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Technological Aspects in the Development of a Mobile Bricklaying Robot

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Abstract

This paper presents a process for automated masonry construction on a building site by means of a mobile robot. A scenario for the on-site operation of a man-machine-system comprising the mobile bricklaying robot and a skilled worker is outlined. An automated method for the application of thin-bed mortar is presented and verified by experiments. Furthermore, the vacuum handling system of the bricklaying robot and a device which integrates technological functions such as calibration of the brick position, determination of material tolerances and application of bonding material in a single unit are described in detail.

1. INTRODUCTION

The German construction industry and especially the area of masonry construction currently suffer from a dramatic lack of skilled workers. With the predicted building boom and the decreasing availability of workforce from other countries, this deficit of skilled workers is expected to grow during the next years. In order to meet the challenges of this upturn and to make careers within the construction industry more attractive, the development of a mobile bricklaying robot has been forced in Germany.

The tasks of this robot which will be operated on the construction site include picking bricks or blocks from prepared pallets, the application of bonding material and the erection of brickwork at high accuracy and quality. In recent years, the authors presented a cost analysis [1] and enabling technologies such as a modern configurable robot control system [2], feedback control strategies for electrohydraulic servodrives and robust application specific sensing equipment [3] which showed the economical and technical feasibility of such technology. Prototype realisation of the bricklaying robot which is based on a commercial construction machine is done within a joint project by two research institutes in close cooperation with ten industrial partners.

The design of the robot is strongly influenced by technological aspects such as the types of bricks or blocks and the mortar technology used. Proper function of the robot requires

(1) handling different kinds and sizes of bricks and blocks,

(2) detection and compensation of material tolerances,

(3) calibration of the brick or block position with respect to the TCP (Tool Center Point),

(4) automated dispensing of bonding material,

(5) robust, site-specific and cost-effective solutions.

For these problems mentioned above, a number of solution approaches had been presented during the last few years: In Israel, a mobile robot for building interior walls has been developed. Using a vacuum gripper, the robot picks gypsum blocks with interlocking edges and places them without using any bonding material (dry method). Optical sensors are used for TCP calibration [5]. Automated laying of conventional clay bricks and application of bonding material is investigated in the UK by means of a stationary gantry type robot. Both clamp and suction type grippers are used for material handling. Quality control and TCP calibration are achieved by using vision systems, laser beacons and ultra-sonic sensors [6].

A bricklaying system for lining steel converters with refractory bricks has been developed within a EUREKA project [7]: It comprises a SCARA robot operating on a working platform inside the converter and additional machinery such as a depalletizing robot, an elevator with brick feeding mechanism and a brick centering device. A pneumatic gripper with suction pads is used for picking the bricks and placing them in their final positions using a dry method. The bricks are put into a well-known pick-up position by pneumatic pushers. Serving as an end-effector for a mobile masonry robot system a fault-tolerant assembly tool has been developed [8]. The system provides suction pads for material handling and clamps for mechanical calibration of the block position.

Each of the systems described in [5-8] covers only part of the requirements listed above. This paper presents a practical, cost-effective solution to the handling, calibration and bonding problems for a mobile bricklaying robot which meets all the requirements (1) - (5). After a brief description of a scenario for automated masonry construction (section 2) an automated method for application of bonding material is presented in section 3. Section 4 gives an outline of a robust vacuum handling system. Finally, in section 5 a multi-functional technological unit is introduced which fulfills several tasks.

2. A SCENARIO FOR AUTOMATED ON-SITE CONSTRUCTION OF MASONRY

Being a highly repetitive and physically exhausting task, bricklaying is especially suitable for automation. For this purpose a concept for a man-machine-system was developed that enables automated on-site construction of masonry. The system consists of a mobile robot and a skilled worker acting as an operator. The conceived robot manoevers upon the floor of the wall to be built, and assisted by computer control, completes the brickwork of the floor based on brickwork plans which are generated off line (see Figure 1).

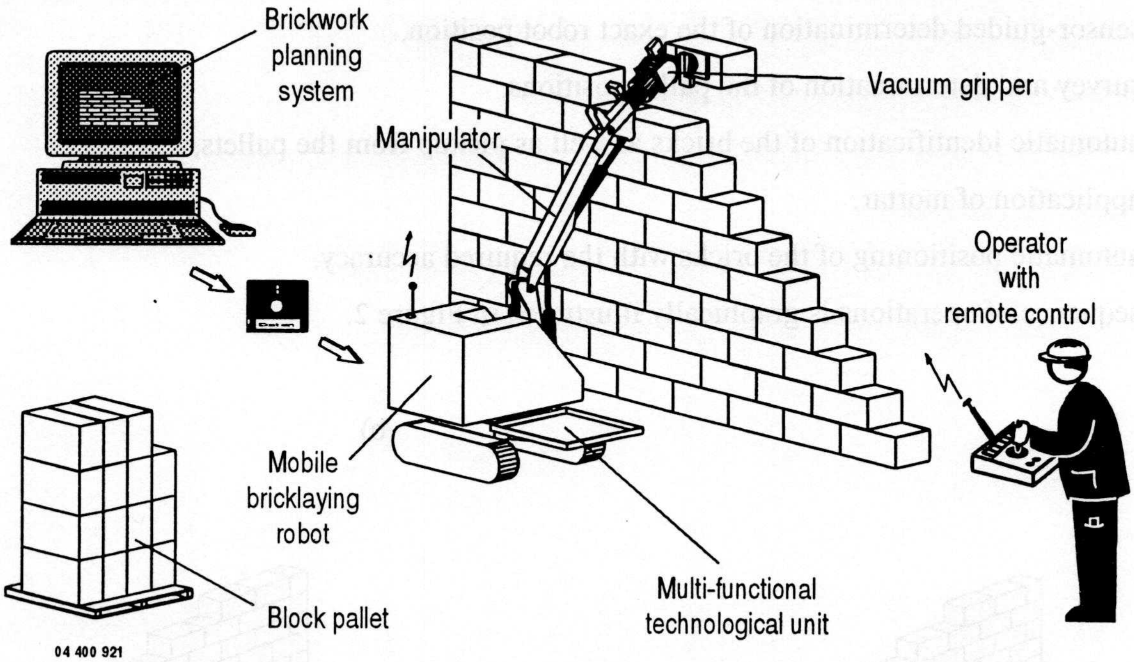


Figure 1.Scenario of a man-machine-system for automated bricklaying on the job site

This automation is achieved by picking up bricks from prepositioned pallets, applying mortar and laying them in their correct positions. Such automated on-site masonry construction places additional requirements on the planning of the construction work and the necessary preliminary work in comparison to manual construction methods. Before the actual construction by the robot, the site staff have to carry out the following tasks :

- survey of the floor area and marking of the start position of the robot as well as of the material locations (pallets with bricks or blocks),
- supply and set-up of the material and quality control thereof,
- erection of position reference points for the robot,
- installation and starting of the robot.

During automated construction the operator has the following tasks:

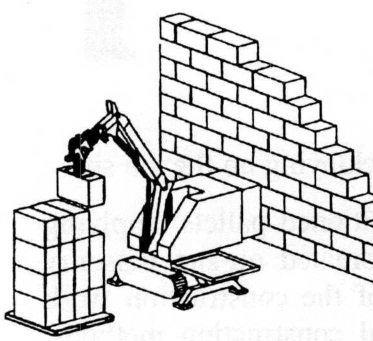
- supervision of the automatic masonry construction process and correction of any errors that occur,
- supply and testing of material,
- manual completion of brickwork which cannot be performed by the robot.

The robot consists of a mobile platform which enables changes of the working position, a device for applying mortar to the bricks as well as a manipulator with a wide working envelope and a high load-bearing capacity. Based on off line generated data transfered to the robot's control system, the robot moves in a program-controlled manner on the floor and performs the following operations :

- automated manoevering,
- sensor-guided determination of the exact robot position,
- survey and determination of the pallet positions,
- automatic identification of the bricks as well as pickup from the pallets,
- application of mortar,
- automatic positioning of the bricks with the required accuracy.

The sequence of operations is graphically illustrated in Figure 2.

a)



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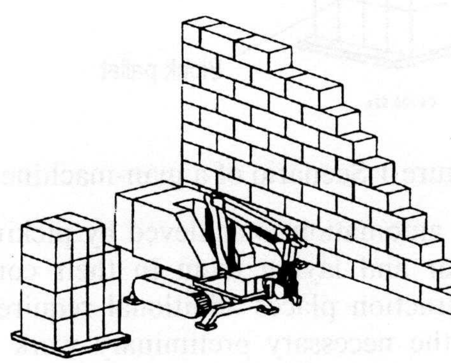

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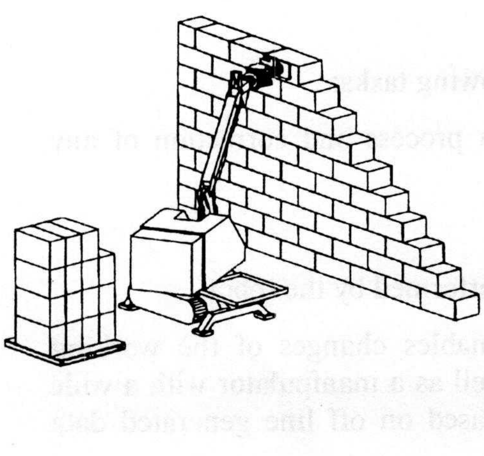


Figure 2. Operation sequence of automated bricklaying

a) Pick-up of a brick from a prepared pallet

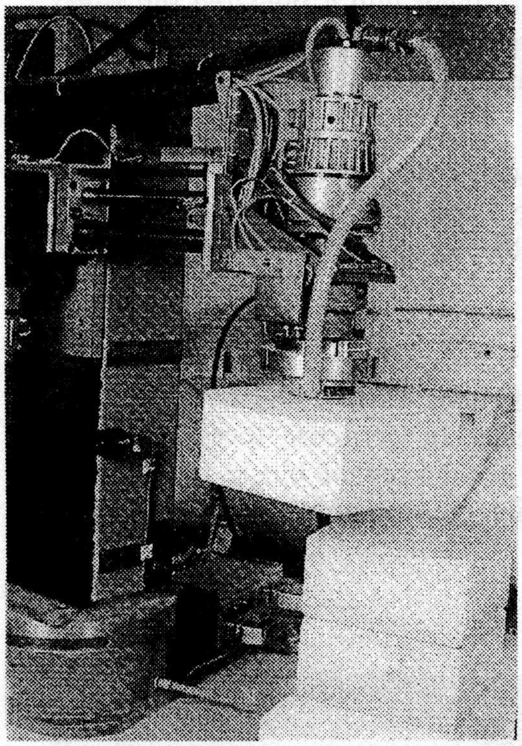
b) Automated application of mortar

c) Final placement of the brick

3. AUTOMATED APPLICATION OF THIN-BED MORTAR

In order to compensate for the sometimes considerable dimensional tolerances of conventional bricks, they are usually layed in a mortar bed with an approximate depth of 12 mm. The exact application of such a layer of mortar is technologically difficult and thus not suitable for automation. Thus the automated laying of close fit concrete precision blocks, for example aerated concrete blocks will be examined. These blocks are manufactured with dimensional tolerances of 1 mm and are hence suitable for laying in so called thin-bed mortar.

a)



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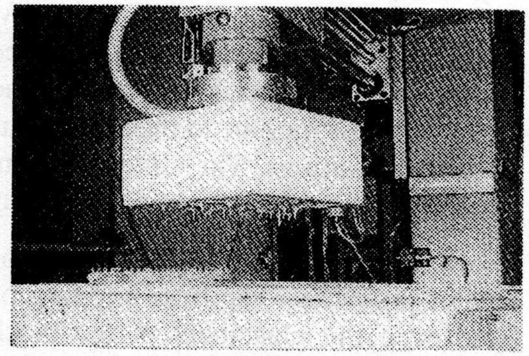

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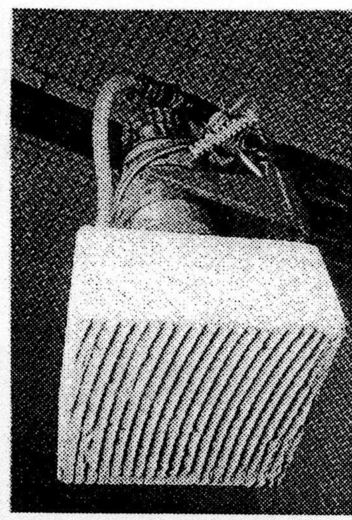

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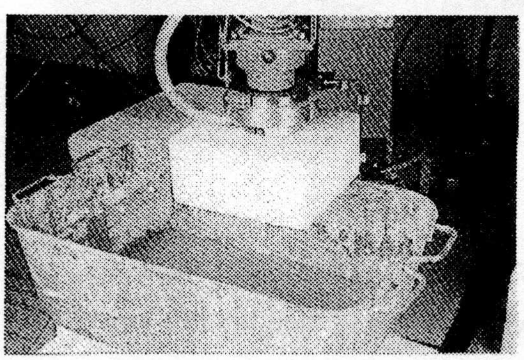


Figure 3. Automated application of thin-bed mortar by an experimental robot

a) Experimental robot with vacuum gripper for handling aerated cement blocks
b) Dipping a block into the mortar tub
c) Situation after leaving the mortar tub
d) Situation after stripping the mortar

Normally, thin-bed mortar is applied with a trowel with a thickness of a few millimeters and then smoothed with an indented trowel. With this method the amount of mortar can be exactly controlled, so a 1 mm deep mortar joint results after the brick has been layed. The advantage of this method is that it can also be performed as a dipping method. Here the brick to be layed is dipped into a mortar bath; after which, due to the cohesive forces, the mortar sticks to the bottom of the brick and its depth can be determined exactly by moving it along an indented trowel.

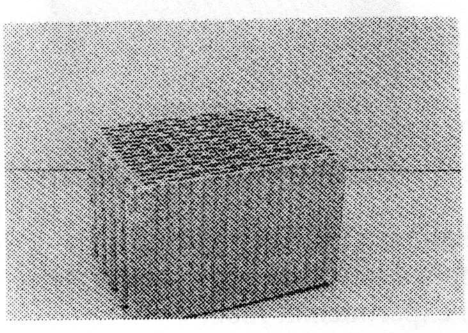
The dipping method is easily automated and can be performed with little difficulty by a robot (see Figure 3). In order to verify this by experiments, an electrical test robot at the University of Stuttgart has been equipped with a vacuum gripper and has been programmed to pick up aerated cement blocks, to dip them into a prepared tub filled with thin-bed mortar, to measure the mortar with a stripper and to place the blocks in the required positions. The effect of the mortar measurement can be seen clearly in Figures 3c (before stripping) and 3d (after stripping).

Various experiments proved that automated dipping with a robot is possible without any major problems. The firm gripping of the blocks, the exact measurement of the mortar and even the placement of the blocks with acceptable accuracy have been verified - initially without any sensor guidance.

4. VACUUM HANDLING SYSTEM

In order to be accepted by the end users the bricklaying robot must be capable of processing the most relevant types of bricks and blocks. In Germany, these are bricks (market share: 42.9%), sand lime stones (31.6%) and aerated cement blocks (14.1%) [2]. Figure 4 shows two examples of typical materials which are commonly used for building exterior walls.

a)



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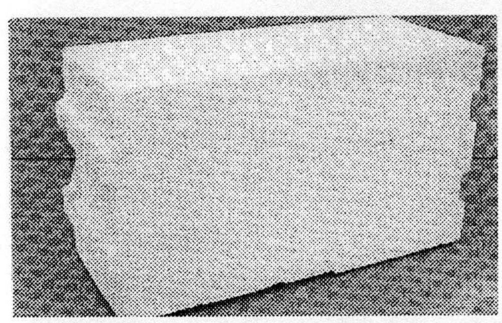

Figure 4. Typical bricks and blocks for construction of exterior walls

a) Conventional brick (length: 500 mm, width: 360 mm, height: 250 mm)

b) Aerated cement block (length: 625 mm, width: 360 mm, height: 250 mm)

The following requirements are placed on a proper handling system for the mobile bricklaying robot:

- handling of bricks, sand lime stones and aeraeted cement blocks with dimensions up to 625 mm x 360 mm x 250 mm and weights up to 50 kg,
- handling of cut stones down to a quarter of the full length,
- picking the bricks or blocks directly from prepared pallets,
- robust solution for use on the job site,
- cost-effective implementation by use of standard components wherever possible.

All these requirements are met by a vacuum handling system the suction plate of which carries a special rubber seal. This seal is made to cope with the surfaces of different bricktypes, even with the wave shaped surfaces of conventional clay bricks. All other components of the system such as vacuum generator, accumulator, valves, filters and water separators meet industrial standards. The pneumatic scheme of the complete vacuum handling system is shown in Figure 5.

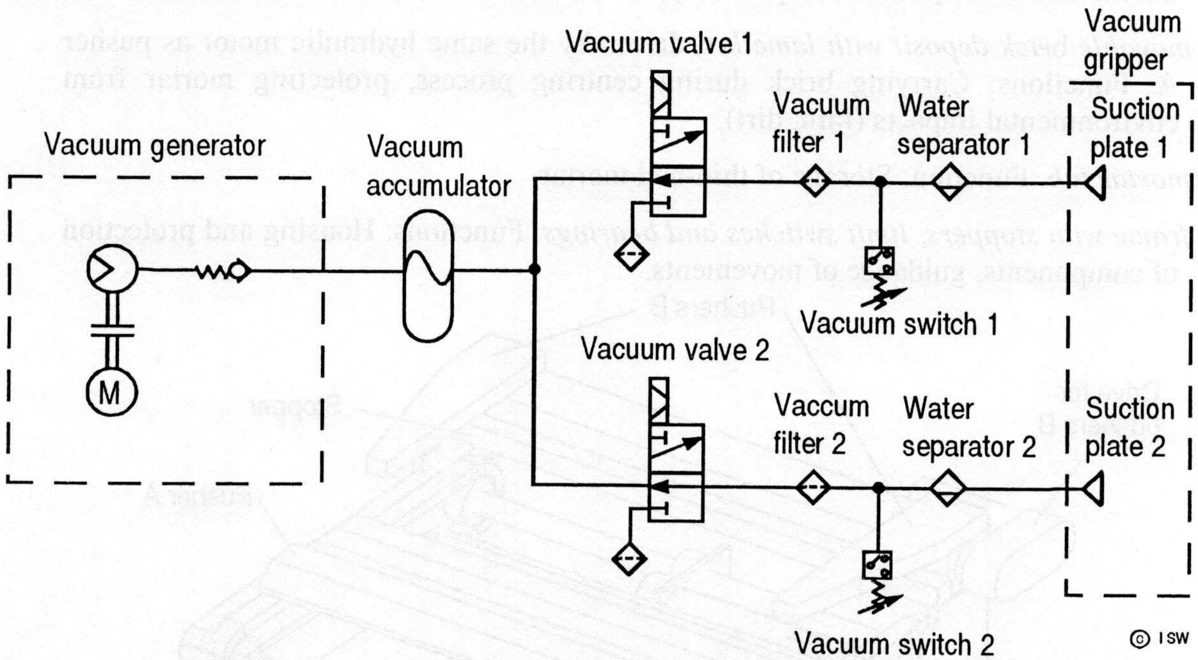

Figure 5. Pneumatic scheme of the vacuum handling system

Considering static gravity and suction forces, dynamic acceleration and centrifugal forces, reaction forces and a proper safety factor, a suction plate area of 214.5 cm^2 is required for safe operation. In order to allow proper handling of cut stones this area is divided into 2 separately controlled suction plates.

5. INTEGRATED MULTI-FUNCTIONAL TECHNOLOGICAL UNIT

Once the robot has picked a brick or block from the pallet three tasks must be performed before it can be put into its final position:

(1) TCP calibration, i.e. moving the brick into a well-defined position and orientation with respect to the Tool Centre Point (TCP) of the robot gripper,

(2) measurement of the brick dimensions in order to eliminate inevitable tolerances,

(3) application of thin-bed mortar.

In order to fulfill these tasks a so called "multi-functional technological unit" has been developed which is fixed to the mobile platform of the bricklaying robot. The basic structure and the main elements of this unit are shown in Figure 6. The unit comprises the following components and subsystems:

- *pusher A with integrated mortar dispenser*. The pusher is driven by a hydraulic motor with a chain drive. Functions: Moving the brick and calibrating its position in crosswise direction, stripping of excess mortar,
- *pushers B*, driven by a hydraulic motor with angular measurement system, belt drive and spindle with combined right-hand and left-hand threads. Functions: Moving the brick and calibrating its position in lengthwise direction, measuring actual length of the brick,
- *hydraulic servo valves and pressure switches*. Functions: Controlling and stopping the motion of the pushers, respectively,
- *movable brick deposit with lamellas*, driven by the same hydraulic motor as pusher A. Functions: Carrying brick during centring process, protecting mortar from environmental impacts (rain, dirt),
- *mortar tub*. Function: Storage of thin-bed mortar,
- *frame with stoppers, limit switches and bearings*. Functions: Housing and protection of components, guidance of movements.

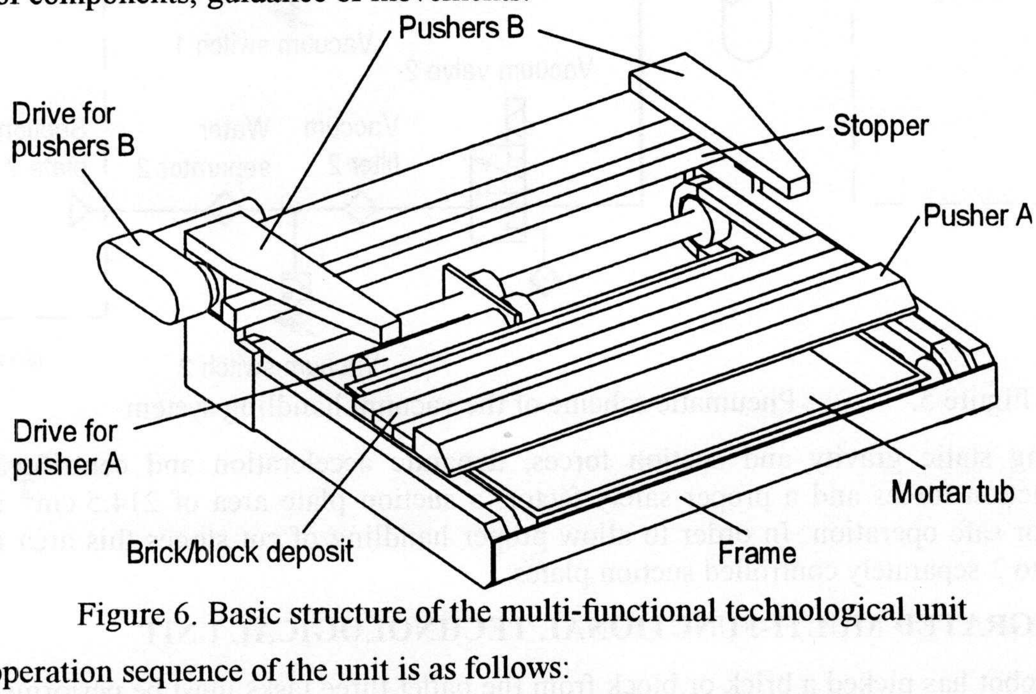

Figure 6. Basic structure of the multi-functional technological unit

The operation sequence of the unit is as follows:

(1) After the block has been picked up from the pallet the manipulator moves towards the technological unit. The block is laid down on the deposit and the vacuum gripper is switched off.

(2) The block is moved towards a fixed stop by pusher A. When the block touches the fixed stop the motion of pusher A is stopped. Thus, calibration of the block position in crosswise direction is achieved. In order to allow calibration in lengthwise direction pusher A is moved slightly backwards.

(3) Centering the block in lengthwise direction is done by activating pushers B. After stopping the motion of pushers B the block is left in a well-defined position.

(4) The exact positions of pushers B are determined with the angular measurement system which is attached to the spindle. These pusher positions are used to calculate the precise length of the block.

(5) The block is picked again by the manipulator and pushers A and B are released. By the motion of pusher A the deposit is automatically moved backwards giving free access to the mortar tub.

(6) By proper movements of the manipulator the block is dipped into the mortar bath, lifted again and stopped in a defined position for stripping the mortar.

(7) Now pusher A is moved forward again. Thus, mortar is stripped by an dispenser which is mounted on pusher A. At the same time, the deposit is moved in its home position thus shutting the mortar tub and preparing the unit for calibration of the next block.

(8) The manipulator moves the block with the mortar on it to its final position in the wall.

The multi-functional technological unit described above is characterized by the following features:

- exact calibration of full and cut bricks and blocks of all relevant types as specified in section 4,
- measurement of exact block lengths at an accuracy of 1mm,
- automated application of thin-bed mortar using the dipping method,
- protection of mortar against sun and rain,
- servo-controlled motion of pusher drives,
- simple, rugged and cost-effective solution.

Prototyping of the unit is currently underway. First experimental results are expected shortly.

6. CONCLUSION

In this paper a concept for automated bricklaying on the construction site by means of a robotic man-machine-system has been presented. The automatic application of thin-bed mortar using the dipping method has been verified by trials with an experimental robot. Important subsystems of a mobile bricklaying robot for on-site use have been described. A standard industrial vacuum handling system which has been slightly modified turned out to cover all relevant types and formats of bricks and blocks. A unit has been developed which integrates technological functions such as TCP calibration, measurement of the block tolerances and application of bonding material.

Future research will include the integration of the described subsystems in the prototype of the bricklaying robot and extensive experimental investigation.

7. ACKNOWLEDGEMENTS

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