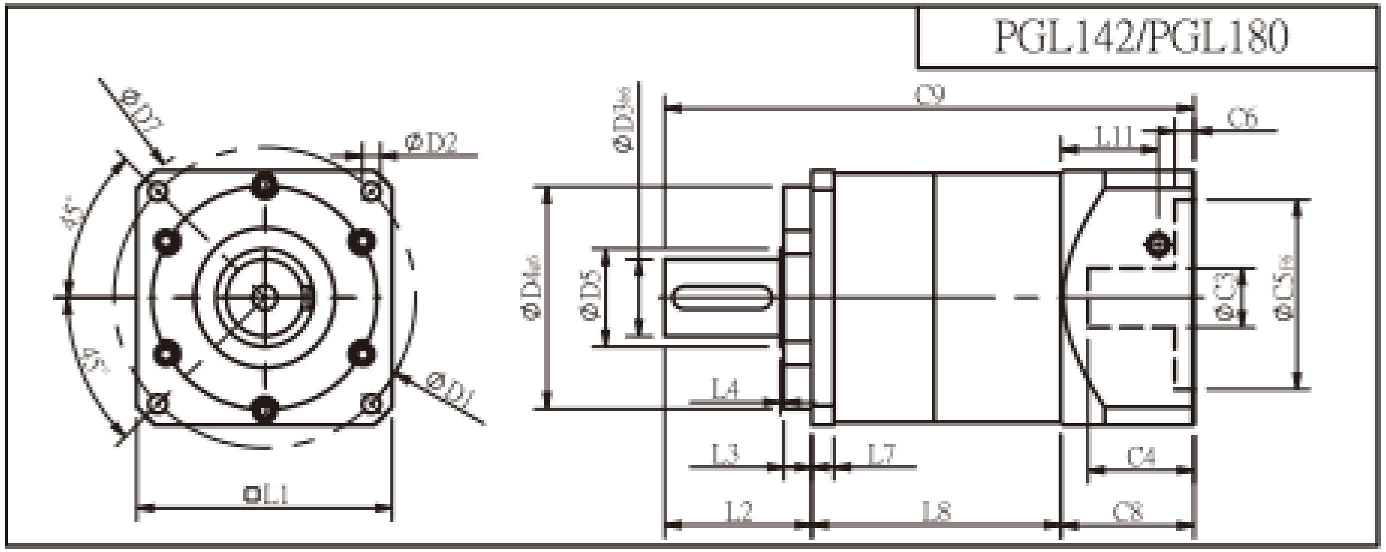
- 2 stage reducer
- Reduction ratio of 35
- Max input rpm 4000
- Max output torque 1151 Nm

DIMENSIONING REDUCER

Motor shaft dia : 28 mm
Input end reducer ≤ 50mm

Couples shaft through a dynamic balanced collar mechanism system for zero slip at high rpms.

Output shaft diameter : 55mm



Dimensions	PGL42	PGL60	PGL90	PGL115	PGL142	PGL180
D1	50	70	100	130	165	215
D2	3.4	5.5	6.5	8.5	10.5	13
D3 h6	13	16	22	32	40	55
C1 [2]	46	70	90	115	145	200
C2 [2]	M4x0.7P	M5x0.8P	M6x1.0P	M8x1.25P	M8x1.25P	M12x1.75P
C3 [2]	≤8	≤14	≤19/≤24	≤24/≤28	≤35	≤50

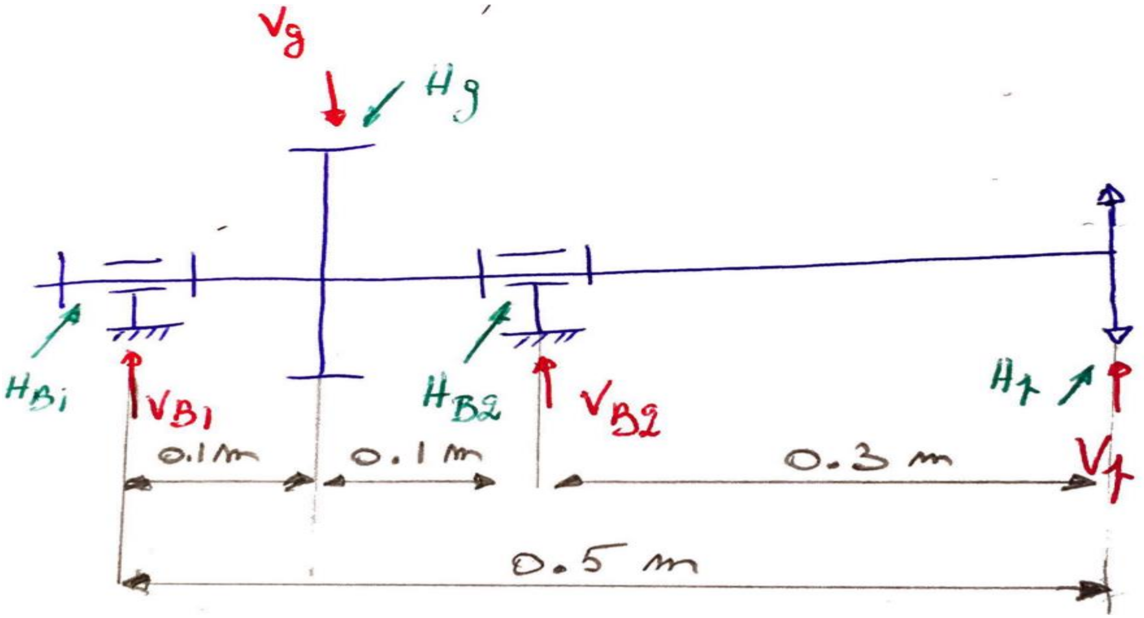
DIMENSIONING – Shaft

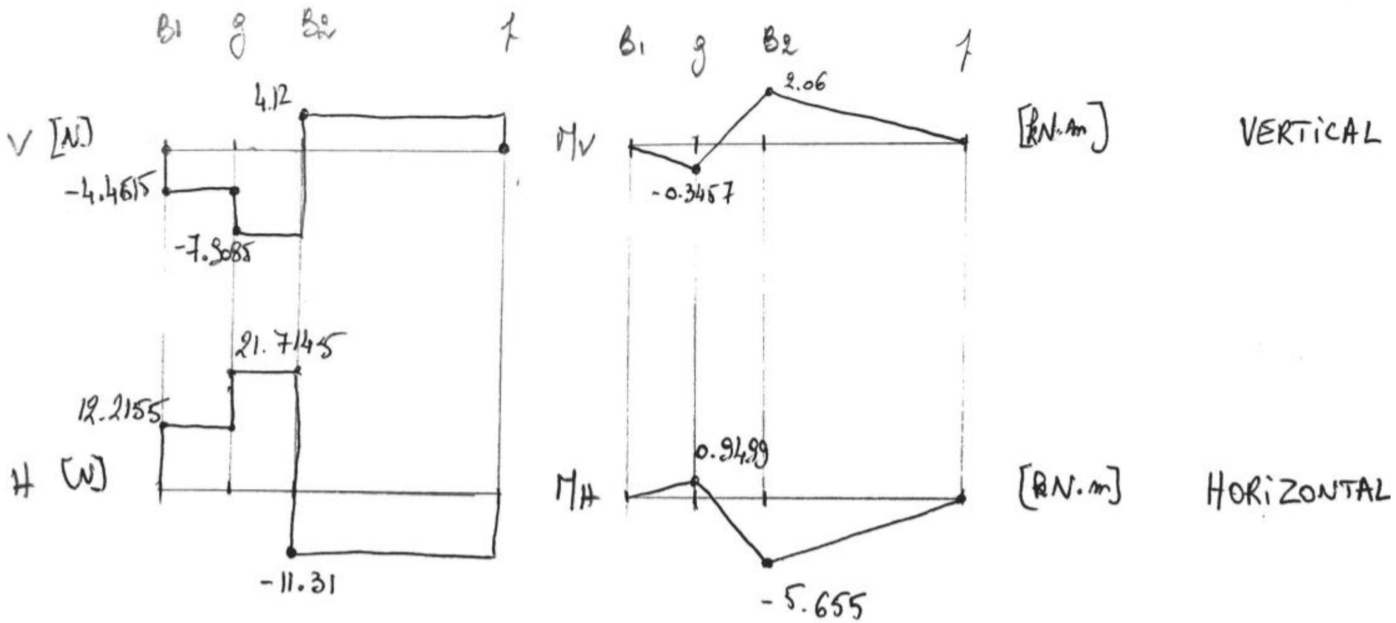
Power = 2.3 kW
Torque = 712.5 Nm
Dia of pinon on shaft = 0.126 m
Dia of gear on shaft = 0.15 m
Bore of gear on shaft = 75 mm

Radial force : $F_r = F_t \tan(20) = 4.12$ kN
Tangential force : $F_t = m \cdot (\mu \cdot g + a) = 11.31$ kN
With $\mu = 0.005$ and $a = 0.3$ [m/s^2]

Solving $\Sigma V = 0$ and $\Sigma M_V = 0$; $\Sigma H = 0$; $\Sigma M_H = 0$

1. $V_{B1} = -(V_{B2} + V_p + V_g) = -4.4515$ kN
2. $V_{B2} = -5\,(0.5V_p + 0.1\,V_g) = 12.0285$ kN
3. $H_{B1} = -(H_{B2} + H_p + H_g) = 12.2155$ KN
4. $H_{B2} = -5\,(0.1\,H_g + 0.5\,H_p) = -33.0245$ KN





DIMENSIONING – Shaft

$M_{max} = (M_{VB2}{}^2 + M_{HB2}{}^2)^{1/2} = 6.02$ [kNm]

MAX BENDING MOMENT:

$\sigma = 32 \cdot M_{max} / \pi d^3 = 145.35$ MPa

MAX TWISTING MOMENT:

$\tau = 16 \cdot T / \pi \cdot d^3 = 8.6$ MPa

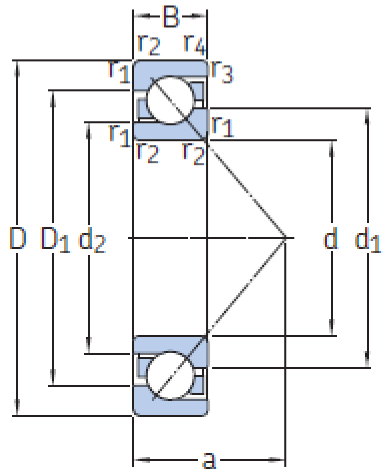
The equivalent stress : $\sigma_{eq} = (\sigma^2 + 3 \cdot \tau^2)^{1/2} = 146.11$ [MPa]

For safety : $\boldsymbol{\sigma_{eq} < \sigma_y}$

Material selection from Juvinall : Carbon alloy steel (1212 HR – see Juvinal) - Yield strength of 193MPa

DIMENSIONING – Ball Bearings

3.1 Single row angular contact ball bearings
d 65 – 75 mm



1) Static dimesioning

Equivalent static load : $P_0 = X_0\ F_r + Y0\ F_a = 35.15$ [kN]

Assuming no axial force : $Y_0 = 0$, $X_0 = 1$

Safety coefficient for high certitude on $s_0 = 2$

$C_0 = s_0\ P_0 = 70$ [kN]

2) Rating life dimensioning

For 25 000[h] at maximal speed : $L_{10} = \left(\frac{C}{\mathrm{P}}\right)^p$

C = 11.273 [kN]

Based on C and C0 : in the SKF catalogue : ball bearings with angular contact – dimensions :
D = 160 [mm]; B = 37 [mm] and C and C_0 higher than the values computed

DIMENSIONING – Rollers

- X-Translation :

Maximum mass to lift : ~170t

Critical case when all weight on one side

➡ ~170t supported by rollers on one side

3 Rollers

Lifting capacity : 60t each

Diamater : 630mm

Ref : DEMAG, DWS 630

- X-Translation :

Maximum mass to lift : 22.5t ?

Weight distributed between 4 rollers

➡ Maximum 22.5/4t per rollers

4 Rollers

Lifting capacity : 7t each

Diameter : 160mm

Ref : DEMAG, DRS 160

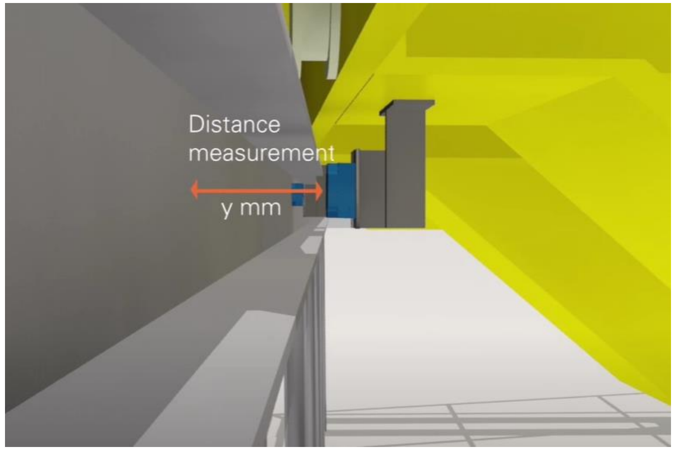
SENSORS

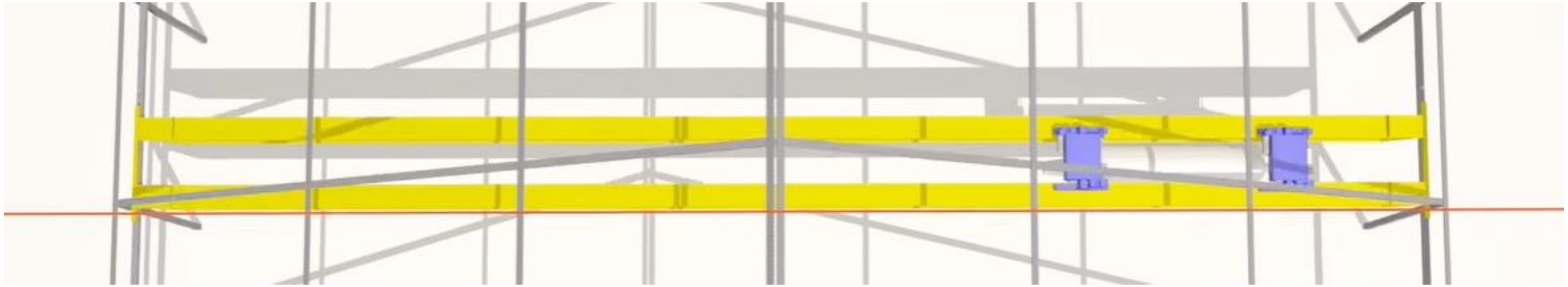
- Assure bridge alignement

  Laser sensor :

  Measure distance between crane and support on both side of the crane

→ Adjust to have same distance





Reference : KEYENCE, Série LK-G

SENSORS

- Position in hangar : Laser distance sensor

Z-Position

Range : 0.2-35m

Repeatability : >=0.5mm

Reference :

SICK, DL35-B15552

Y-Position

Range : 0.2-50m

Repeatability : >=0.25

Reference :

SICK, DL50-N2225

Z-Position

Range : 0.15-300m

Repeatability : 2mm

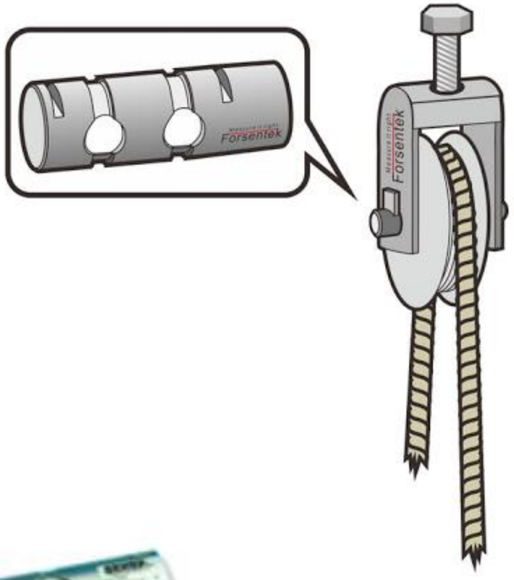
Reference :

SICK,DL100-23AA2101

SENSORS

- Overload protection :

Replace pin in the sheave with a load pin with bonded strain gauge



  - 3-5% precision --> protection
  - Need to calibrate

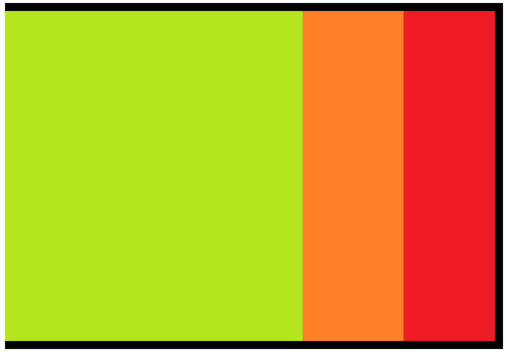
Lift capacity : 1 to 1000t

Reference : SENSY, Axe dynamométrique 5000

SENSORS

- Speed check: Avoid collision with the wall

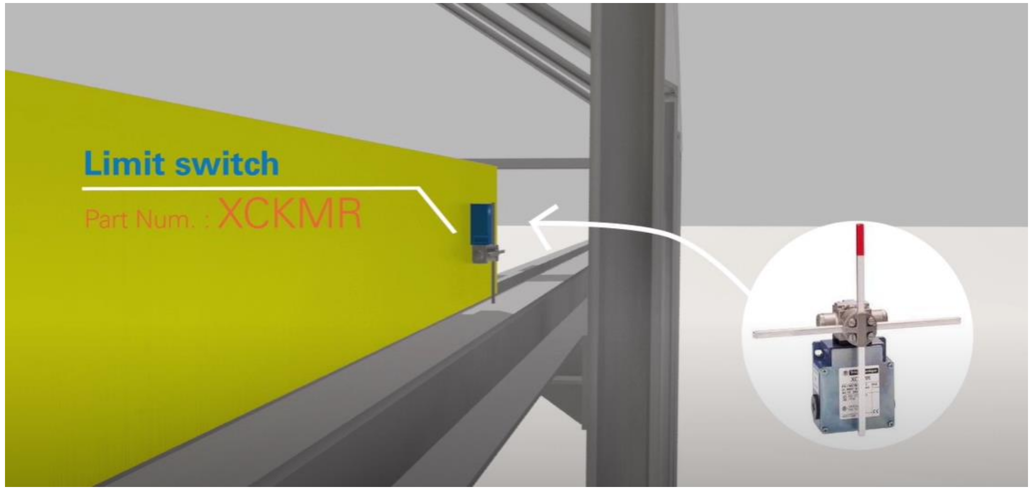
Limit switch

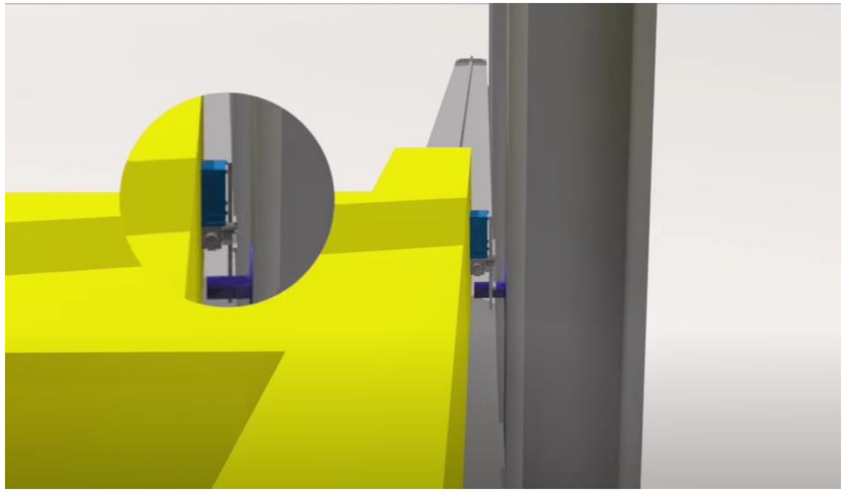


Slow speed

Full speed

STOP



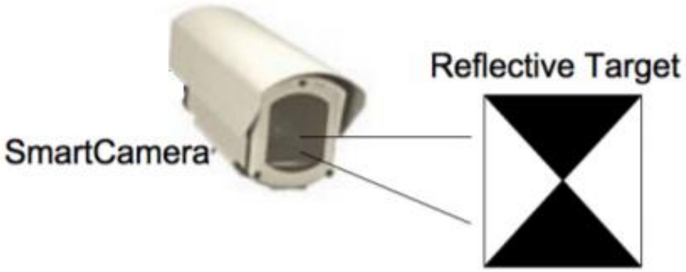


Reference : Telemecanique Sensor, XCKMR44D1H29

SENSORS

- Anti-sway system :

1-) Estimate and calculate load swing



2-) Automaticaly adjustate crane travelling motion :

anti-sway software to work with a crane’s PLC

Remove load swing for any load

Reference : SmartCrane, Anti Sway Crane Controle

Thank you for your attention !

Any questions ?