Mechanical design of material handling solutions for automated warehouses

Projeto mecânico de soluções de movimentação de carga para armazéns automáticos

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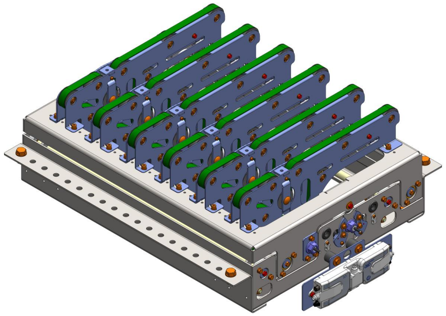
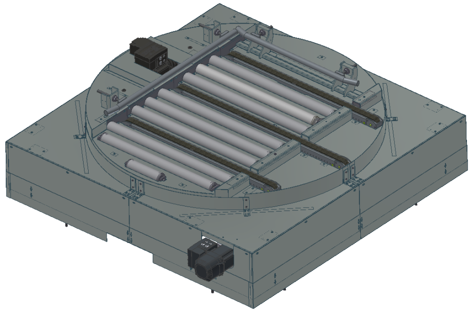
PRESENTATION LAYOUT

- Context – Automatic warehouse;
- Examples of national companies;
- Case study 1 (CS1) – Orthogonal transfer for direction shifting;

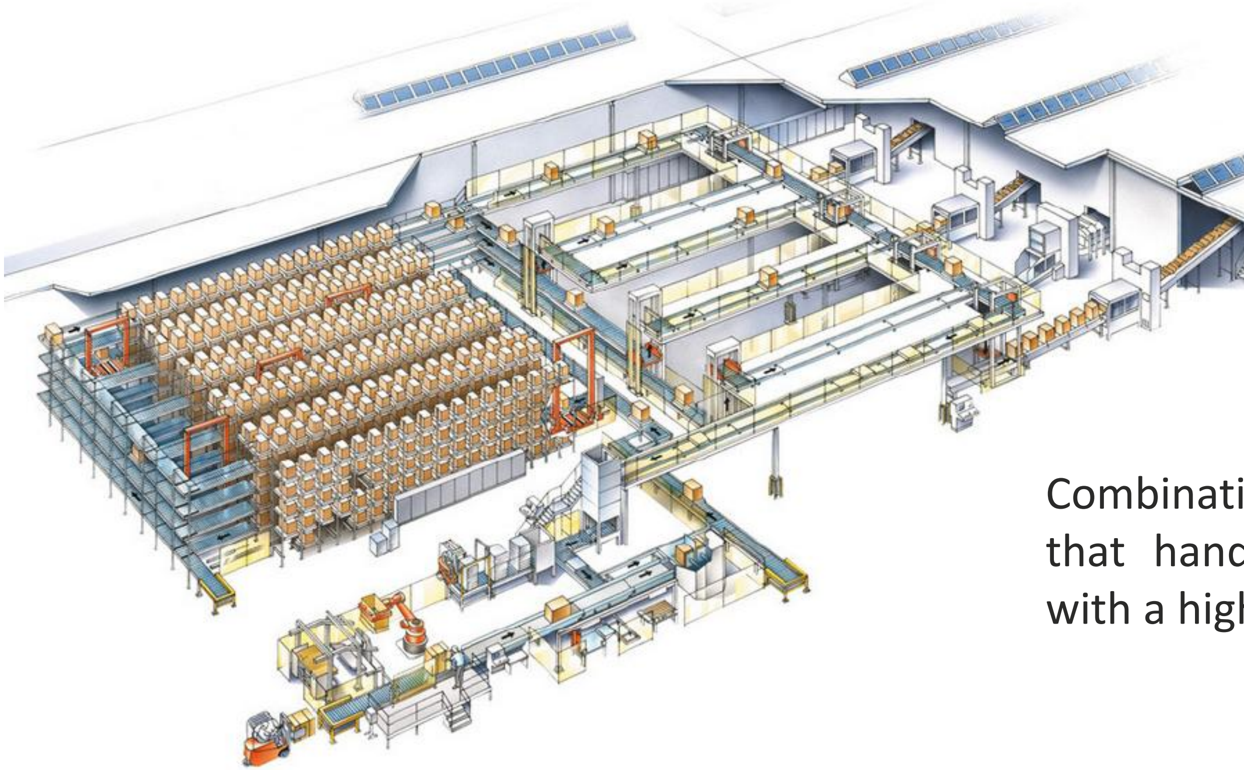


- Case study 2 (CS2) – Rotary table;



- Conclusions.

FRAMEWORK – AUTOMATIC WAREHOUSE

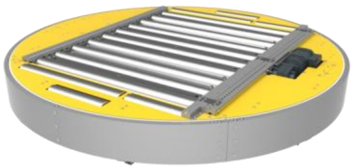
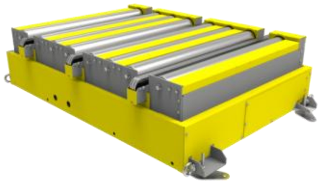


Combination of equipment and controls that handle, store and return materials with a high degree of automation.

Composed essentially by:

- Racks
- Stacker cranes
- Peripheral equipment (conveyors, autonomous vehicles, and others).

EXAMPLES OF NATIONAL COMPANIES

Roller conveyor	Chain conveyor	Turntable	Orthogonal pallet transfer	RGV
				

EXAMPLES OF NATIONAL COMPANIES

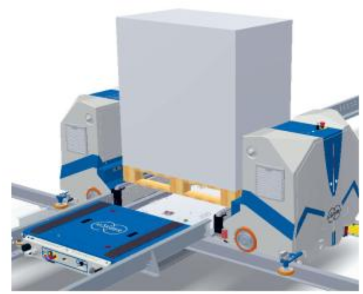
Stacker cranes

AB InBev
Coca-Cola
JYSK
Super Bock Group
Luis Simões
Nestlé
WARAK
Grupo RNM

Elevators

Conveyors

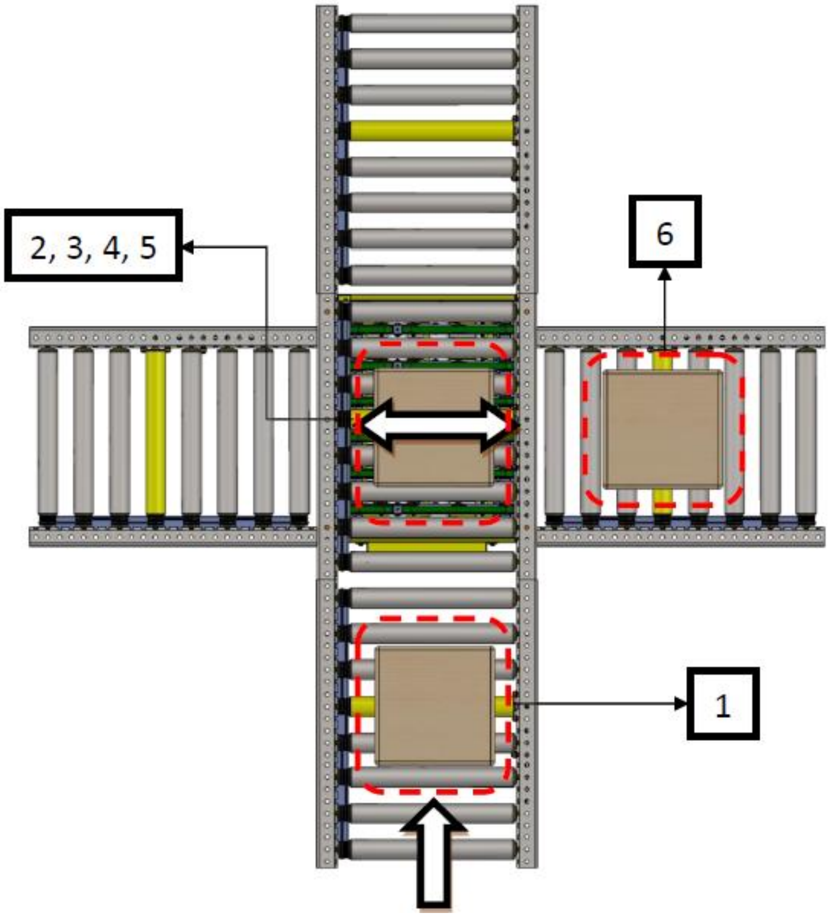
Autonomous vehicles



CS1 – OBJECTIVES

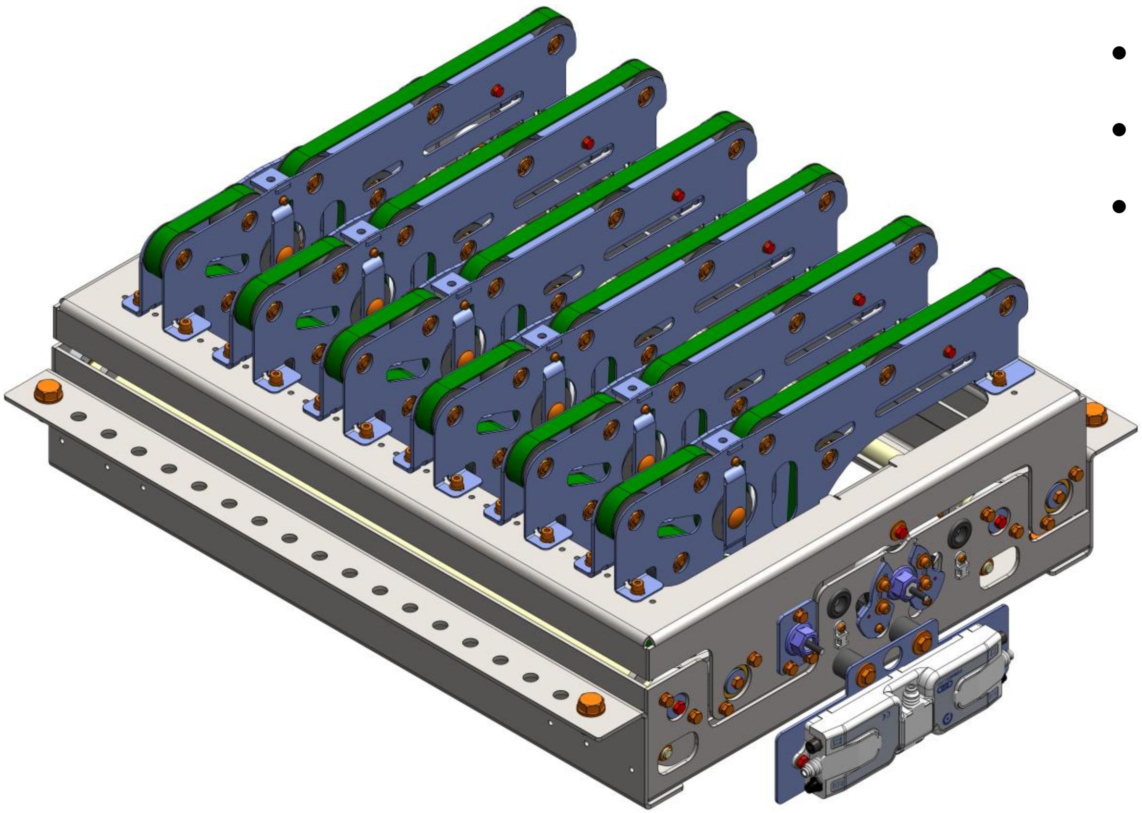
- Development of an ortogonal transfer;
- Standardization of the equipment;
- High flexibility;
- Ease of assembly and maintenance;
- Guaranteed operational safety;
- High construction quality;
- Compliance with all applicable regulations;
- Throughput ≈ 1500 units/h;
- Max load: 50 kg.

CS1 – PROCESS DESCRIPTION



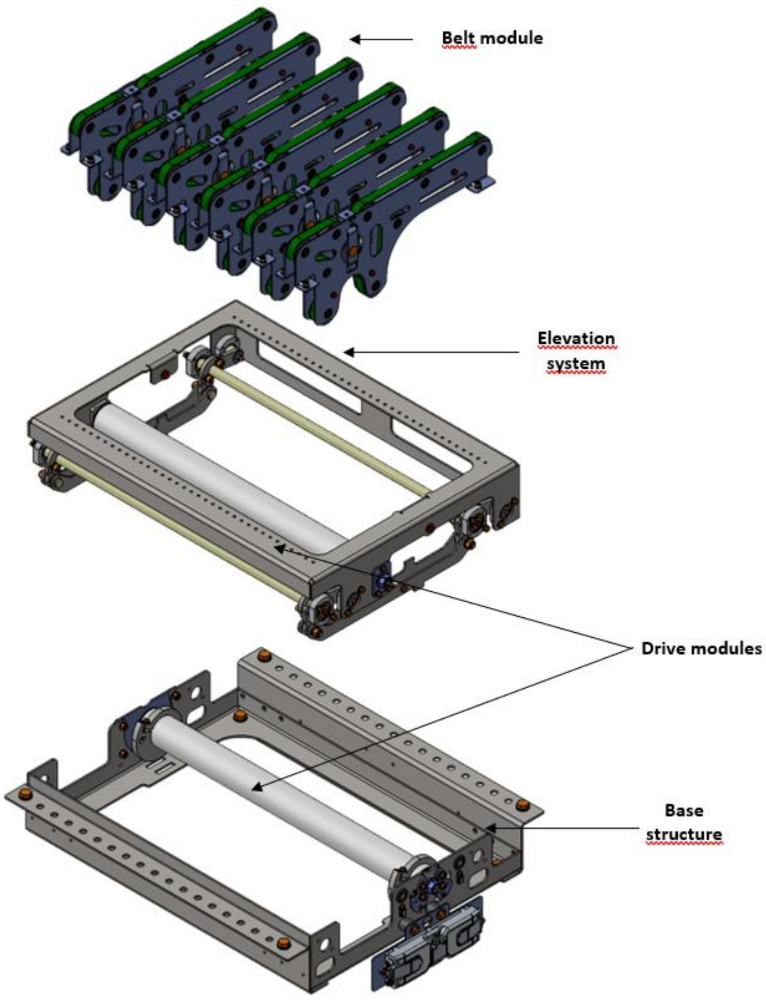
1. The box travels in a roller conveyor;
2. The box is detected by a photovoltaic sensor, ordering the roller conveyor to stop, immobilizing the box in the transfer area;
3. The transfer belts elevate the box;
4. The belts move the box to an adjacent conveyor;
5. The belts return to their original position;
6. The box travels in another conveyor.

CS1 – 24V ORTOGONAL TRANSFER



- Width = 450 mm
- Pitch = 90 mm
- 6 Belts

CS1 – SUB ASSEMBLIES



- Belt contacts with the load and transfers it to another conveyor

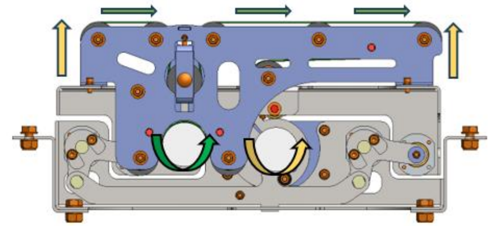
- Mechanism guarantees stability during elevation

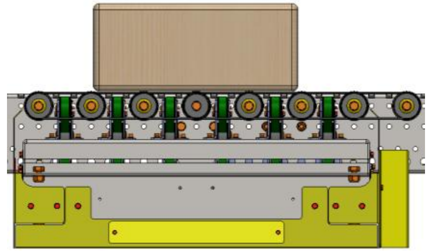
- 2 Roller drivers, one responsable for the elevation and the other for the activation of the belts

- Base structure anchores the equipment to a Roller conveyor

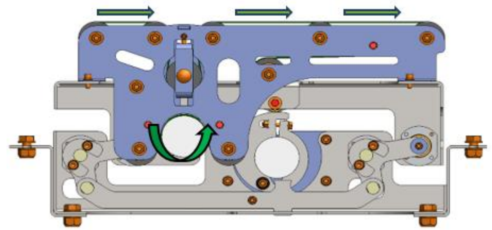
CS1 – OPERATING PRINCIPLE

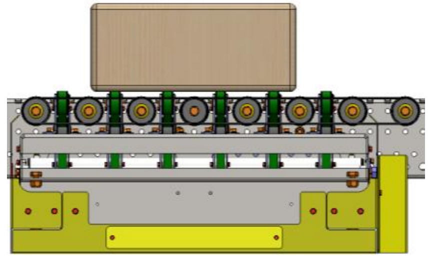
- Detection of the box in the transfer position which stops the roller conveyor;
- Both driver systems are activated. Belts start moving and the superior structure is elevated;



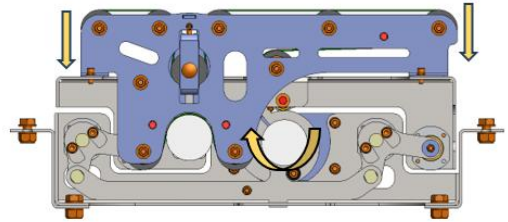


- The belts transport the box to an adjacent conveyor.





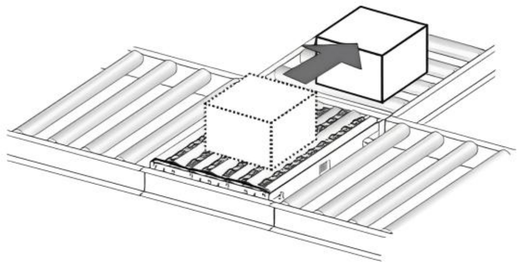
- The belt driver system is deactivated while the elevation driver system in the opposite direction, making the superior structure descent to the original position.



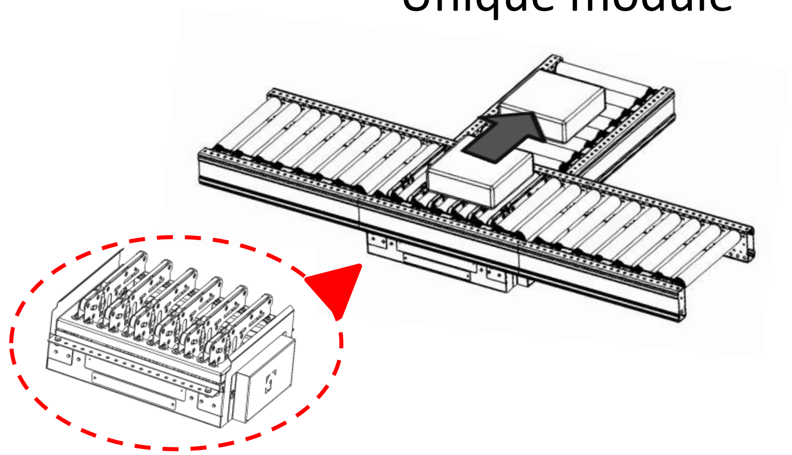
CS1 – PRE DESIGN

GENERAL CONCEPT

Complete module



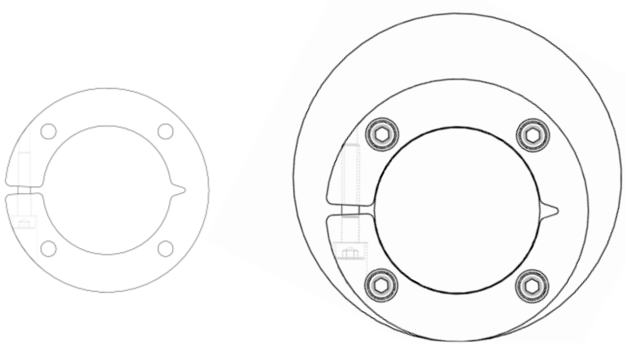
Unique module



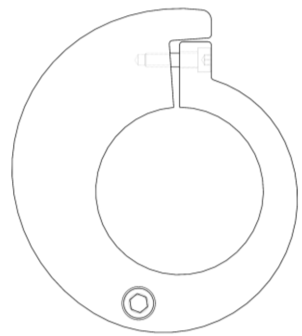
DRIVE MODULE

Gearmotor	Motorized roller	Air spring	Pneumatic cylinder	Electric cylinder
				

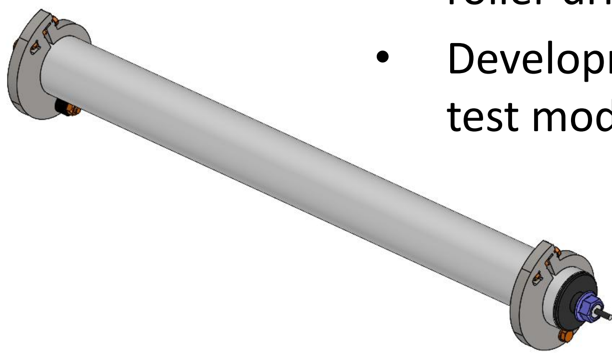
CS1 – PRE DESIGN – ELEVATION MODULE



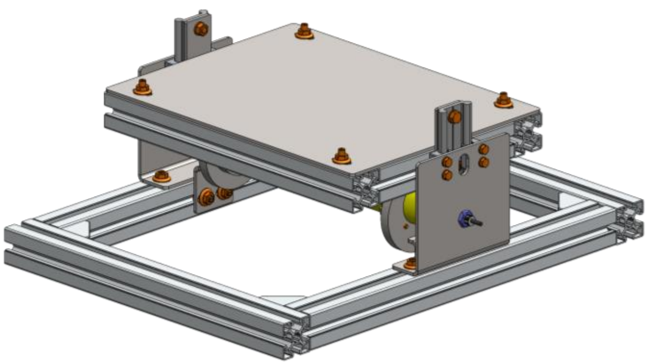
Eccentric cam



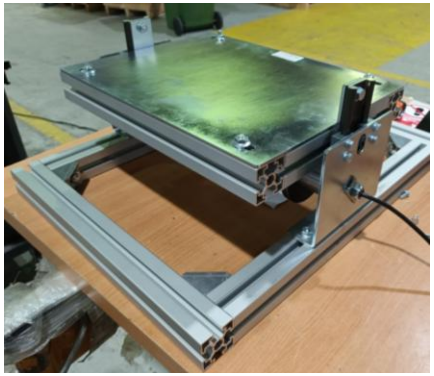
Snail cam



- Design of a system to fix the cam to the roller driver;
- Development of a test model.



Cad version of the test module

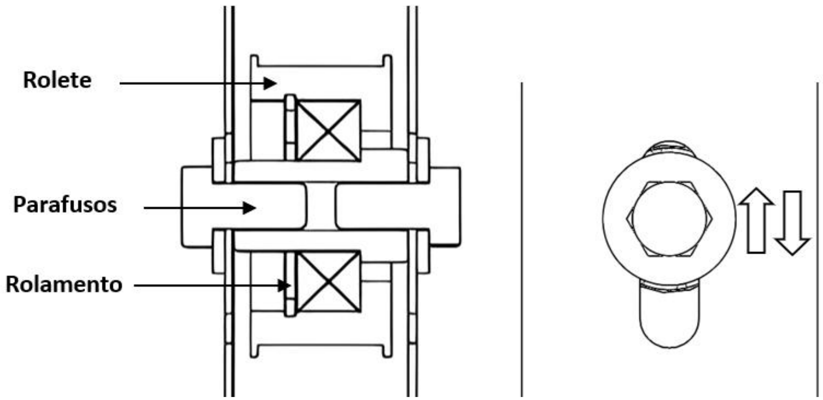


Real version of the test module

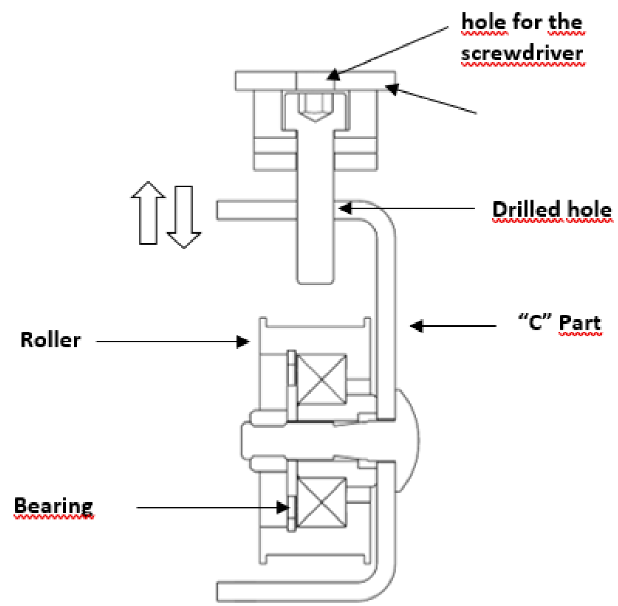
Component	Maximum load (kg)
Eccentric	23
Snail	37

Test results

CS1 – PRE DESIGN - TENSIONING MODULE

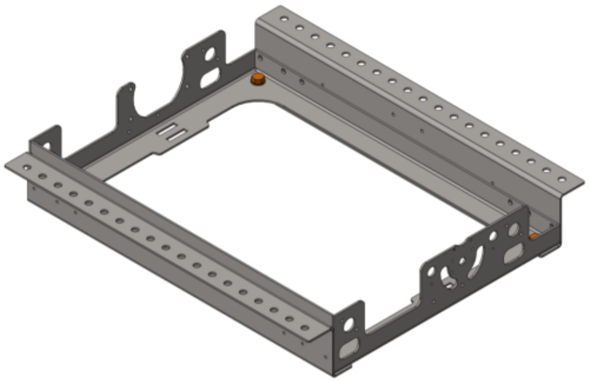


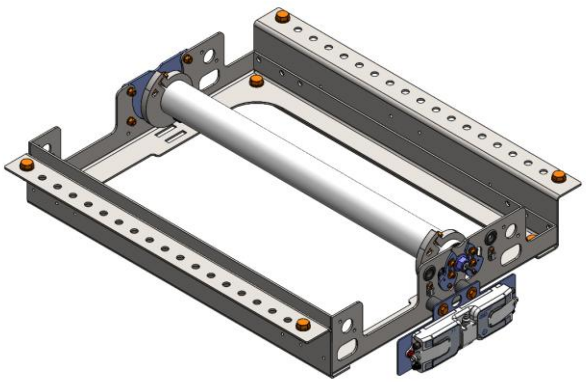
Simple module

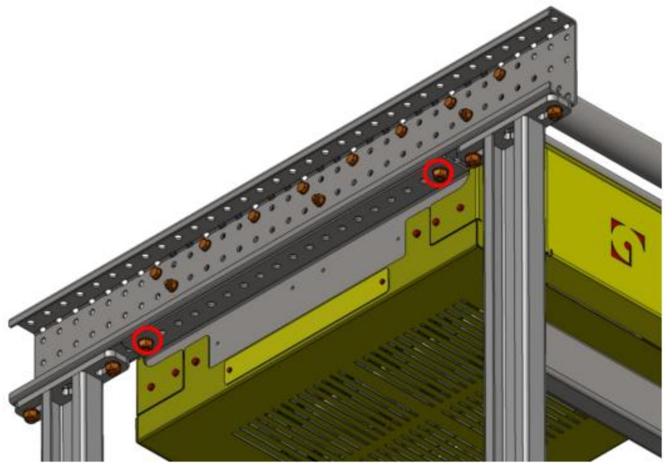


Complex module

CS1 – DESIGN - STRUCTURE







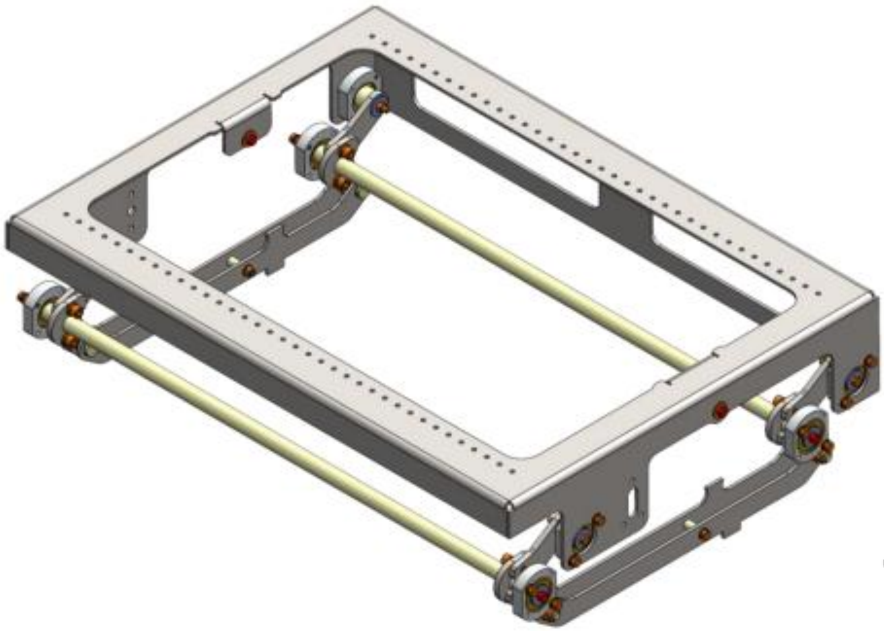
Structure

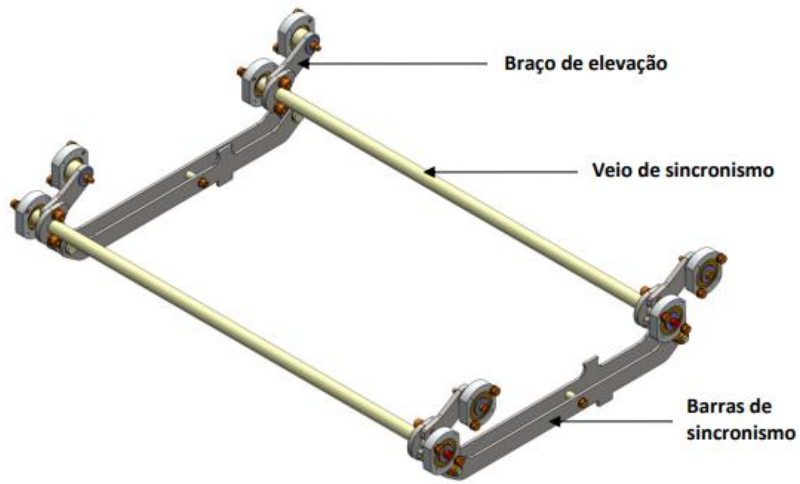
- Composed by 3 parts bolted together;
- Bent sheet metal;
- Windows to facilitate access during maintenence.

Anchor points

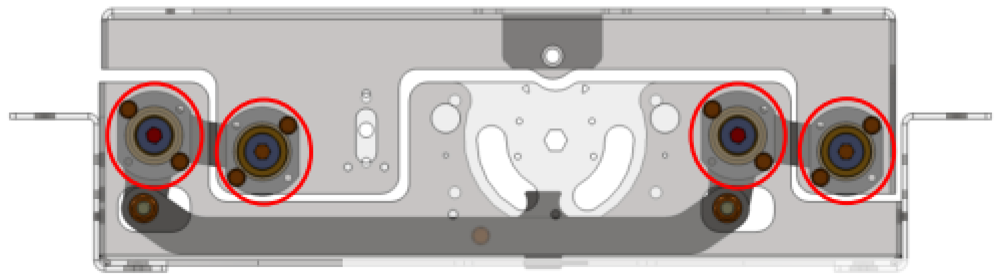
- Same pitch between holes as the standard conveyor for high placement flexibility

CS1 – DESIGN – ELEVATION MODULE



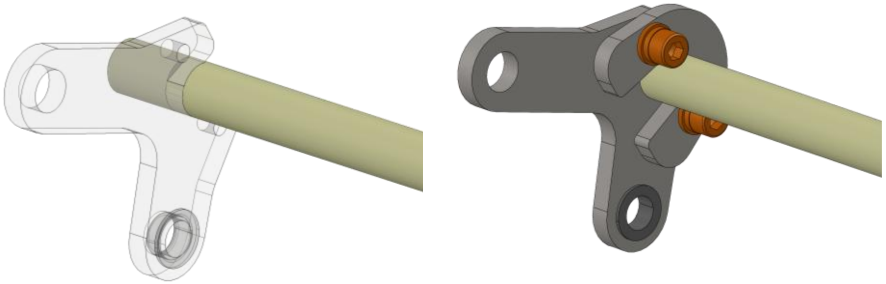


Synchronism module

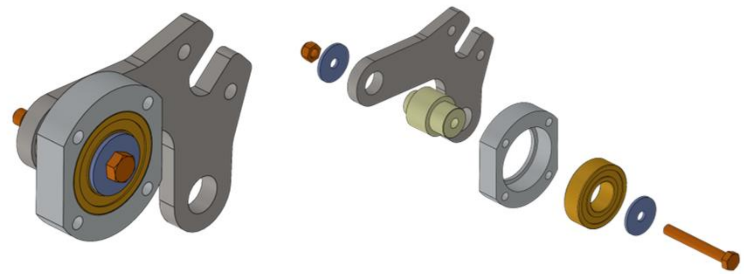


Fixing points

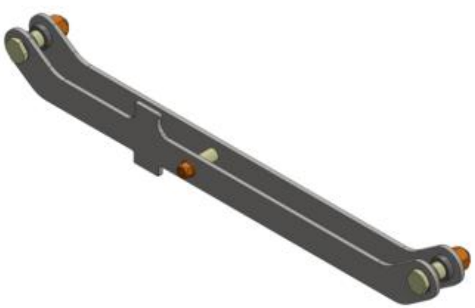
CS1 – DESIGN – ELEVATION MODULE



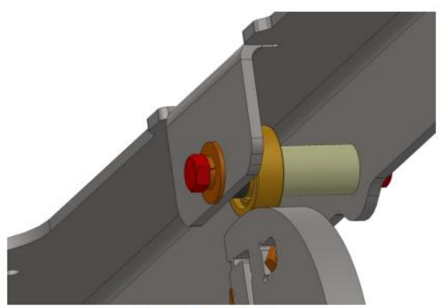
- Longitudinal synchronism (detail)



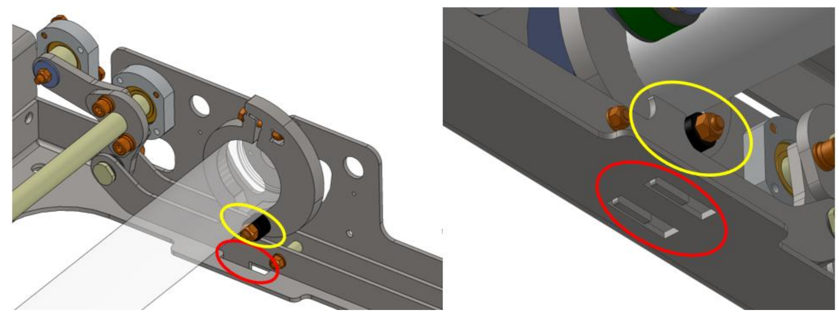
- Elevation arm and superior structure link



- Transversal synchronism (detail)

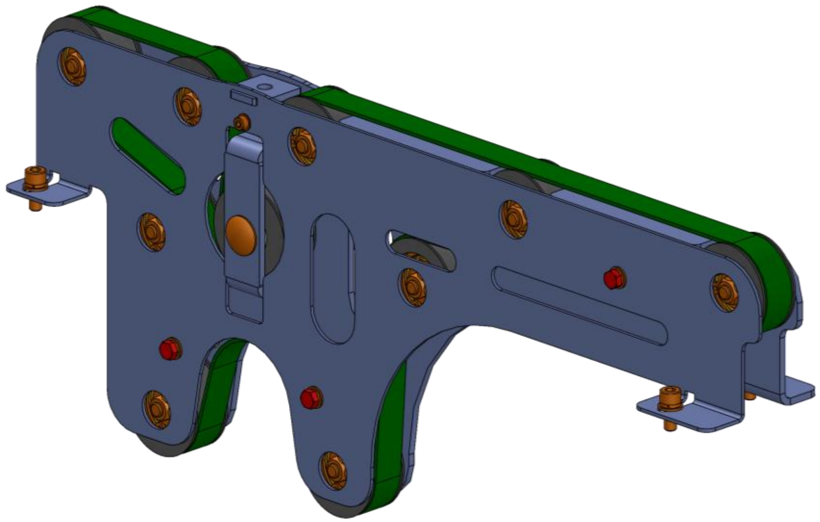


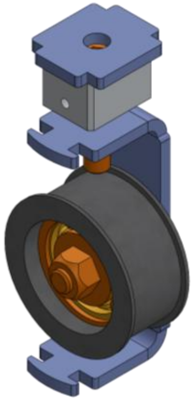
- Contact point between the snail cam and a bearing



- Stopper (double redundancy)

CS1 – DESIGN – BELT MODULE





Belt tensioner module

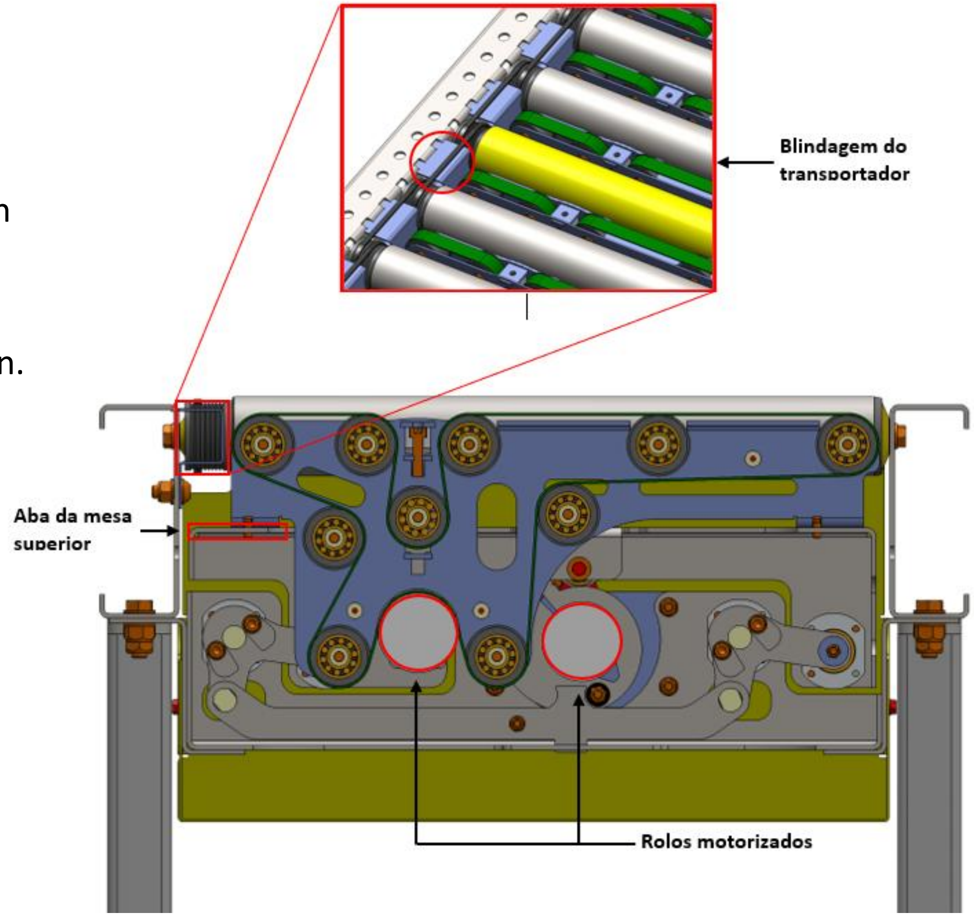
Roller assembly

- Two bent sheet metal parts for structure;
- 10 rollers;
- Tensioner module;
- 3 steel shafts to increase stiffness;
- Horizontal tuning option.

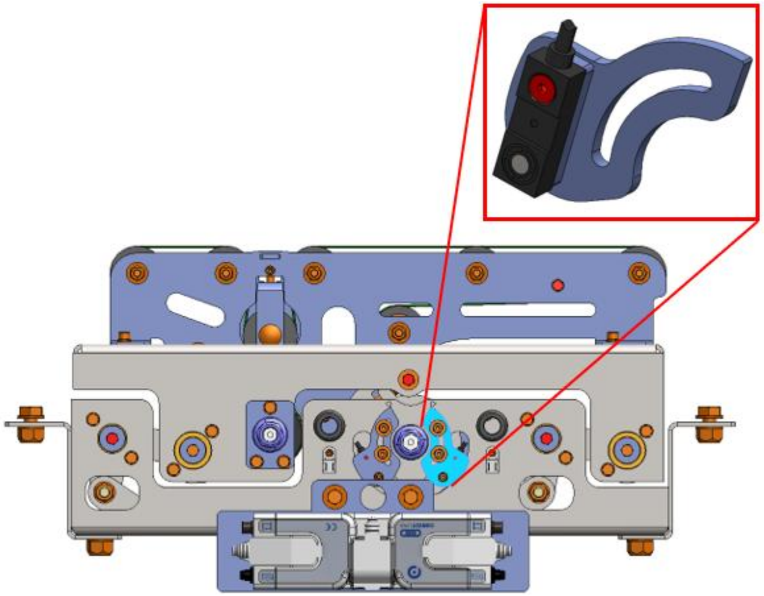
CS1 – DESIGN – BELT PATH

Design constrains

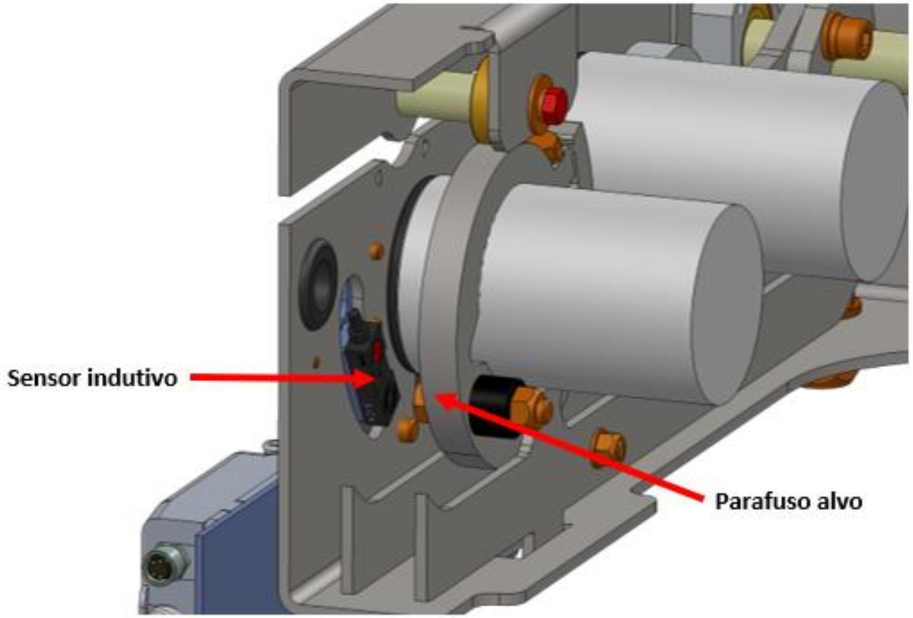
- Conveyor transmition shield;
- Table top;
- Roller drivers position.



CS1 – DESIGN - CONTROL SYSTEM

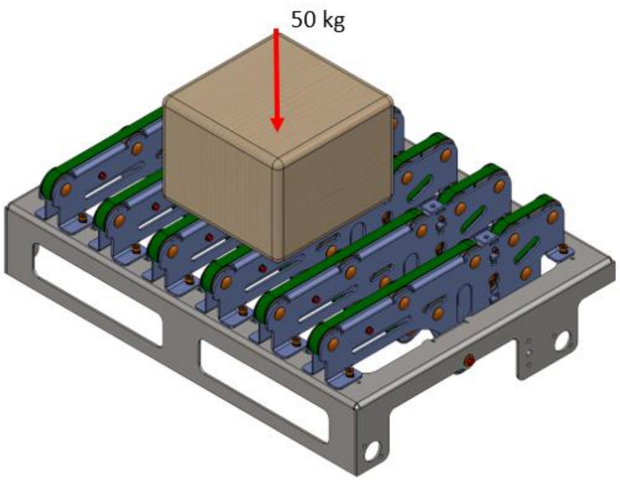


Sensor positioning
with tuning



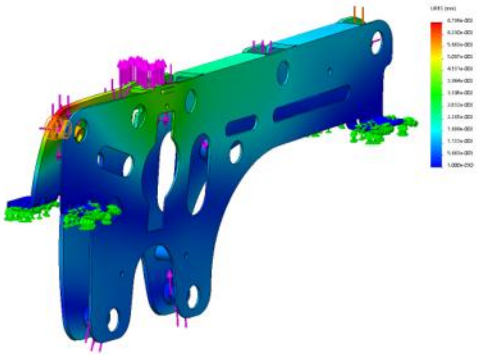
Sensor and target bolt
With tuning

CS1 – DESIGN - FEM



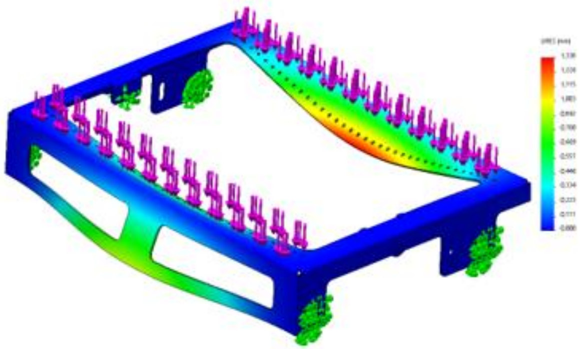
Critical case

Belt module



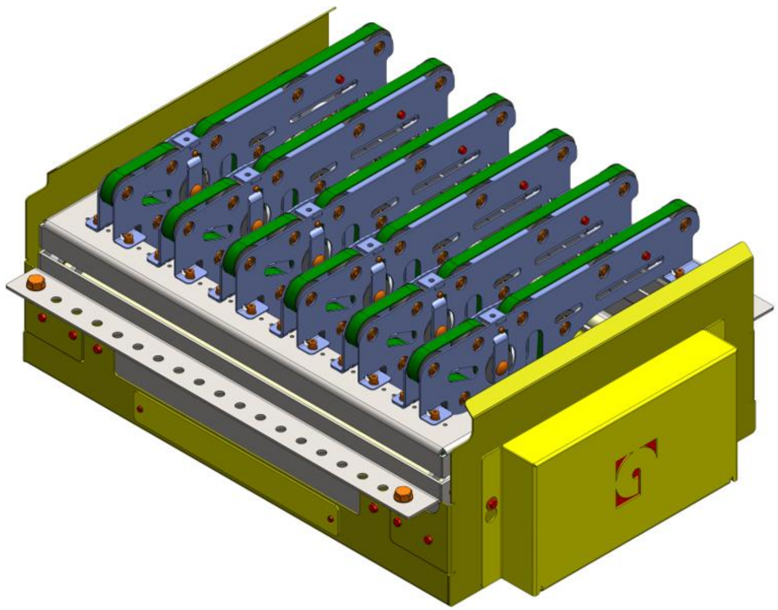
Maximum von Mises stress [MPa]	≈ 20
Resultant displacement [mm]	0,12
Safety coefficient	11,75

Superior structure

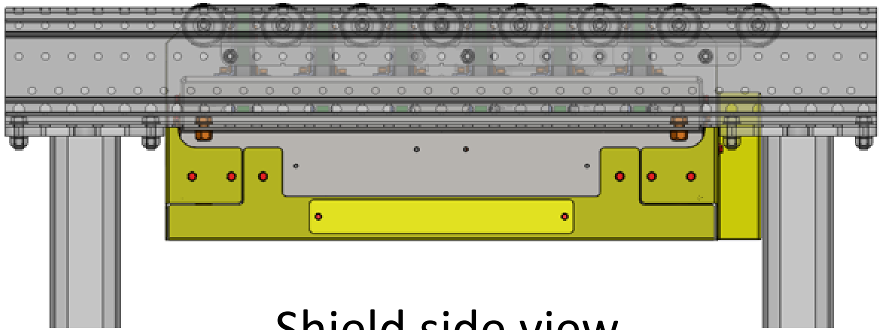


Maximum von Mises stress [MPa]	55,7
Resultant displacement [mm]	1,338
Safety coeficiente	4,2

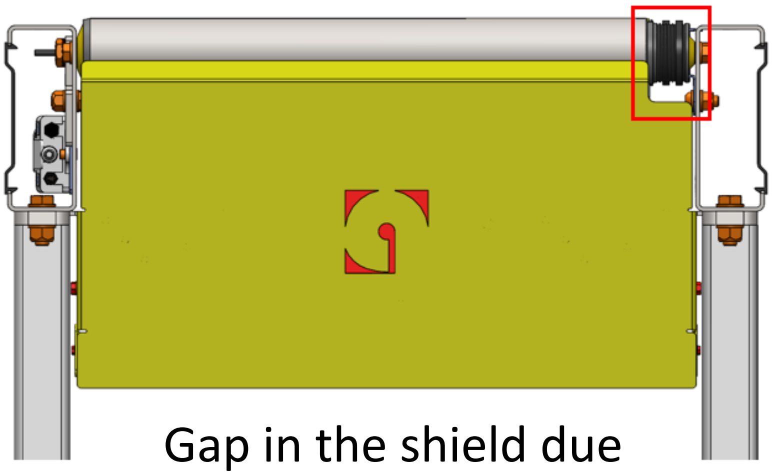
CS1 – DESIGN - SHIELDING



24 V transfer with shields

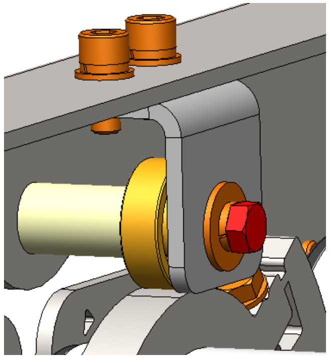


Shield side view

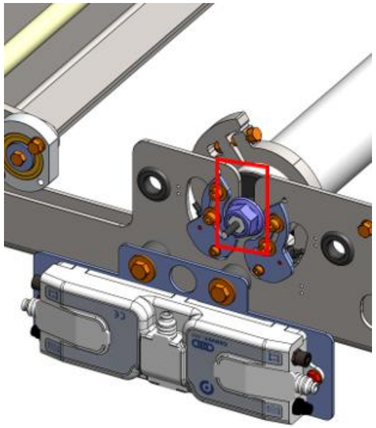


Gap in the shield due to poly-v transmition

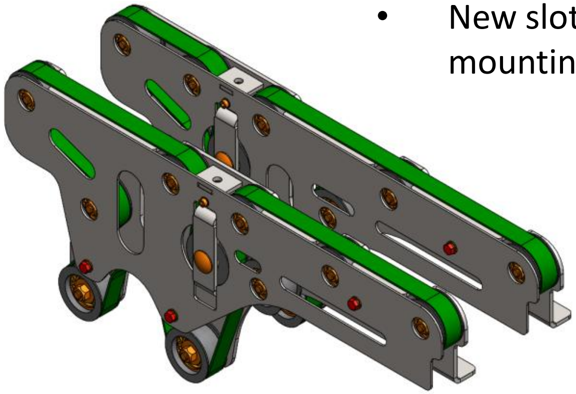
CS1 – ASSEMBLY AND TESTING



- Bearing support change



- New slot in the base structure to allow easier mounting of the Roller driver



- New belt module

CS1 – TESTING

- No-load test

- 50 kg test – continuous cycles

Box weight [kg]	Cycle time [s]	Throughput [units/hour]
10	≈ 1,6	2250
30	≈ 1,8	2000
50	≈ 2,0	1800

- Test results for multiple box weights

CS1 – CONCLUSIONS AND FUTURE WORK

Conclusions

- 50 kg box elevation was achieved;
- Throughput of 1500 units/h was surpassed;
- During testing it was verified that the equipment is capable of handling the previous conditions with high reliability.

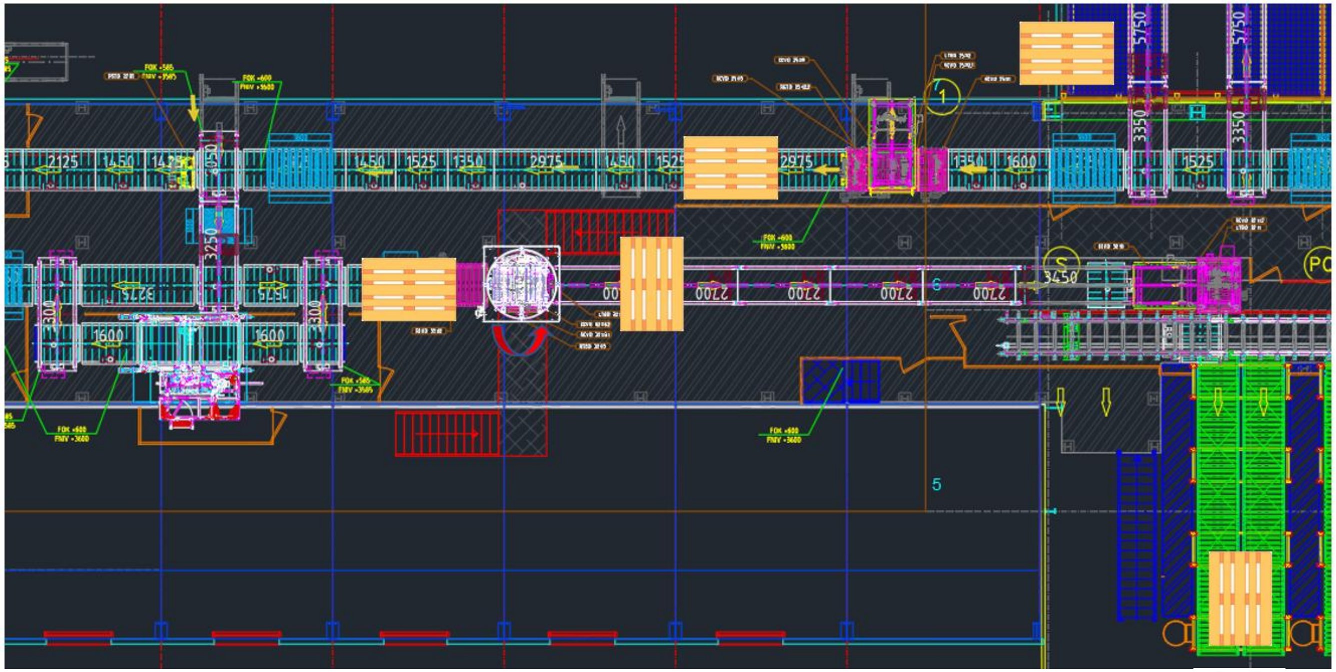
Future work

- Further FEM optimization
- Using the elevation mechanism to develop diferent types of transfers (timing belt / 45º diverter)

CS2 – OBJECTIVES

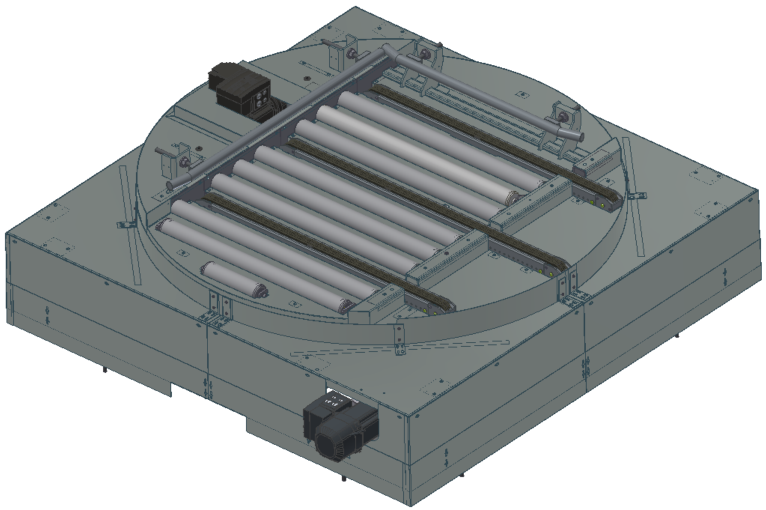
- Develop a machine that receives a Euro or CHEP type pallet, coming from a roller conveyor, makes a 90° rotation and delivers the pallet on a chain conveyor;
  - Develop a rotation and lifting system for a pallet rotary table;
  - Develop security system;
  - Define basic and essential electrical control equipment;
  - Preparation of manufacturing and assembly drawings.

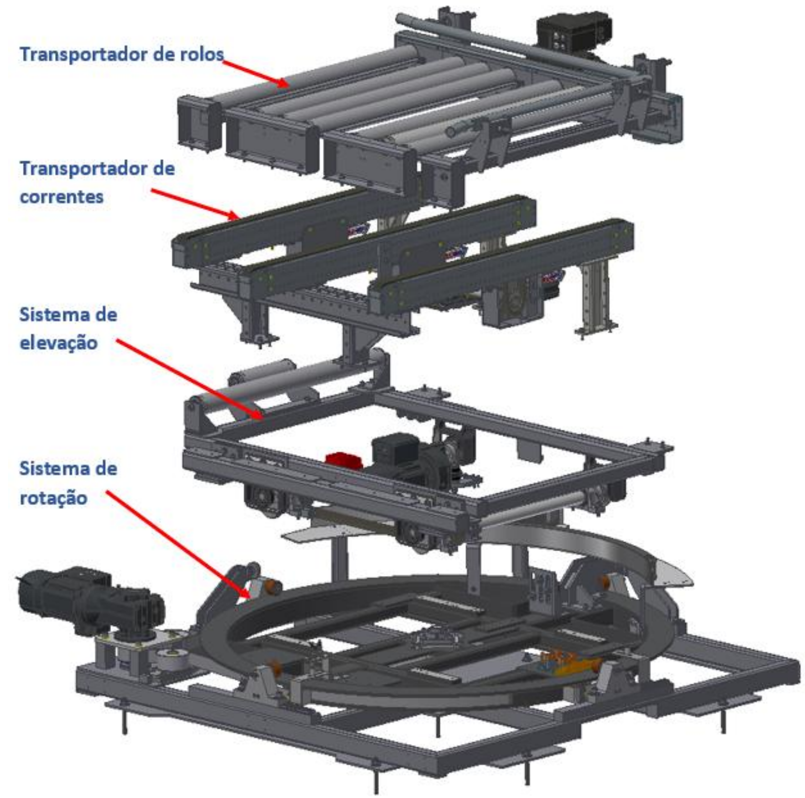
CS2 – PROBLEM DESCRIPTION



CS2 – WORKING PRINCIPLE OF THE PALLET ROTARY TABLE

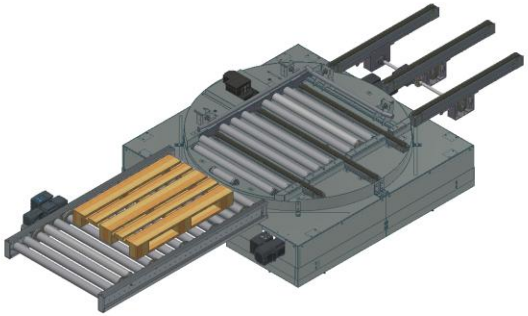
- Rotary table with transfer
  - Roller conveyor
  - Chain conveyor
  - Lifting system
  - Rotation system



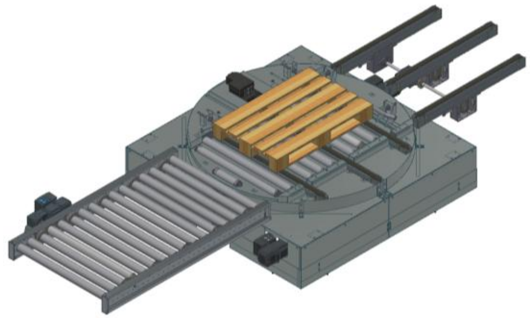


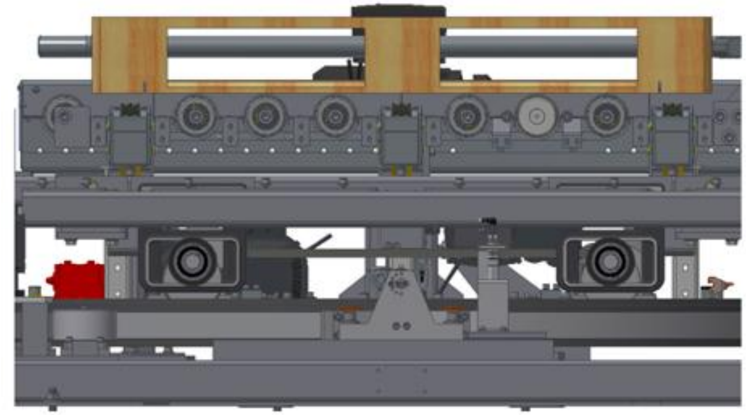
CS2 – WORKING PRINCIPLE OF THE PALLET ROTARY TABLE

Step 1

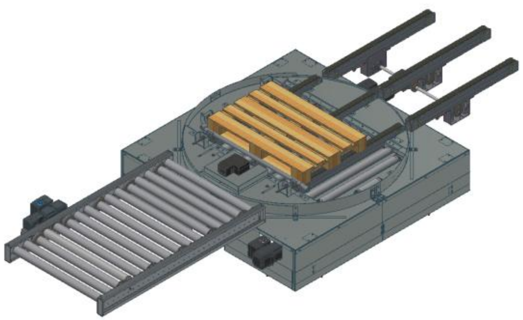


Step 2

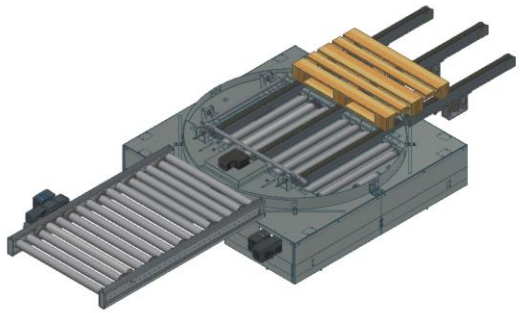


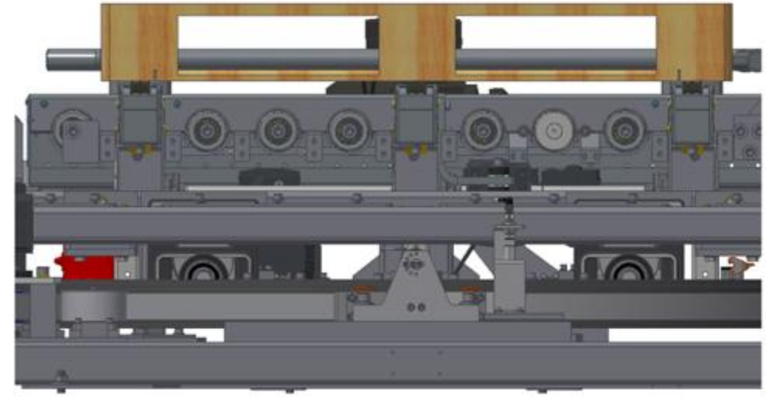


Step 3



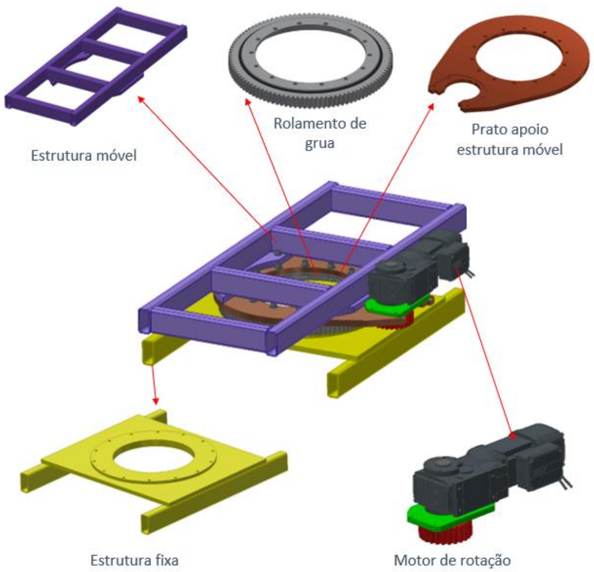
Step 4



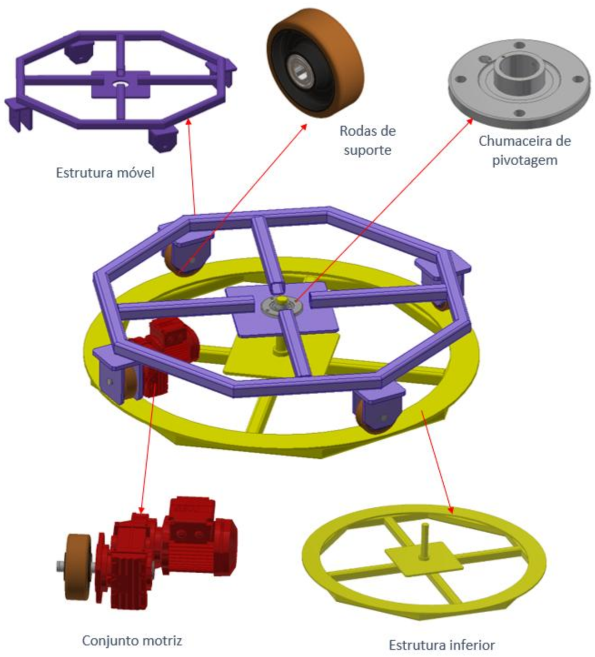


CS2 – MECHANICAL DESIGN – SKETCHES OF THE ROTATION SYSTEM

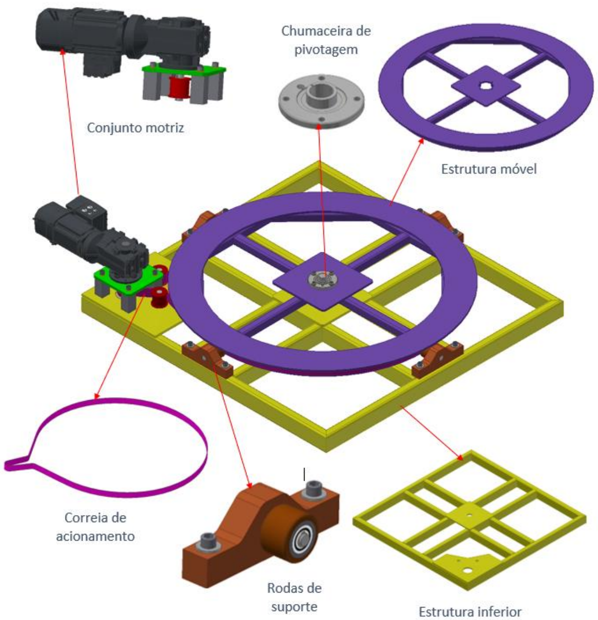
Crane bearing



Support wheels and drive wheel

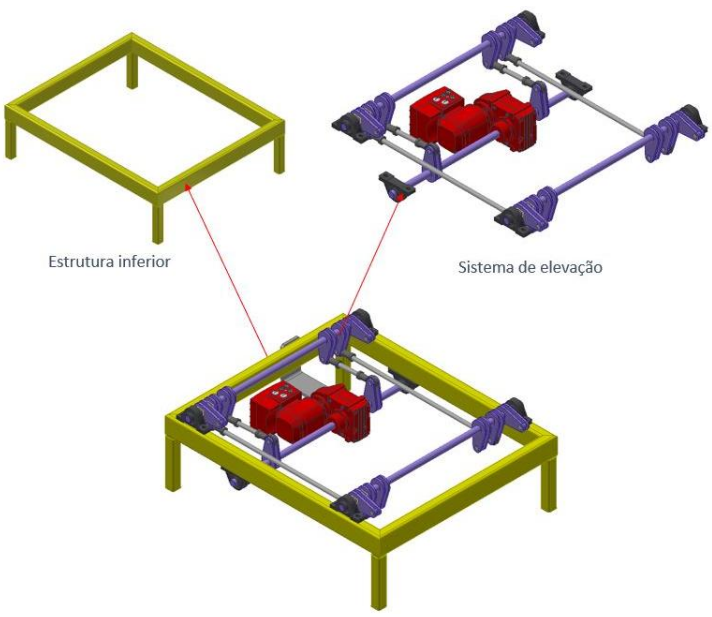


Support wheels and drive belt

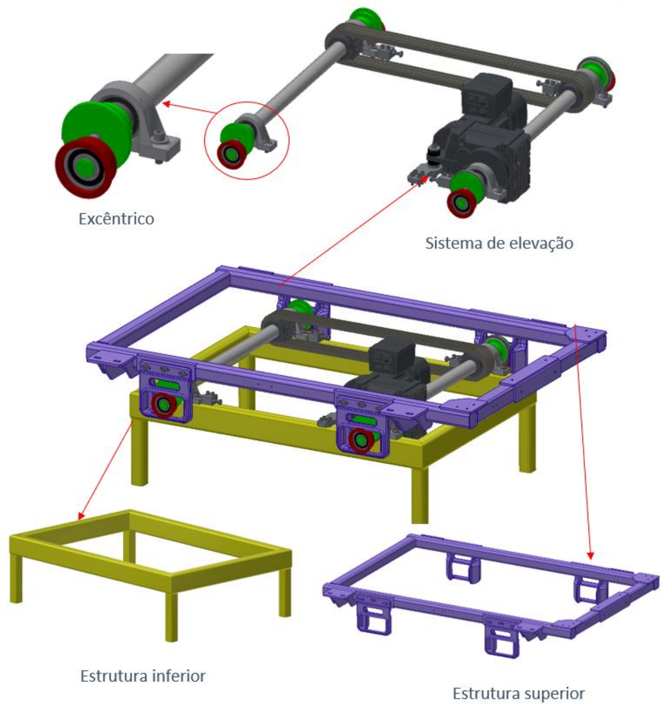


CS2 – MECHANICAL DESIGN – SKETCHES OF THE LIFTING SYSTEM

Crank-rod bearing

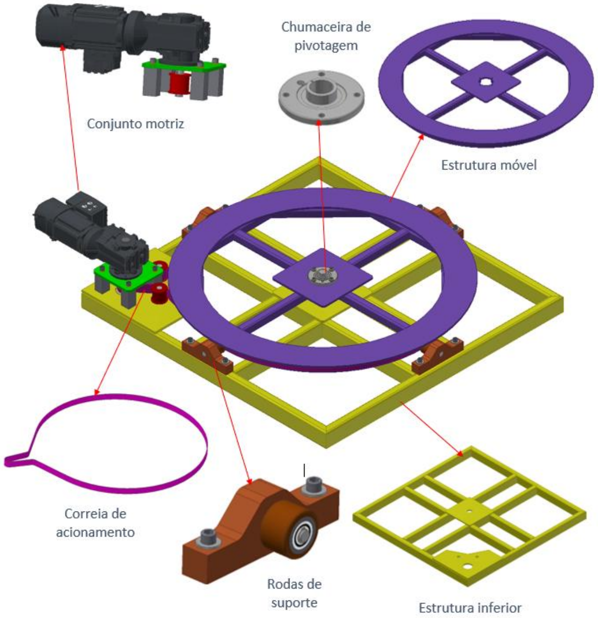


Eccentric system



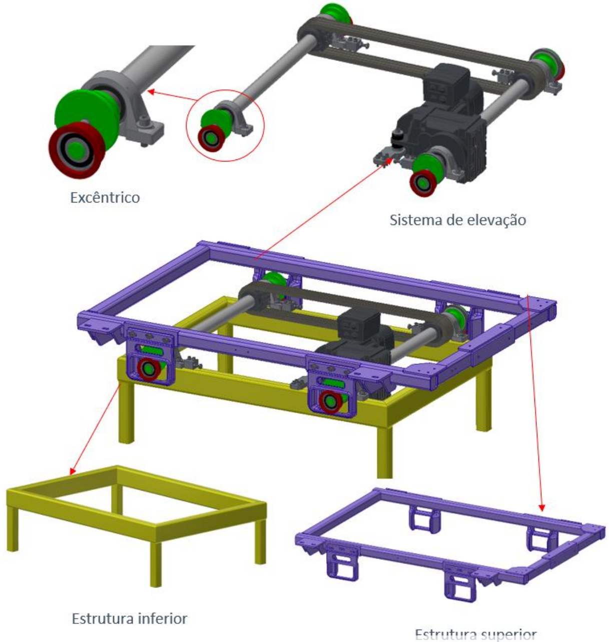
CS2 – MECHANICAL DESIGN – CHOSEN SOLUTIONS

Support wheels and drive belt



- Robust system;
- Simple and compact design;
- Toothed belt eliminates slipping under high accelerations;
- Low height system;
- Ease of maintenance of the drive system;
- Ease of maintenance of the support wheels.

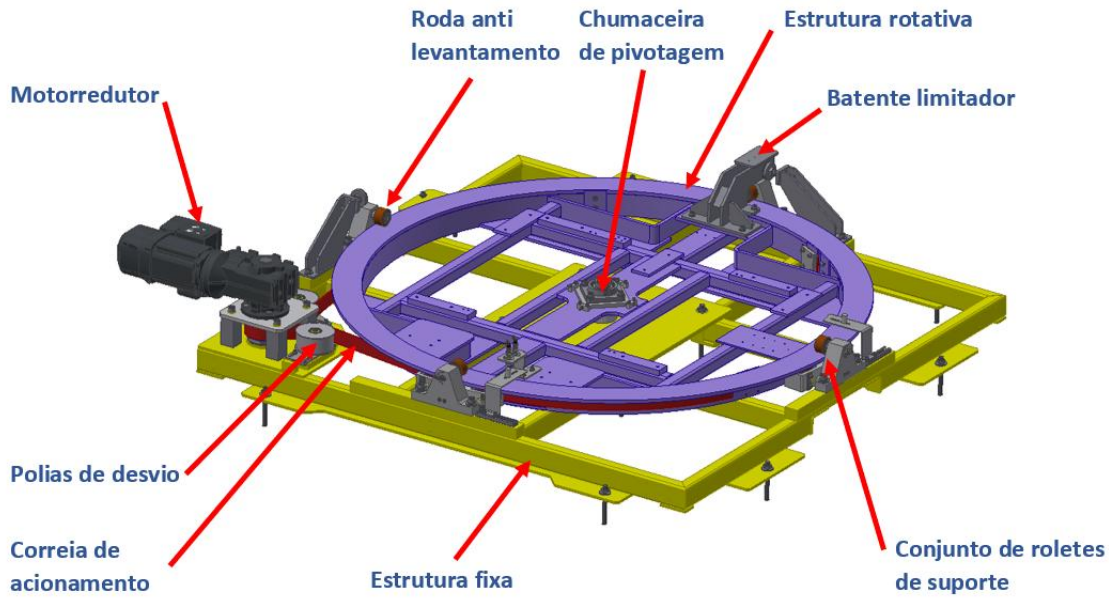
Eccentric system

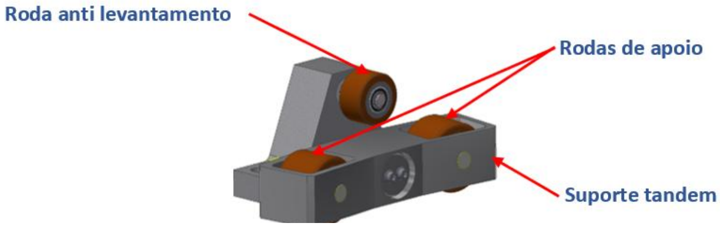


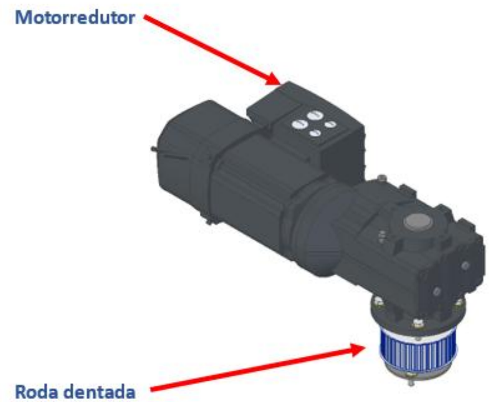
- Easy synchronization of the shafts through the transmission chain;
- Allows handling high loads;
- It does not require reversing the direction of the gearmotor with each up and down movement;
- Fully electric.

CS2 – MECHANICAL DESIGN – ROTATION SYSTEM

- The rotation system serves to rotate the conveyors by 90°.





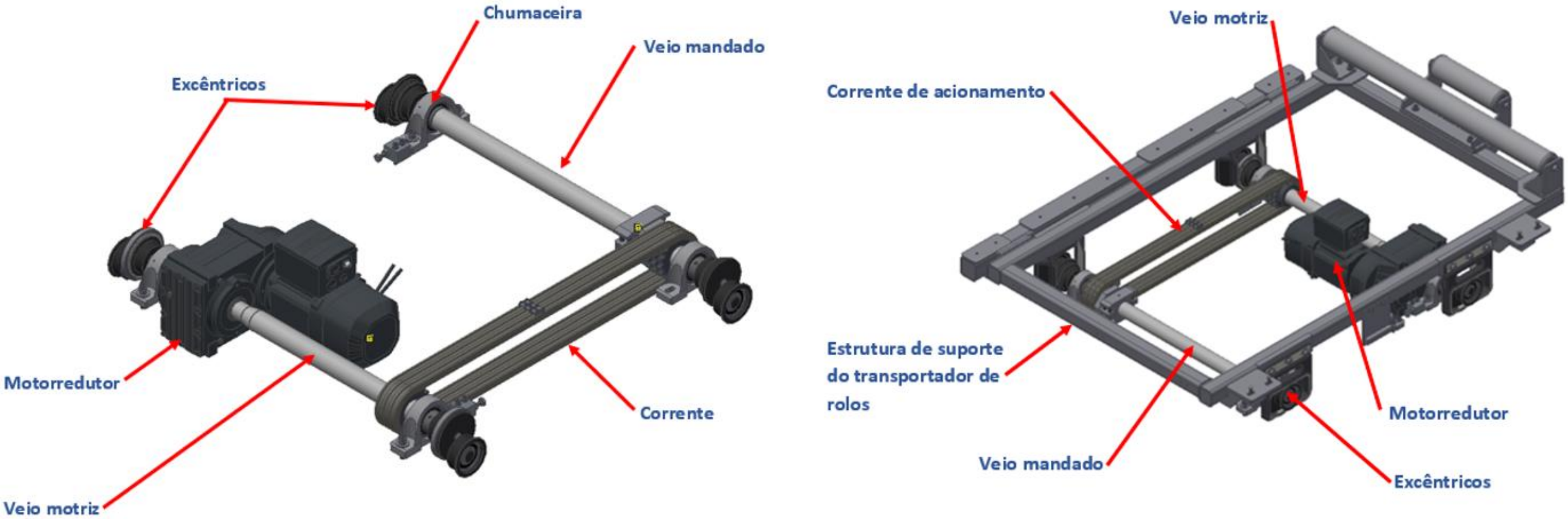


System composed of:

- Fixed structure to support the entire machine;
- Rotating structure to support the conveyors and lifting system;
- Drive set consisting of a gearmotor and toothed belt.

CS2 – MECHANICAL DESIGN – LIFTING SYSTEM

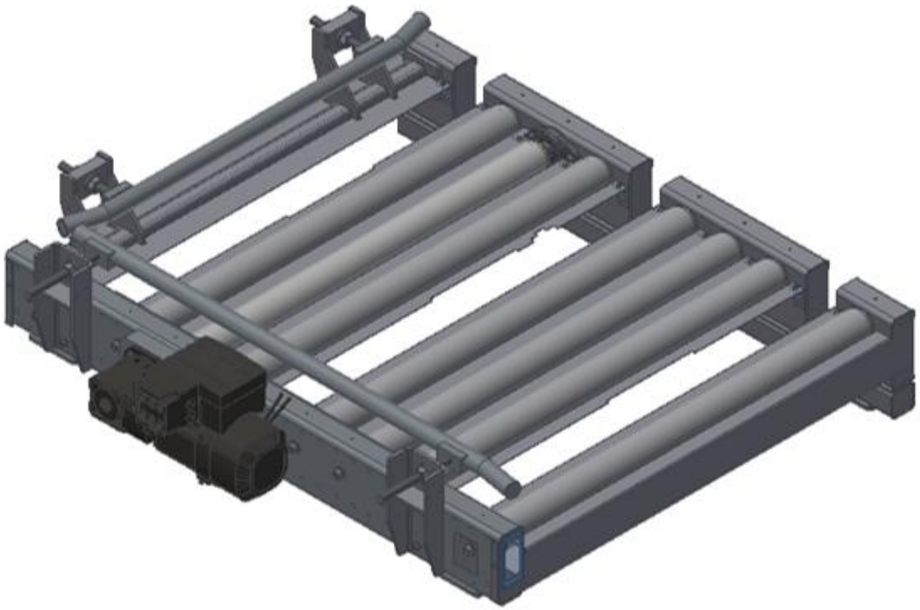
- The lifting system serves to lift the roller conveyor.

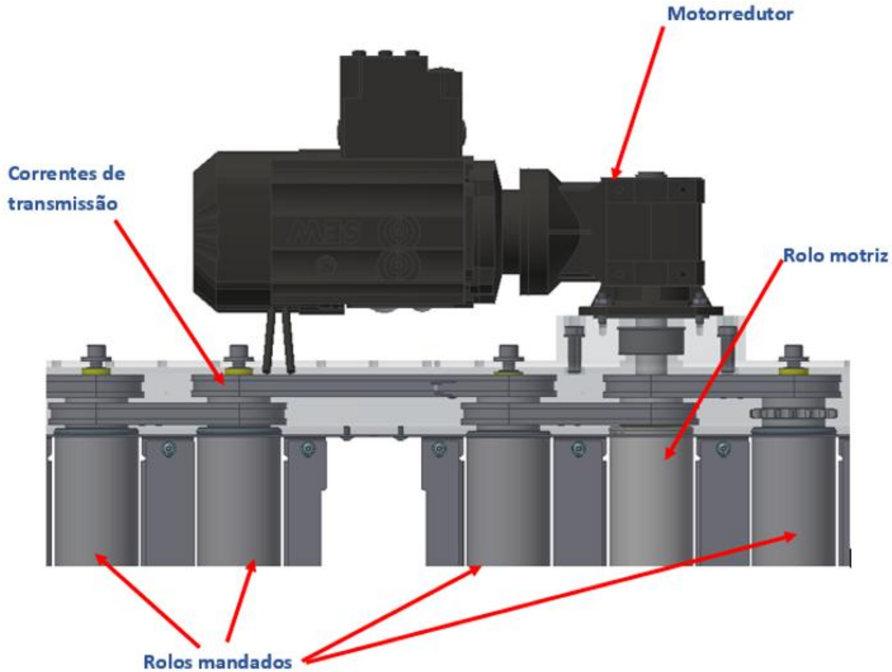


System composed of:

- Shafts with eccentrics, supported by bearings;
- Hollow shaft geared motor for drive;
- Synchronization belt;
- Roller conveyor support structure.

CS2 – MECHANICAL DESIGN – ROLLER CONVEYOR

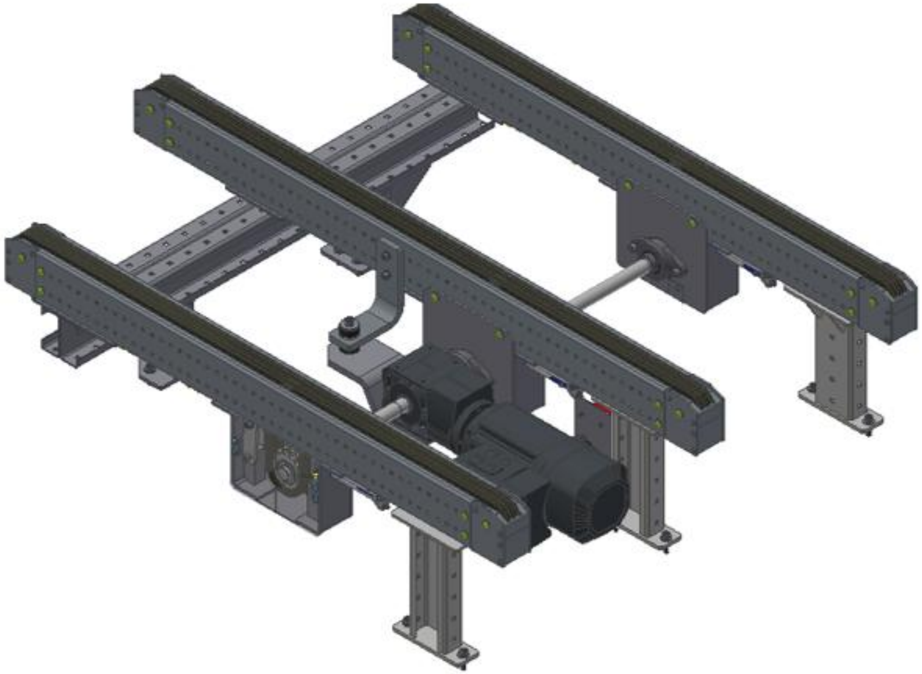


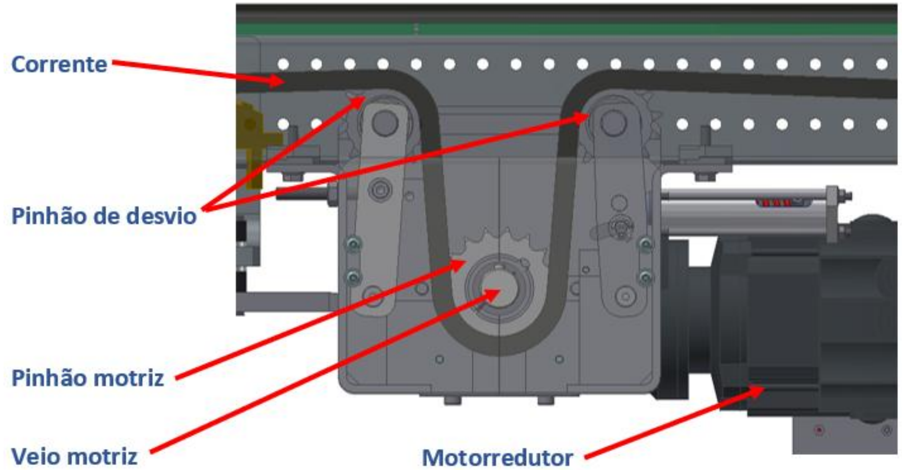


Main features:

- Steel construction;
- Drive by gearmotor;
- Transmission of torque between rollers by system of side chains;
- Pallet alignment stops.

CS2 – MECHANICAL DESIGN – CHAIN CONVEYOR



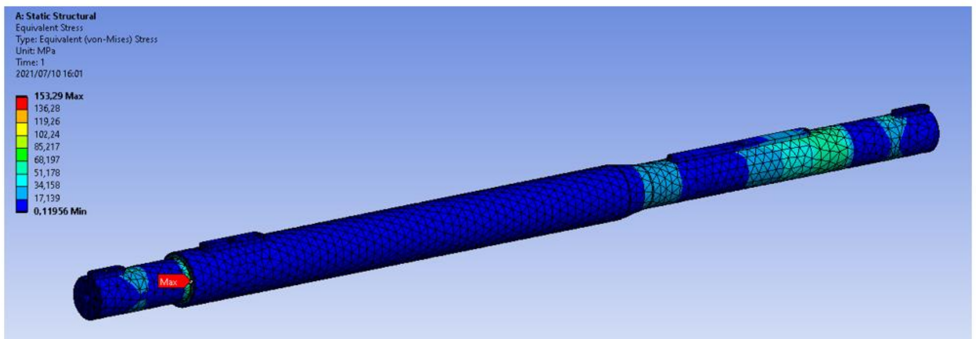


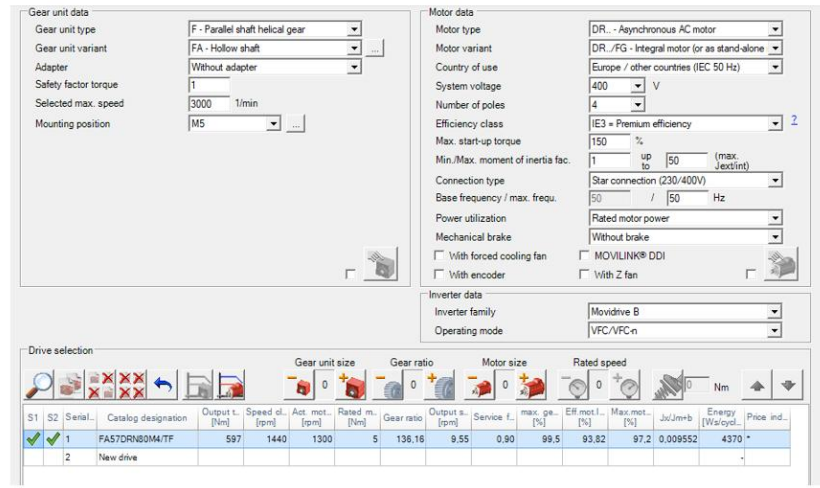
Main features:

- Steel construction;
- Drive by gearmotor;
- Single shaft to drive the 3 stringers;
- Automatic chain tensioning system.

CS2 – MECHANICAL DESIGN – VERIFICATION CALCULATIONS

- Verification calculations of rotary table parts were performed.





S1	S2	Serial...	Catalog designation	Output t... [Nm]	Speed cl... [rpm]	Act. mot... [rpm]	Rated m... [Nm]	Gear ratio	Output s... [rpm]	Service f...	max. ge... [%]	Eff.mot.l... [%]	Max.mot... [%]	Jx/Jm+b	Energy [Ws/cycl...	Price ind...
✓	✓	1	FA57DRN80M4/TF	597	1440	1300	5	136,16	9,55	0,90	99,5	93,82	97,2	0,009552	4370	*
		2	New drive												-	

Structural parts (complex geometry):

Simulation by Finite Elements

(Ansys)

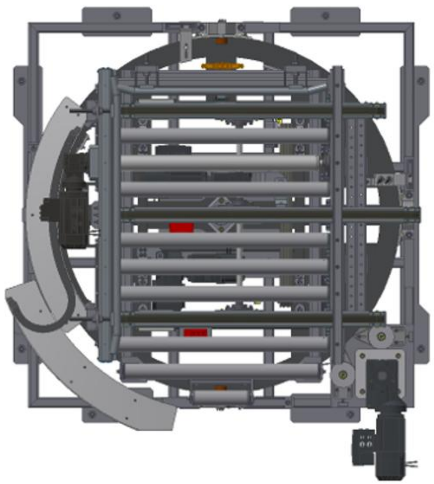
Standard components:

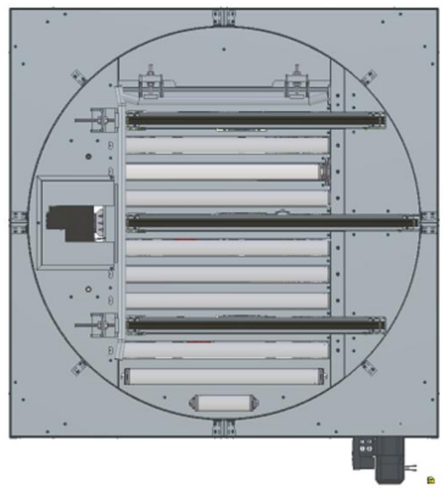
Specific software

(SEW Workbench, INA, among others)

CS2 – MECHANICAL DESIGN – SAFETY SYSTEMS

Shields





Dimensions in millimetres

Part of body	Illustration	Opening	Safety distance, s_r Slot	Square	Round
Fingertip		$e \leq 4$	≥ 2	≥ 2	≥ 2
		$4 < e \leq 6$	≥ 10	≥ 5	≥ 5
Finger up to knuckle joint		$6 < e \leq 8$	≥ 20	≥ 15	≥ 5
		$8 < e \leq 10$	≥ 80	≥ 25	≥ 20
Hand		$10 < e \leq 12$	≥ 100	≥ 80	≥ 80
		$12 < e \leq 20$	≥ 120	≥ 120	≥ 120
		$20 < e \leq 30$	≥ 850 [a]	≥ 120	≥ 120
Arm up to junction with shoulder		$30 < e \leq 40$	≥ 850	≥ 200	≥ 120
		$40 < e \leq 120$	≥ 850	≥ 850	≥ 850

The bold lines within the table delineate that part of the body restricted by the opening size.

[a] If the length of the slot opening is ≤ 65 mm, the thumb will act as a stop and the safety distance can be reduced to 200 mm.

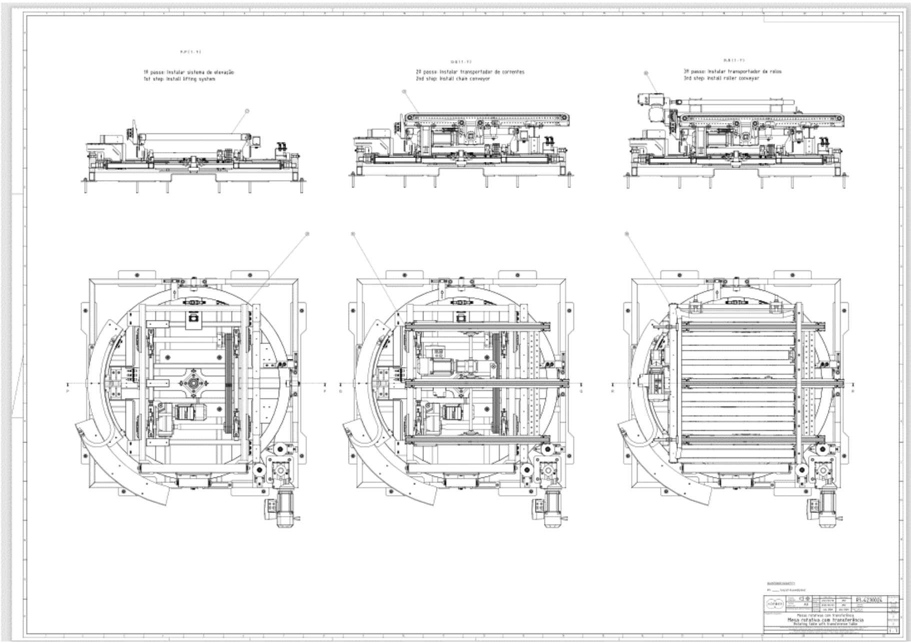
ISO 13857:2019

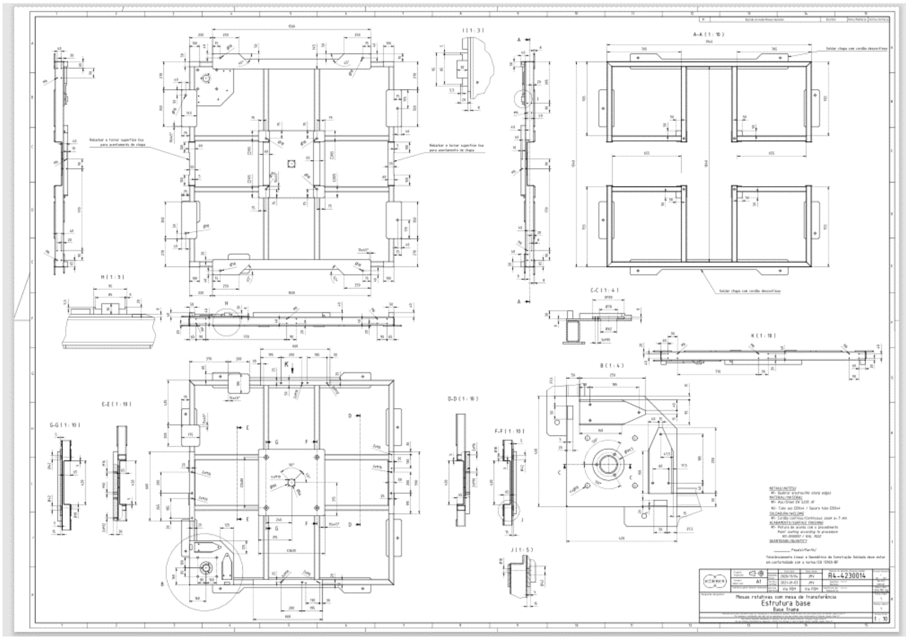
Safety of machinery — Safety distances to prevent hazard zones being reached by upper and lower limbs

Protection against pinching and crushing limbs.

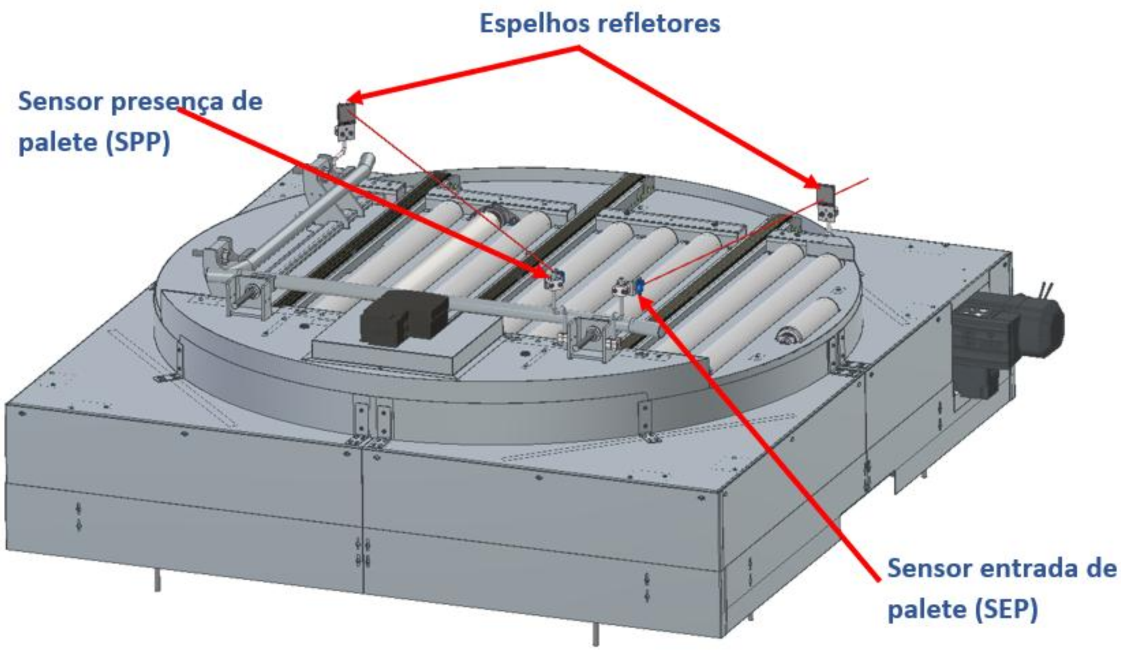
CS2 – MECHANICAL DESIGN – TECHNICAL DRAWINGS

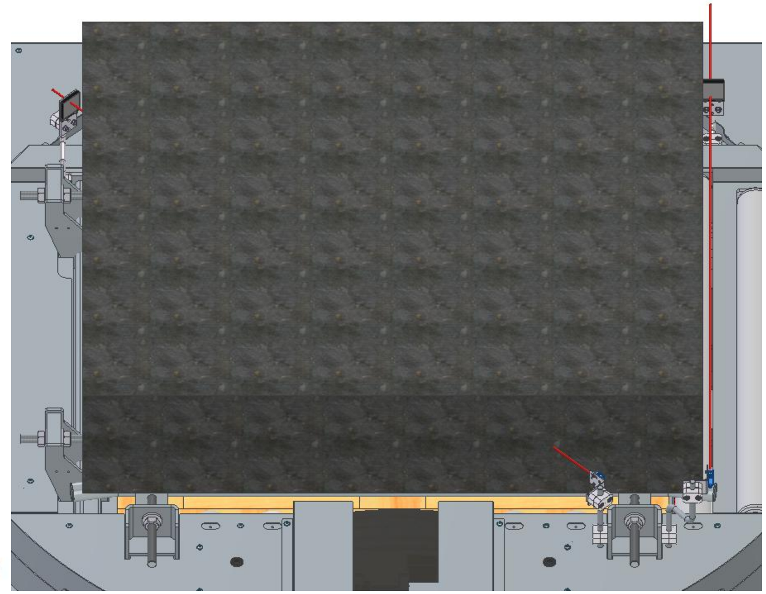
- All the detail drawings necessary for the manufacture of parts and assembly of the rotary table were made.





CS2 – ELECTRICAL DESIGN – PALLET PRESENCE SENSORS

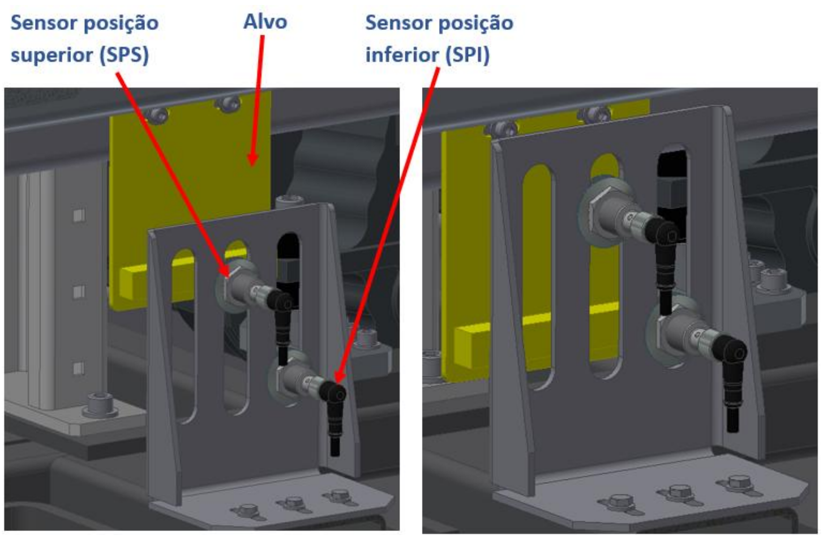




Reflection sensors for detecting pallets in the machine.

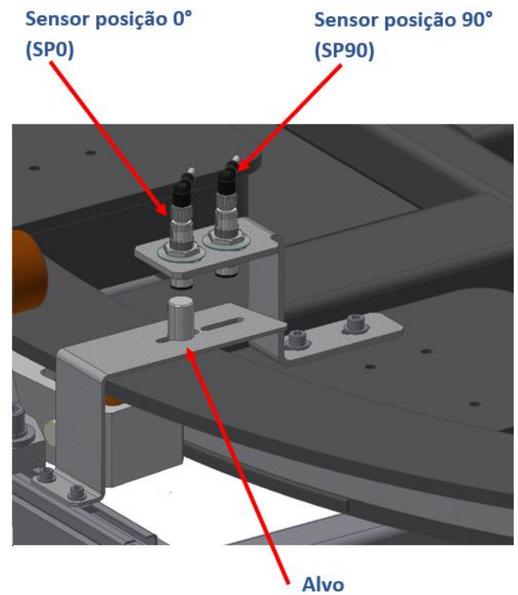
CS2 – ELECTRICAL DESIGN – POSITION SENSORS

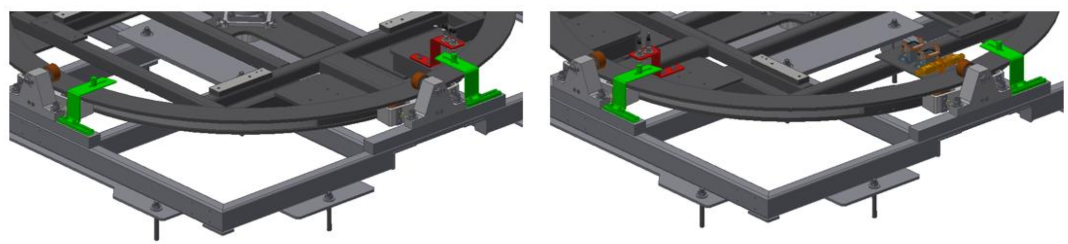
Lifting system position



Inductive sensors to detect the position of the lifting and rotation system.

Rotation system position





CS2 – PROTOTYPE CONSTRUCTION AND VERIFICATION

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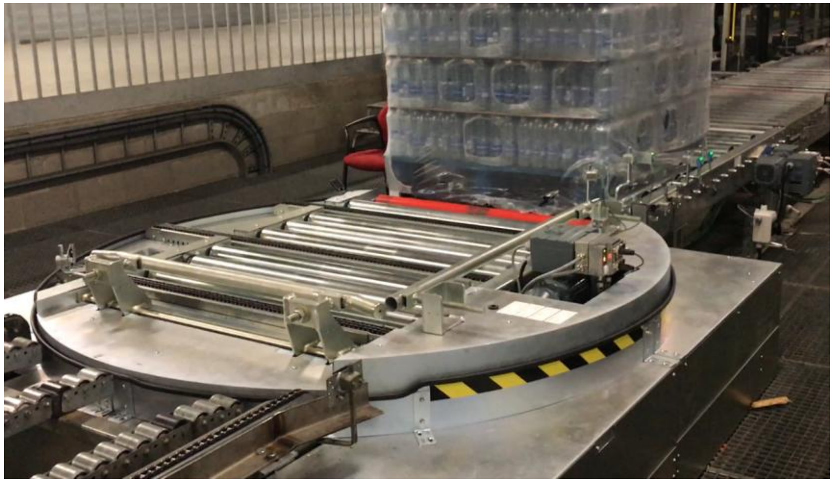
1



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2

4

CS2 – CONCLUSIONS

General requirements	Fulfilment
Compatibility with EURO and CHEP industrial pallets.	Roller and chain conveyors.
Pallet alignment system.	Pallet alignment stops.
Compatibility with the existing line of roller and chain conveyors in the installation.	Roller and chain conveyor with compatible dimensions and speeds as those existing in the installation.
Lifting and rotating system for interface between roller conveyor line and chain conveyor line.	Rotation and lifting system capable of handling a 1500 kg pallet.
The equipment must be fully automatic.	Machine equipped with all electrical and mechanical equipment that allow 100% automatic operation.
All actuators must be electric.	Machine driven by electric gearmotors.
The equipment must be equipped with all safety devices that ensure safe use by users.	Shields to protect operators.
Maintenance of the equipment must be facilitated in terms of accessibility to the various components of the machine.	Some components difficult to access.

OVERALL CONCLUSIONS

- The automatic warehouse performance is strongly dependent on the quality of **local mechanical solutions**, particularly in transfer, positioning, and interface equipment.

- Concept selection is key to success > Pre-design

- Modular design and standardization enable:
    - Easier integration in different layouts
    - Reduced manufacturing costs
    - Faster assembly and commissioning
    - Simplified maintenance and part replacement

- Successful solutions result from **integration with the global intralogistics system**, not from isolated optimization.

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