



# Hydraulic Modules of Mobile Robotic Bricklaying System

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**Abstract.** This article deals with the evaluation of the hydraulic modules used in the ZSM (Zrobotyzowany System Murarski) mobile robotic bricklaying system. This robotics bricklaying system was developed as a research project in cooperation between a scientific leader, the research and development partner, and the industry partner. Mobile ZSM is the first robotic brickwork system in Poland, designed primarily for the construction of facades and partitions in office and residential buildings, as well as in industrial buildings. A mobile ZSM has been designed and developed as an innovative demonstration solution for the construction industry to automate heavy, labour-intensive and burdensome masonry work traditionally done manually by masons. The ZSM mobile set was made up of an ABB industrial robot with six degrees of freedom (6DoF), a Hinowa tracked undercarriage, a robot support frame, a hydraulic lifting-levelling unit, a brick warehouse, a brick feeder, a mortar applicator, a control cabinet, an operator panel, and a hydraulic gripper. The evaluation involved the specified hydraulic modules of the mobile ZSM, such as the hydraulic power and control unit, the hydraulic drive of the tracked undercarriage, hydraulic control of the lifting-levelling unit, and the hydraulic robot gripper. The human-machine interface (HMI) operator touch panel was presented with the start screen and control screens for the individual hydraulic modules of the mobile ZSM. The HMI touch panel was visually programmed to manage the mobile ZSM.

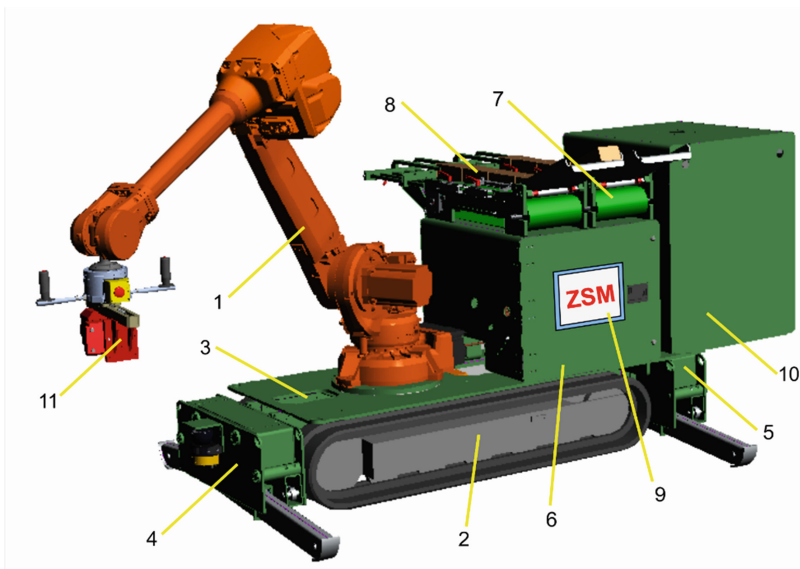
**Keywords:** Hydraulic power and control module · Hydraulic driven track undercarriage · Hydraulic lifting-levelling module · Hydraulic robot gripper

## 1 Introduction

The main problem in the construction industry is not only improving productivity, but also the lack of an adequate number of skilled construction workers. The implementation of advanced automated and robotic construction technologies significantly accelerates bricklaying work and improves the quality of the work performed. At present, the construction industry is approaching a revolutionary period of robotics of technological processes and therefore of automation of traditionally manual works, such as bricklaying and plastering. Automation and robotization are considered the best solution to improve the efficiency of the construction industry. There have been many reports in

the literature on the use of robots for various masonry and plastering tasks. The study [1] presents research on the possibility of automation of bricklaying. A robotic bricklaying system with the ability to build walls from slag blocks was designed. Pritschow et al. demonstrated the automated process of building walls on a construction site using a mobile robot [2]. Madsen analyzed the advantages and disadvantages of semi-automated bricklaying (SAM100) in collaboration with a mason to smooth excess mortar [3]. In the article [4], the author introduced a comprehensive methodical process to implement automation and robotics in residential buildings. An alternative to automation of bricklaying on a construction site is pre-fabrication of brick panels produced in manufacturing plants [5].

As part of the research project, the authors have developed an innovative mobile ZSM [6–10]. Mobile ZSM was created in cooperation between Kielce University of Technology as the leading researcher, the CB RTP research and development partner, and the STRABAG industry partner. Mobile ZSM is the first Polish robotic bricklaying system. It is designed to build facades and walls in office, residential, and industrial buildings. Figure 1 shows the 3D CAD design of the mobile ZSM.

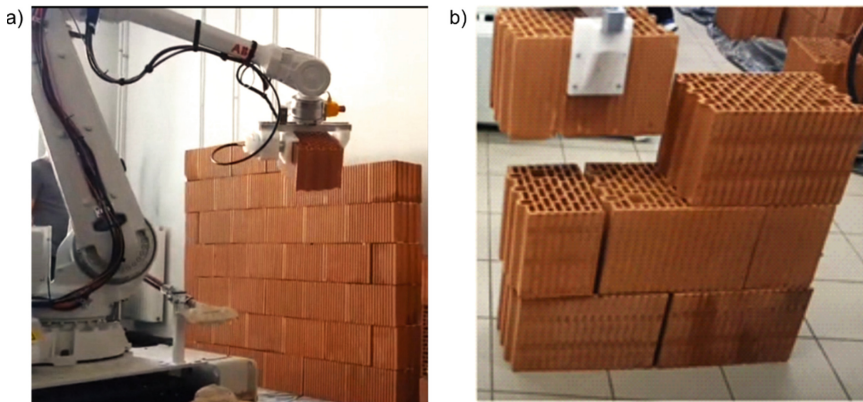


**Fig. 1.** 3D CAD design of mobile ZSM: 1 – ABB industrial robot, 2 – Hinowa tracked undercarriage, 3 – robot support frame, 4 – front hydraulic lifting-levelling module, 4 – rear hydraulic lifting-levelling module, 6 – hydraulic power and control module, 7 – brick warehouse, 8 – brick feeder, 9 – control panel, 10 – control cabinet, 11 – hydraulic robot gripper [11, 12].

The mobile ZSM consists of an ABB industrial robot with six degrees of freedom (6DoF), replaceable hydraulic gripper, Hinowa tracked undercarriage, robot support frame, front and rear hydraulic lifting-levelling module, hydraulic power and control module, brick warehouse, brick feeder, control panel, and control cabinet. The mobile ZSM enables the bricklaying of walls in large workspaces, limited by the robot's working

range. The ABB industrial robot of type IRB4600 was used, with weights of 450 kg, a maximum vertical range of 3.055 m, a maximum horizontal range of 2.55 m and a repeatability of 0.06 mm.

Bricklaying begins with the drive, positioning, lifting, levelling, and anchoring of the ZSM on the bricklaying site, the determination of the bricklaying area using a laser sensor, and the programming of the robot for the automatic bricklaying. Robot programming takes into account how bricks are placed on the walls, the dimensions of the wall, the dimensions of the bricks, and the number of bricks in the wall. During the brickwork process, the bricks are picked up from the feeder, the mortar is applied to the brick by the applicator, and then the bricks are placed in the right place on the wall. Figure 2 shows the robotic bricklaying process under laboratory conditions.



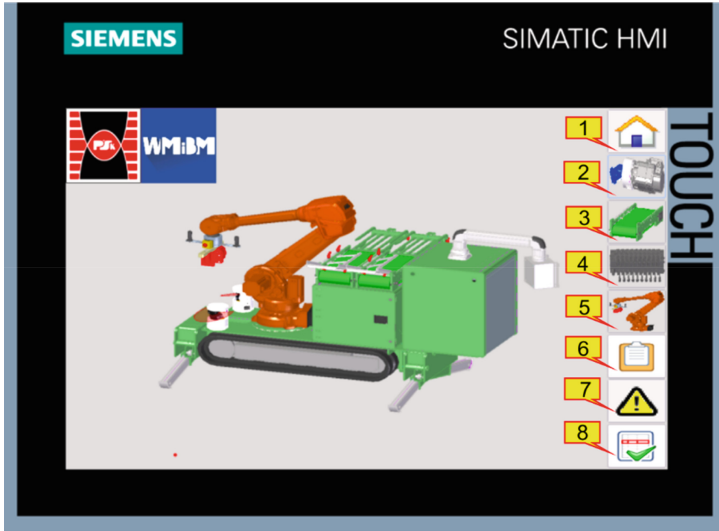
**Fig. 2.** View of the bricklaying process on a partition wall: a) robot during bricklaying, b) laying the brick on the wall [12].

## 2 ZSM Control Panel

The ZSM control is based on the Simatic S7-1500 programmable controller in the fail-safe version that monitors the proper functioning of all devices. The ZSM controllers are located in the control cabinet and the robot control cabinet. The ZSM controller is in constant communication with the robot control system. The control system operates on the Profinet communication network. The operating elements of the electric, hydraulic, and mechanical systems are used.

The Simens Simatic HMI touch panel allows the operator to communicate visually with the ZSM management controller. When power-up is activated, the control panel with the application developed from WinCC Advanced V16 starts. The Simatic HMI touch panel has several screens that can be called by the corresponding buttons. Figure 3 shows the Simatic HMI touch panel with a function menu.

The ABB FlexPendant is a portable (hand-held) operator unit with a touch panel that is used to perform many of the tasks while operating a robot system, such as running



**Fig. 3.** Simatic HMI touch panel with a function menu: 1 – Start Home, 2 – settings of the hydraulic power and control module, 3 – control of the building material feeder, 4 – control of the tracked undercarriage drive and lifting-levelling module, 5 – robot control, 6 – programming of technological procedures, 7 – emergency events, 8 – reset settings [12].

programmes, jogging the robot, modifying robot programmes, etc. Figure 4 shows the ABB FlexPendant hand-held operator.

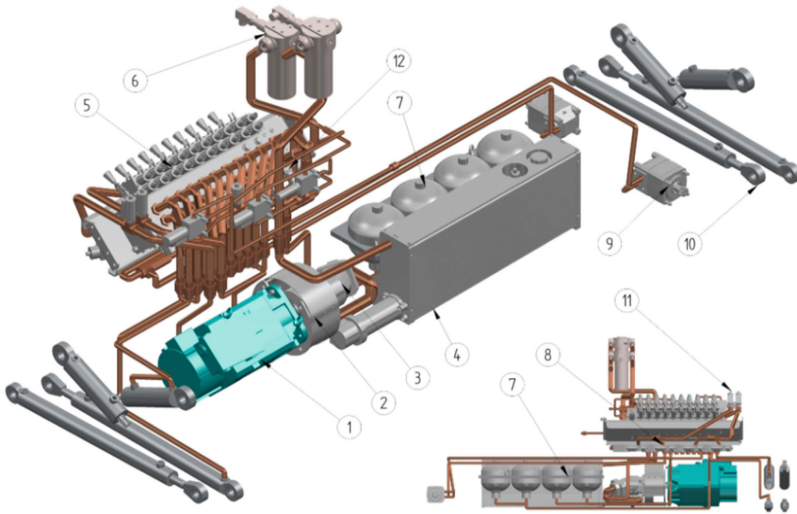


**Fig. 4.** ABB FlexPendant hand-held operator.

The FlexPendant consists of both hardware and software and is an independent computer. The FlexPendant is an integral part of the ABB robot, connected to the controller via a cable and connector. The hot-plug option allows the FlexPendant to be connected and disconnected at any time, even during automatic control of the robot.

### 3 ZSM Hydraulic Power and Control Module

The main devices of the ZSM hydraulic power and control module are a servo-pump consisting of a Simens Simotics electric servo-motor and a Hydro-Leduc fixed displacement hydraulic pump. The servo-pump power system is supplemented by hydro-pneumatic accumulators. Figure 5 shows the 3D CAD design of the ZSM hydraulic power and control module.



**Fig. 5.** 3D CAD design of the ZSM hydraulic power and control module: 1 – Simens servo-motor, 2 – clutch, 3 – Hydro-Leduc fixed displacement pump, 4 – oil tank unit, 5 – multi-section proportional directional valve, 6 – filter unit, 7 – hydraulic accumulator, 8 – hydraulic accumulator manifold, 9 – low-speed hydrostatic motors to drive the tracked undercarriage, 10 – cylinders of lifting-levelling modules, 11 – pressure switches in the hydraulic accumulator manifold, 12 – pressure transducer for pressure monitoring in hydraulic actuators [11].

The Siemens Simotics M type 1PH8103-10002-0GA1 compact electric asynchronous servo-motor with nominal speed 1500 rpm, maximum speed 9000 rpm, nominal torque 34 Nm, maximum torque 60 Nm, nominal power 6.3 kW was used. The Simotics M-1PH8 servo-motor is freely configurable for specific applications thanks to its modular design. The Simotion control system is based on the drive control chart (DCC), which allows variable speed operation of the hydraulic pump. The Simotics servo-motor provides an innovative and energy-efficient solution concept for ZSM hydraulic drive and control. The operating principle of the hydraulic system is to control the pressure and volumetric flow rate not by valve technology but directly by the speed and torque of the Simotics servo-motor. As a result, hydraulic power is supplied only by the servo-pump when it is necessary to operate the hydraulic actuators (motors and cylinders). In the open-circuit control system, a single servo-pump provides sequential control for multiple hydraulic actuators. The advantages of the Simotion control system are high energy efficiency and economy thanks to the use of speed-controlled hydraulics,

as well as the availability of the solution based on the servo-pump for both single- and multi-axis systems, high dynamics thanks to the use of Simotics servo-motors with low rotor inertia, and high precision of synchronization of hydraulic multi-axis drives. The servo pump unit uses a Hydro-Leduc type XPi 12 0523820 fixed displacement piston hydraulic pump with bent axis with geometric displacement  $12 \text{ cm}^3/\text{rev}$ , flow rate of 24 L/min, maximum pressure 380 bar, maximum speed 3150 rpm and maximum torque 76 Nm. Hydro Leduc XPi bidirectional bent-axis pumps are specifically designed to meet the needs of mobile devices. This pump model has a 7-piston design to ensure optimal flow regularity and can withstand continuous working pressures up to 380 bar and 420 bar peaks. The pump automatically sets to required direction of rotation. Four Hydac diaphragm accumulators of type SBO210 - 2E1/112U 330 AK 030 with a capacity of 2 L were used. Figure 6 shows the control circuits of the ZSM hydraulic modules.

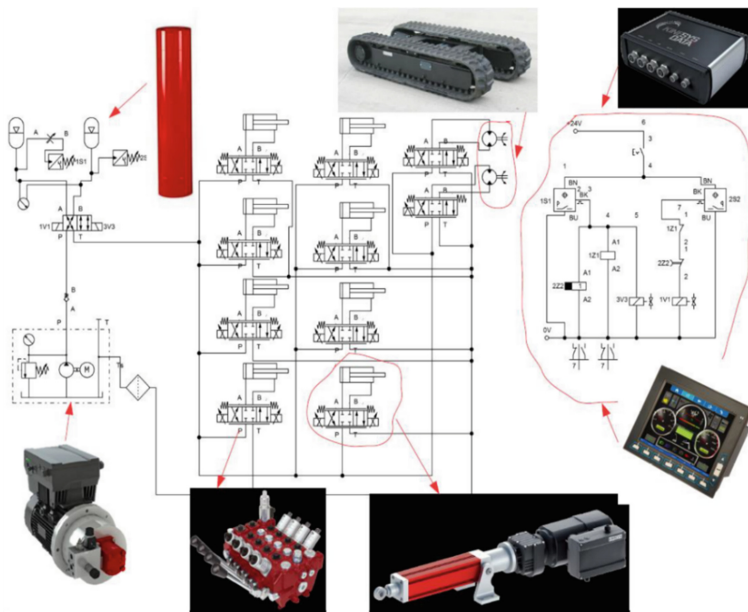


Fig. 6. Control circuits of the ZSM hydraulic modules [11].

The Hydac LX-610 multi-section directional proportional valve is the main hydraulic power distribution element in the ZSM hydraulic control system. This valve plays an important role in the stability and reliability of hydraulic system control even under higher loads. The Hydac valve LX-610/B0 with a nominal pressure of 350 bar and a nominal flow rate of 160 L/min can independently control the operating functions of ten ZSM hydraulic actuators. The pressure in the hydraulic actuators is monitored by a pressure transducer located behind the multi-section proportional directional valve.

## 4 Tracked Undercarriage Hydraulic Drive Module

A conventional Hinowa rubber track undercarriage type PT20GL was chosen for mobile ZSM (Fig. 7). The Hinowa tracked undercarriage with rubber tracks, due to its highly maneuverable design, can move efficiently over longer distances between construction sites. It can move for short distances and is placed precisely on the bricklaying site. The built-up tracked undercarriage has been patented as utility models [13, 14].

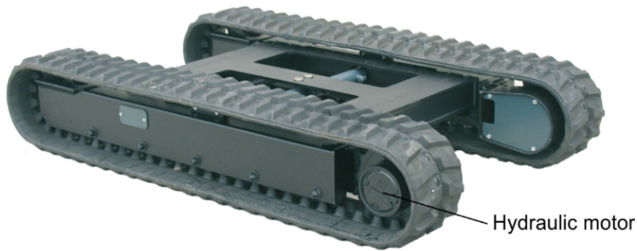


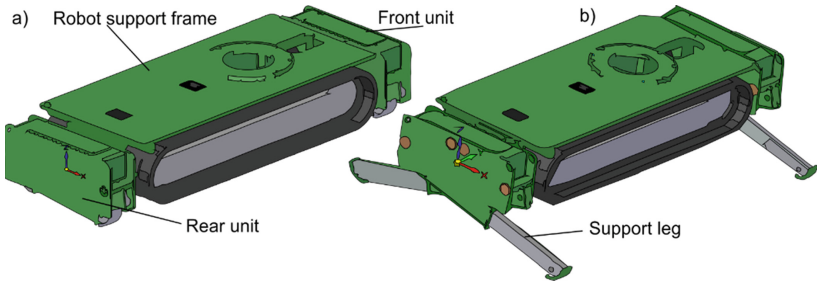
Fig. 7. Hinowa tracked undercarriage.

Specifications of the Hinowa tracked undercarriage type PT20: 2000 kg maximum total weight (robot + undercarriage), 1935 mm length, 1100 mm width, 250 mm track width, 370 mm track height, 5 + 5 rollers. The tracked undercarriage can move forward and backward at a speed of 0.56 m/s, the maximum slope of the driveway  $\pm 15^\circ$ , and maximum lateral inclination  $\pm 8^\circ$ . The track undercarriage motor is powered and controlled by a hydraulic power and control module. The tracked undercarriage is driven by two Bravini CTM1022 hydraulic orbital gear motors of the BRZV series with a displacement of  $80.4 \text{ cm}^3/\text{rev}$ , a maximum flow of 65 L/min, a maximum pressure of 210 bar, a maximum rotational speed of 119 rpm, and a maximum torque of 1280 Nm. The CTM1022 hydraulic gear motors were specifically designed for small track drives with a maximum weight of 2500 kg. These units feature a planetary gearbox (one reduction stage), fail-safe brakes (optional), built-in motor, and a braking valve (optional).

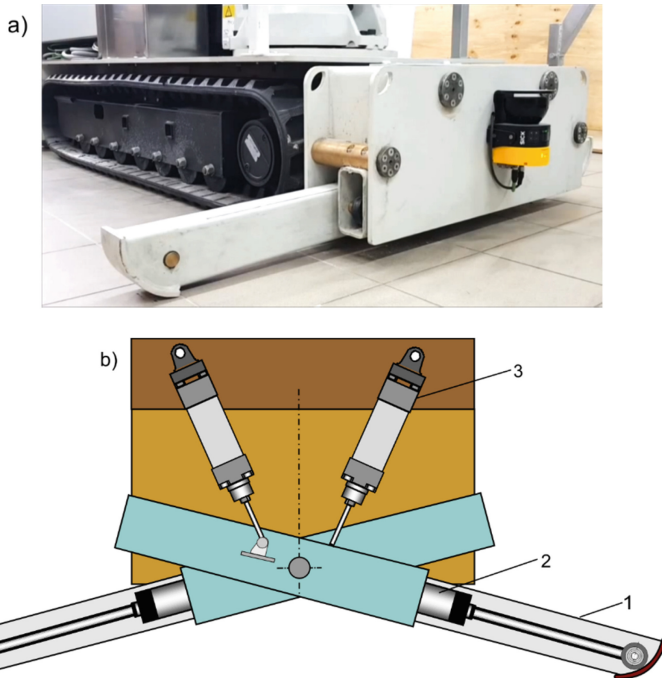
## 5 Hydraulic Lifting-Levelling Module

The robot support frame is built on the track undercarriage, on which hydraulic lifting-levelling modules are mounted at the front and rear (Fig. 8). These two hydraulic lifting-levelling modules were used to stabilize the position of the robot during automatic bricklaying. A single hydraulic lifting-levelling module is constructed using two double-acting differential cylinders Ponar Luban UCJ2F-16-40/25/500z+U for the extension of support legs and two double-acting differential cylinders Ponar Luban UCJ2F-16-50/28/100z for the lifting of the robot support frame. Figure 9 shows the working principle of the lifting-levelling module.

Lifting and levelling the robot support frame takes place in two steps. In the first step, the hydraulic cylinders extend the support legs without external load until they come



**Fig. 8.** Tracked undercarriage build-up: a) folded support legs, b) extended support legs [11].



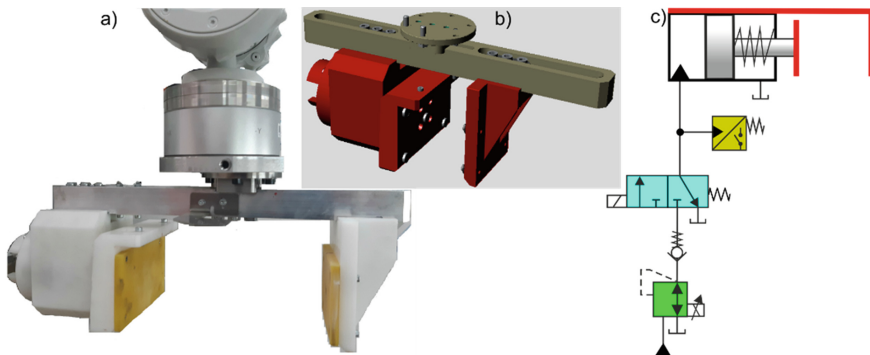
**Fig. 9.** Hydraulic lifting-levelling module: a) view of the extended support leg, b) design model of the hydraulic lifting-levelling module: 1 – support leg, 2 – double-acting cylinders for the extension of support legs, 3 – double-acting cylinders for the lifting of robot support frame.

into contact with the ground. In the second step, the hydraulic cylinder was pressing on the support legs until the robot's frame was raised to the required height. A robot support frame levelling control system was developed using feedback from the support leg position errors. [15]. When the robot support frame is level, the support legs are locked mechanically.



## 6 Hydraulic Robot Gripper

A special adjustable hydraulic robot gripper was constructed that can be adopted for different sizes of materials for building construction (brick, hollow brick, ceramic hollow brick, gas concrete blocks, cellular concrete, etc.). This is a two-jaw parallel gripper with an adjustable jaw and a moving jaw. The parallel gripper has five replaceable jaws to grip and handle bricklaying blocks with widths according to the dimensional specification of 80, 120, 180, 240, and 250 mm, and weighing up to 25 kg. Figure 10 shows the view, the 3D CAD design and the on/off mode operating scheme of the hydraulic robot gripper for the bricklaying blocks.



**Fig. 10.** Hydraulic robot gripper for bricklaying blocks: a) view, b) 3D CAD design [11], c) operation scheme in on/off mode.

The robot gripper adapted to the size of the bricklaying blocks picks them up from the warehouse, handles them, and places them on the wall. The robotic bricklaying algorithm considers the size of the bricklaying blocks and the size of the wall. During robot control, the gripper with the bricklaying blocks is correctly orientated against the wall coordinates. A laser calibration system was used to eliminate inaccuracies and minor deviations that occur as a result of the brick being misaligned by the robot gripper. Inaccurate gripping and handling of the bricks negatively affects the accuracy of the bricklaying, and therefore the flatness and uniformity of the masonry wall.

## 7 Conclusions

The ZSM mobile robotic bricklaying system was created as part of the POIR.04.01.02-00-0045/18-00 research project, funded by a grant from the National Centre for Research and Development in Poland within the framework of the Smart Growth Operational Programme 2014–2020. The mobile ZSM is designed to perform bricklaying tasks on construction sites. The hydraulic modules of the mobile ZSM perform their tasks effectively and energy efficiently. The hydraulically driven tracked undercarriage can efficiently travel the ZSM around construction sites. Hydraulic control of the tracked undercarriage allows for accurate positioning and displacement of the ZSM in place of

the bricklaying work. Hydraulic lifting-levelling modules stabilize the position of the ZSM subjected to impact loads during robotic bricklaying. The stable position of the ZSM is of great importance for the quality of the brickwork made by the robot. The accuracy of the trajectory of the robot's hydraulic gripper depends not only on the mass of the bricklaying blocks being handled, but also on the precision of their gripping.

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