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Deployment of Industrial Robotic Turbocharger Manipulator into the Production Process – Construction of a Crate Feeder Workstation

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Abstract

An industrial enterprise can remain competitive only if its production process is continually made more efficient. An analysis of operators' workload in a real-world operation involving balancing turbochargers for internal combustion engines has shown that cyclically repetitive and strenuous human work can be optimised through automated processes. For this reason, there is room for applied research, resulting in the machine's ability to reproduce only the necessary manipulation activities required in the turbocharger balancing process. Therefore, the proposed automatic line includes balancing machines to determine the amount and location of unbalanced masses on the turbocharger rotor. Following the overall resolution of the issue, a significant increase in the efficiency of a technologically feasible workplace, adapted to the needs of modern industry, is expected.

Keywords

motion, turbocharger, automation, robotic workplace, structural design

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1. Introduction

The present era is marked by numerous innovations that continually bring new demands for production and development. Therefore, industrial robotic manipulators have become integral to most production processes. Their main advantage is the possibility of continuous operation and a high level of accuracy, force and speed that a person cannot achieve. This method of operation allows manufacturers to increase production and reduce the costs of manufacturing their products. Reliability and a minimal failure rate are key factors when designing equipment intended for automated processes. It is essential to understand the current state of equipping industrial robotised workplaces for the successful deployment of automated processes in production (Eller et al., 2022). Therefore, a brief description of the types of industrial robots, sensors, and their use, as well as optical machine vision systems and effectors coming into physical contact with the transmitted component (in this case, a turbocharger), is an essential part of this work.

An industrial robot can be defined using the PN-EN ISO 8373:2011 standard (ISO 8373:2021, 2021), which states: "... a handling industrial robot is an automatically controlled, programmed, multi-purpose machine with many degrees of freedom that can manipulate and transport workpieces, can be stationary or mobile, for important industrial applications". The standard also specifies the basic parameters of industrial robots:

- The number of controlled axes, typically depending on the robot, ranges from 2 to 7; this parameter determines the degrees of freedom, which are reflected in the degree of complexity of the robot's actions. Each axis has a specific range of angular movements.
- Payload, i.e., the maximum weight the industrial robot can lift or move to another location.
- Reach is defined as the radius of the robot's work area.
- Movement speed determines the maximum speed at which the robot can move in each axis. This parameter is defined in rad/s for rotary axes or mm/s for linear axes.
- Accuracy and repeatability determine the accuracy of the robot's movement. Industrial robots consist of 3 basic elements:

a) A manipulator – the power part of the industrial robot;
b) A control unit – the controller of the industrial robot (electronic systems for drive, safety, logic);
c) A robot control panel is a remote control for the industrial robot (Engineering, 2025).

Industrial robots are utilised in various industries. However, it is essential to consider the robot's movement capabilities, safety, economic feasibility, load capacity, and other relevant factors when selecting a robot for a specific application. When making this choice, there are several options:

- Articulated robotic arms (provide the most flexible movement) (Machine Design, 2025),
- Cartesian robots (used mainly for cutting, drilling, welding and other technological operations) (Siciliano et al., 2010),
- Delta robots (for high-speed and precise assembly work) (Daily Automation, 2025),
- SCARA robot (used mainly for material transfer) (Mitsubishi Electric, 2025).

The analysis of the current state of industrial robots reveals that they are suitable for use wherever it is possible to replace human labour with a robot, i.e., in monotonous, physically demanding activities, and where necessary to achieve a given quality and repeatable accuracy. As seen from the operations for which robots are used, they are primarily employed in processes that can reduce operating time, enhance accuracy, and replace workers in hazardous working conditions (e.g., paint shops, welding shops, and radiation environments).

This article aims to present the results obtained during the design, development and production of a system for automating a production cell consisting of several turbocharger balancers (3 pieces) and the integration of an automatic crate feeder with a CHRA – Centre Housing Rotating Assembly (centre rotating assembly of the turbocharger). The aim is to design an automated cell in cooperation with two or three robots. The design's motion capabilities should reproduce all manipulation activities a human operator performs, as when the balancer is in manual operation. The analysis of manual operation revealed that input crates containing unbalanced CHRAs are inserted into the line on trolleys by the operator, where the crate feeder receives them. Subsequently, individual CHRAs are removed from the crate using an industrial robot. This component is oriented by the robot and inserted into the balancing device in a precisely defined position and orientation. After balancing,

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the CHRA is automatically removed from the balancer and placed on the output conveyor. Then, the conveyor ensures the transport of the balanced CHRA to the output zone, where the component is manually removed by a worker and placed in the output crate. In the case of a defective CHRA, it must be placed in a designated location. The entire process was implemented with an emphasis on precision handling, repeatability of operations and minimisation of human intervention in production.

The basic factor occurring in any material handling is movement. Movement during handling occurs due to the drive of the handling unit (robot). For applications on single-purpose machines, three types of drives are offered: electric, hydraulic, and pneumatic. However, hydraulic drives are not commonly used in automation. This means they are not considered in the design options. The choice of an individual drive method depends on the tasks assigned to the machine. The electric drive of industrial robots offers several advantages, making it the preferred choice in modern industrial applications. First, it is characterised by high accuracy and repeatability of movements, which is crucial for tasks requiring fine manipulations or precise assembly operations. Electric drives also offer high energy efficiency, because their performance can be precisely regulated according to current needs, thus minimising energy consumption.

Additionally, they offer quiet operation and low maintenance requirements, as they do not contain complex hydraulic or pneumatic components. Another advantage is the easy integration with control systems, which allows precise and flexible programming of movements. In addition, electric drives offer a more environmentally friendly solution, as they do not produce waste media or emissions, contributing to industrial processes. Electric motors implement electric drives. One of the most widely used types is the AC asynchronous motor, called an induction motor. Induction motors are perhaps the most widely used type of electric motor. They are generally simple in design and robust, offering reasonable asynchronous performance: a controllable torque and speed curve, stable operation under load, and generally satisfactory efficiency (Hussen et al., 2013; Kirtley, 2005; Šavrnoch et al., 2024; Zaharia, 2019).

Pneumatic drives for industrial robots offer several advantages that make them ideal for use in specific applications where high speed and low cost are key. Due to their simple design and ease of maintenance, they are commonly used in assembly lines, e.g. when assembling small parts in the automotive industry. Pneumatic systems are ideal for driving pneumatic grippers as robot end effectors. Compressed air supplied to the line can also be used to blow off parts where possible dirt needs to be removed. Their high speed and instant start-stop capability allow them to perform repetitive tasks like sorting products or packaging goods efficiently. Additionally, the absence of electrical components that can spark when started makes them safe for use in environments with an explosion risk, such as chemical plants or refineries, where pneumatic robots are used for simple processes like opening and closing valves. Although they have lower accuracy and limited power than electric or hydraulic actuators, their flexibility and reliability make them suitable for applications where high accuracy is not required, but speed and low cost are a priority (Festo, 2018).

2. Materials and methods

The design of any product, including automation lines, begins with compiling specific requirements. These requirements are selected based on specific needs (e.g., dimensional, performance, economics, etc.). The requirements are listed in a document that guides the prototype's design, research, and development. All the requirements that guided the production line's design are listed in Table 1.

A manipulated turbocharger is a compressor that uses the energy of exhaust gases to drive it. It is used for additional supercharging of internal combustion engines, regardless of whether they are spark-ignition or compression-ignition units. Its main advantage is to improve the performance parameters and increase the engine torque. The turbine blades rotate due to the thermal energy of the exhaust gases. The turbocharger rotor rotates at a high speed, depending on the size, purpose, and type of turbocharger. The compressor is connected to the turbine via a shaft and sucks in fresh air, which it then compresses. After compression, the air is fed into the engine cylinders. During compression, the air is heated up to 180 °C. This heated air can be cooled in a compressed air intercooler, where its temperature is reduced and the density for filling the cylinders is increased. The compressed air temperature at the outlet of the intercooler should be approximately the same as the intake air temperature. The pressures without charge air cooling range from 0.02 to 0.18 MPa, while those with cooling range from 0.05 to 0.22 MPa.

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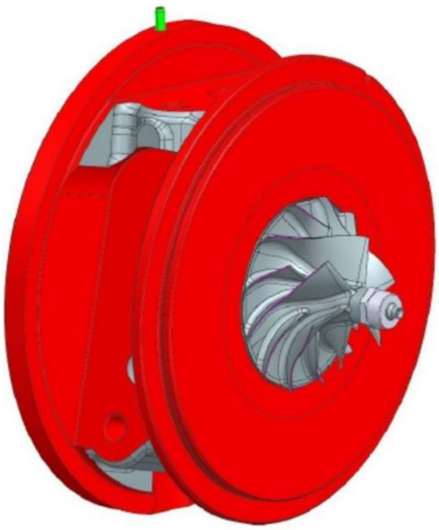
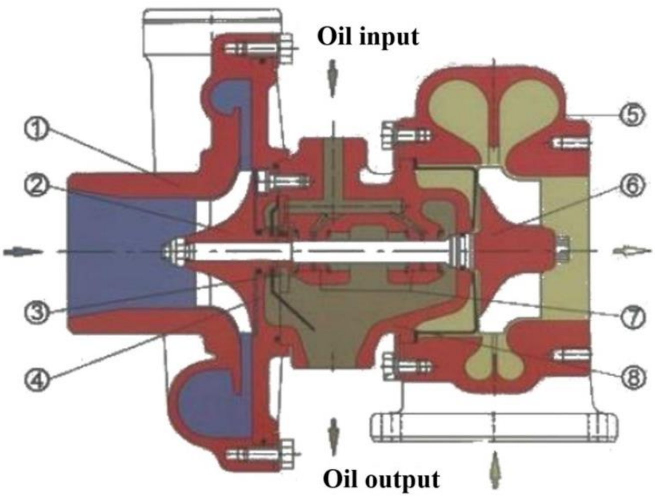
The manipulated structural unit (Figure 1) consists of three main components: the compressor housing, the turbine housing and the bearing housing. The compressor and the turbine impeller are interconnected. They are mounted on a common shaft. The bearings are lubricated with engine oil and are very sensitive to the quality of the oil. Due to the high speeds and significant temperature differences between the compressor and the turbine, high manufacturing precision and durable materials are required.

Table 1. List of demands defining the structural design of a production line cell.

Demand	Importance	Note
Line plan	Required	Up to 6 m × 6.3 m, height up to 3.5 m
Weight transferred by the robotic arm.	Required	At least 5 kg
Fully automated operation	Required	
Various and several settings of applications and parameters	Required	
Universal system for attaching a gripper	Required	
Not damaging the transferred parts of turbochargers	Required	
Continuous operation	Required	
Primarily use electric drivetrains.	Optional	In case of pneumatic drivetrain, max. pressure of 6 bar (treated air)
Brands of robotisation (KUKA	Required	KUKA KR6/10/12
A lifetime of at least 10 years	Required	
Operation in climate conditions from 10°C to 45°C, relative humidity 90%	Required	



(a)



(b)

Figure 1. The center of the manipulated turbocharger with a view of the compressor impeller (a) and a section through the turbocharger (bt), where the individual positions are marked: 1 – compressor housing, 2 – compressor wheel, 3 – axial oil bearing, 4 – rear wall of the compressor housing, 5 – turbine housing, 6 – turbine wheel, 7 – radial oil bearings, 8 – bearing housing.

Therefore, the proposed production line handles the turbocharger to the balancing station. Balancing must be performed on the rotating parts of the turbocharger, specifically on the compressor wheel, which is made of aluminium and mounted on a shaft within a bearing housing. This part is called the turbocharger's centre, specifically the Central Housing Rotating Assembly (CHRA). The specific dimensions of the CHRA required for the design of the gripping device are shown in Figure 2. The weight of the manipulated structural unit does not exceed 2.5 kg.

Static or dynamic balancing balances rotating parts, not just turbocharger rotors. Static balancing is a relatively simple method whose principle consists of inserting a precision shaft into a hole in the centre of the rotating part. Then, the precision

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shaft is placed in carefully aligned bearing supports. If the rotating part is unbalanced, it rotates while the heaviest part is oriented downwards. When it remains in any position due to the balancing and reduction of the heavier parts, it is said to be in static equilibrium (Al Rashid et al., 2024; Lifetime Reliability Solutions, 2025; Kumar et al., 2024). However, a rotating part can be in perfect static equilibrium, but not necessarily in a balanced state, which is especially evident when rotating at high speed. If the part has the shape of a thin disk, static balancing, if carefully carried out, can be accurate at high speeds. However, if the rotating part is long in relation to its diameter, the unbalanced part may be at opposite ends or in different planes. Therefore, such parts must be balanced while rotating to reveal the imbalances using centrifugal force. This process is known as in-service balancing or dynamic balancing.

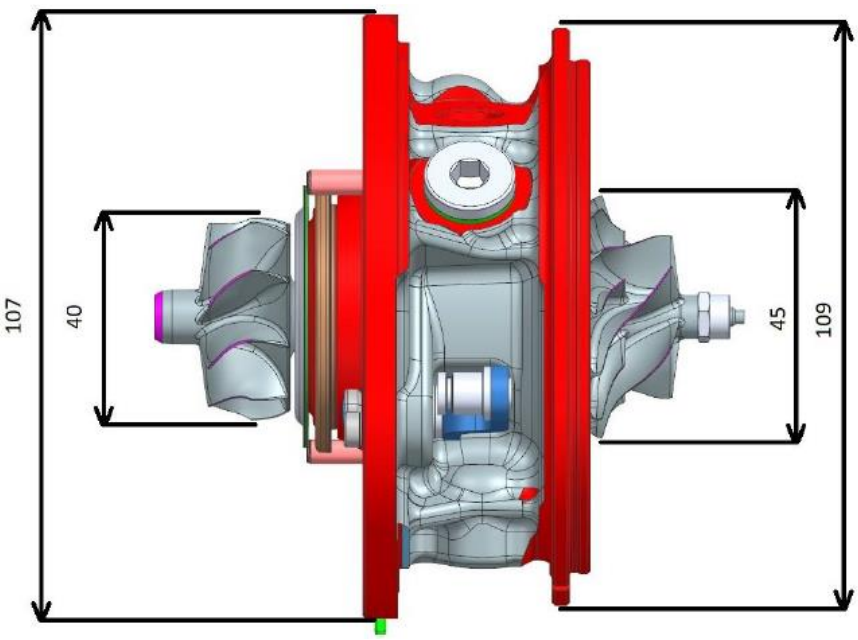

Figure 2. The main dimensions of the gripped structural unit are CHRA.

Therefore, the proposed automated line includes a balancing machine, which determines the amount and location of unbalanced masses on the turbocharger rotor. It is a device that rotates the rotor on a set of spring bearings. Thanks to the floating bearings, any imbalance causes the rotor to move off-axis as it rotates. The device measures the phase angle and amplitude of the movement and calculates the imbalance that must be present to cause the movement. The operator can then make the appropriate corrections (Norfield, 2006; ISO 21940-2:2017, 2017).

3. Results and discussion

This section presents the results of the design, research, and development process for a robotic line cell that handles turbochargers, automating their balancing on a balancing machine. The line layout is roughly determined in Table 1 based on dimensional requirements. The line consists of two robotic arms of different model series from the manufacturer KUKA, three dynamic CHRA balancers, an input section, an output section, a positioning section and a section for storing defective pieces. It also includes ancillary systems, such as fencing and suction units for operating fluids used in CHRA balancing.

The operator loads the turbocharger crates into the feeder on the trolley. The trolley is automatically locked and centred in the feeder. Sensors check the presence of the trolley. The start button starts the automatic palletising of the crates. The crates are stored on the trolley in a maximum of 10 pieces, arranged in 2 rows of 5 pieces each (Figure 4a). One row of crates is lifted by the loading mechanism (Figure 4b) and moved along the chain conveyor (Figure 4a, Figure 5b). In the final position, the individual crates can be lifted separately to the removal position for the elevator (Figure 5b). The loading mechanism transfers the crates from the trolley to the removal chain conveyor. The loading mechanism moves one row of crates at a time onto this conveyor. The mechanism consists of a frame made of welded parts, a pair of pneumatic cylinders, a separating mechanism driven by an electric motor and a chain conveyor that removes the crates from the trolley. The chain

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conveyor moves the crates from the loading mechanism to the removal position and the stacked empty crates to the removal mechanism.

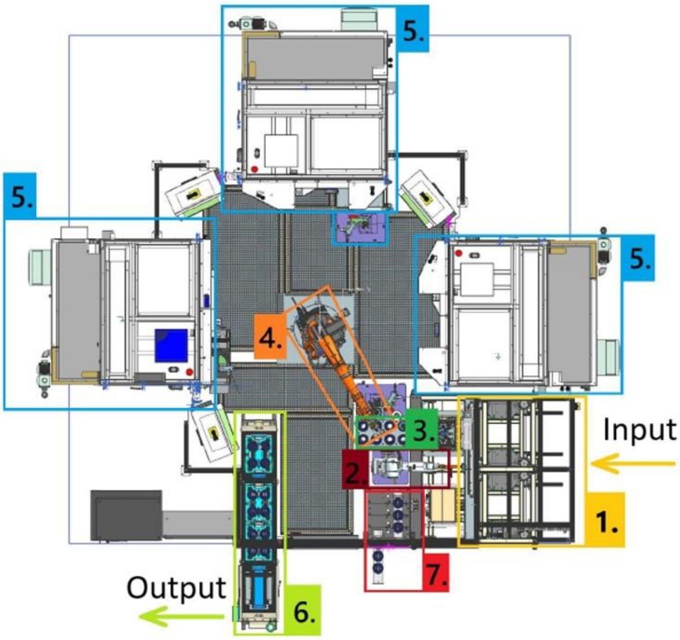
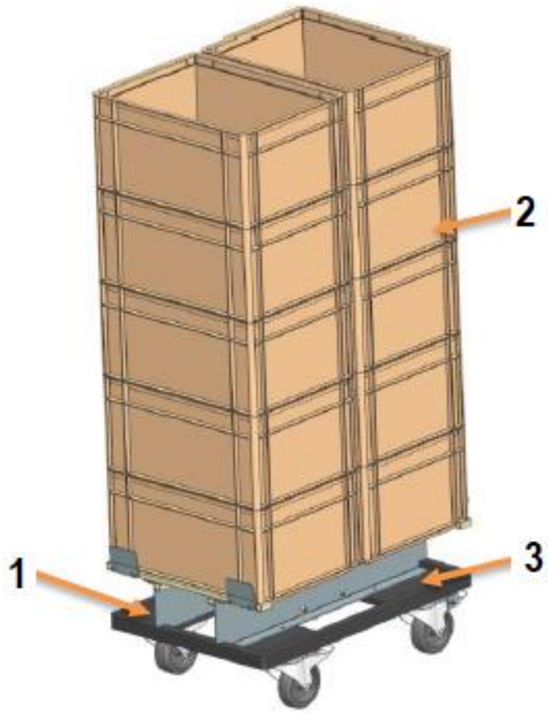
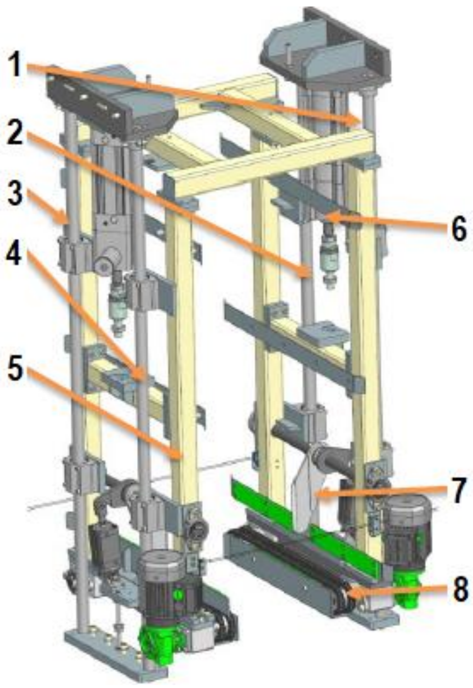


Figure 3. A floor plan of the structural design of the automation line for balancing turbochargers, individual positions are marked: 1 – crate feeder, 2 – robot no. 1, 3 – positioning beds, 4 – robot no. 2, 5 – balancers, 6 – conveyor, 7 – NOK socket.

The handling lifting unit (an elevator) is used to grip and lift the crate to the picking position for robot No. 1 (Figure 6a). After the robot empties the crate, the crate is moved to the position where the crates are stacked.



(a)



(b)

Figure 4. Turbocharged crate trolley: (a) 1 – Dolly Type II 600 × 400 mm, 2 – crates, 3 – trolley superstructure; and the loading mechanism (b) 1, 2, 3, 4 – linear guides, 5 – frame, 6 – pneumatic cylinder, 7 – separation mechanism, 8 – chain conveyor.

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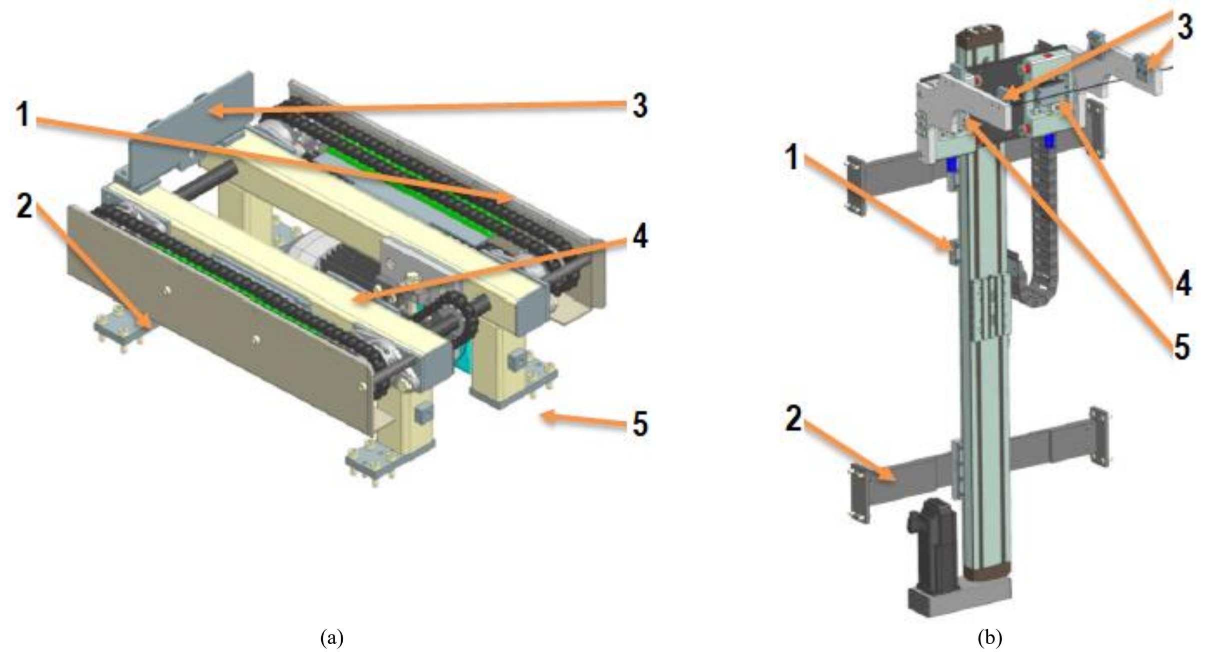

Figure 5. Outfeed chain conveyor (a) 1, 2 – guide rails, 3 – stop, 4 – drive, 5 – frame; and handling lifting unit (b) 1 – Bosch Rexroth linear servo axis, 2 – frame, 3 – gripping arms, 4, 5 – pneumatic cylinders.

The frame of the device (Figure 6b) consists of welded parts assembled. The subframe is made of Bosch Rexroth profiles, and it serves as a mounting point for the safety optical gate. The handling unit for transfer (Figure 7a) is used to grip and move the empty crate from the removal position to the unloading position.

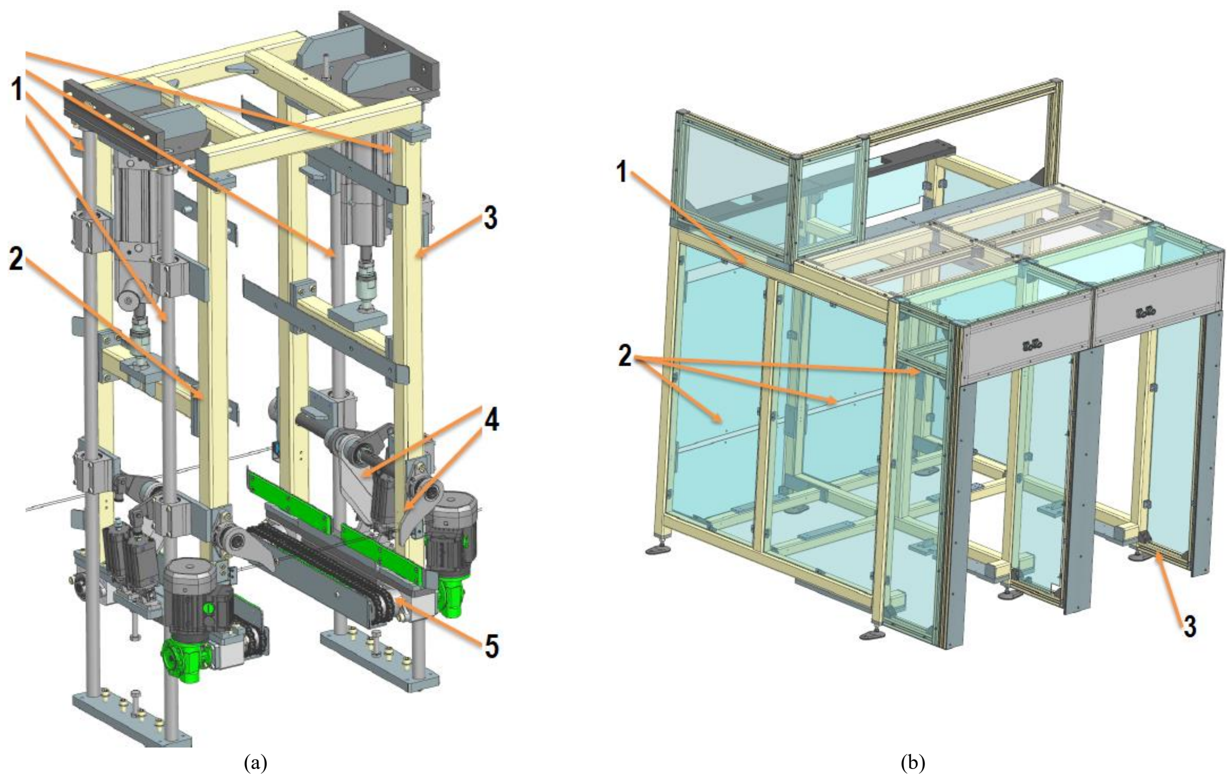

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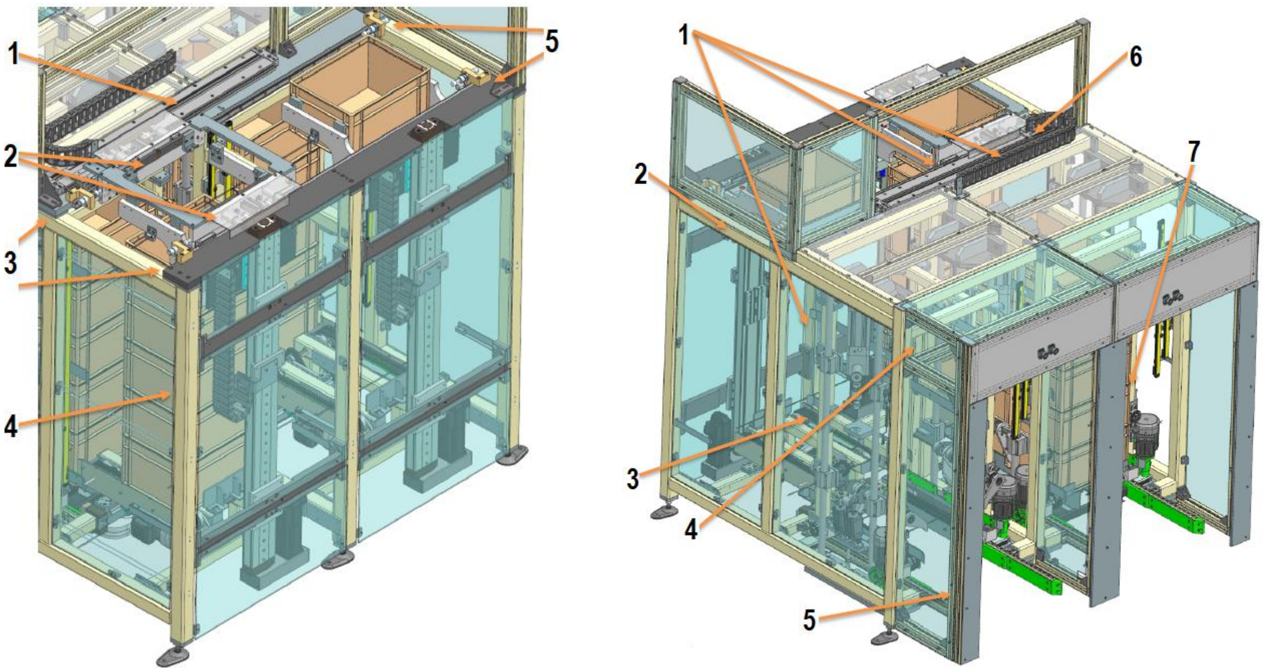
Figure 6. The removal mechanism (a): 1 – linear guides, 2 – frame, 3 – pneumatic cylinder, 4 – separation mechanism, 5 – chain conveyor; and the frame structure of the designed feeder (b): 1 – frame, 2 – mechanical covers, 3 – front frame.



(a) (b)

Figure 7. Handling unit for transfer (a) 1 – pneumatic rodless cylinder, 2 – gripping arms, 3 – end stops, 4 – frame, 5 – end stop with damping; and crate feeder assembly (b) 1 – handling units, 2 – frame, 3 – chain conveyor, 4 – unloading mechanism, 5 – front frame, 6 – removal mechanism, 7 – loading mechanism.

The entire device (Figure 7b) consists of a steel welded and assembled frame, a subframe made of Bosch Rexroth profiles, a chain conveyor, handling units, a removal and loading mechanism, and includes safety features such as mechanical covers and optical gates.

The scientific contribution lies in creating a knowledge base for safe, reliable and efficient operation of the proposed device to maintain low energy requirements and maintenance costs. In addition, the proposed device operates with high precision, which is very important for the reliable assembly and operation of assembled components into a single unit.

4. Conclusions

The primary objective of this research is to design a robotic handling workplace for balancing turbochargers in the automotive industry. The solution analysed the technical, structural, and technological aspects crucial in designing an efficient and reliable robotic system. Requirements and technical specifications were processed, based on which the floor plan of the line was designed. The design corresponded to the rationalisation of the workspace, providing a smooth flow of materials. Given the specific requirements of turbochargers operating at extremely high speeds, implementing a dynamic balancing system was proposed to ensure the required accuracy and balance of components.

Since the conditions for safe operation of the device must be created, it is necessary to design safety elements (such as light barriers, emergency buttons, protective covers and sensors capable of detecting the presence of objects or people in risk zones). In addition, it is necessary to refine the design of the robot assembly No. 1 and No. 2, by designing additional elements: (i) the geometry of the positioning beds for storing the CHRA, (ii) the suction head for residual oil from the CHRA component, (iii) the conveyor for balanced CHRAs from inside the line to the output section, (iv) the NOK station (in case of impossibility of balancing the CHRA), (v) the end effectors (grippers together with adapters and gripping units and fingers) of individual robots supported by calculations. Last but not least, it is necessary to review the manual of the operations procedure for the robotic workplace and perform an analysis of safety requirements for the robotic workplace before installing the prototype.

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