COMPUTER MODELLING OF ROBOTIC ASSEMBLING OF REINFORCEMENT

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ABSTRACT

The paper describes the functional design of a robot system for the assembling of the reinforcement cages for beams and columns. The robot system was developed using a graphic simulation program. The robot cell consists of a frame structure, a supporting mechanism, two robots for moving and assembling of rebars and stirrups, a robot for bending of stirrups, a robot for connecting of rebars and stirrups, and a storage table for delivery of rebars and laying down of manufactured reinforcement cages.

Keywords: Construction; Automation; Rebar

1. INTRODUCTION

Although the computers and information technology have been widely used in design of buildings and civil engineering structures (Fenves, 1995), and for planning of the construction works (Paulson, 1995) as well, the most essential production phase - the construction - has been mostly carried out by classical methods using man-controlled machines or human workers. Automated machines or even robots have been very rarely used in the construction industry. One of the reasons for this state was that the characteristics of the construction works environment both encouraged and discouraged the use of robotics (Haas, 1995). The strongest stimulation for the development and the use of construction robots has been, beside the use of robots in other industries, the lack of qualified and skilled workers for a particular kind of work in the inconvenient circumstances on construction sites. On the other hand, the steadily changing circumstances on construction sites require more sophisticated robots in comparison to other industries.

Assembling of the reinforcement is a typical construction process, for which design and planning processes are highly computerised, and in some cases even the production of reinforcing elements (bars and meshes) is carried out by automated machines (Navon, Rubinowitz and Coffler, 1995). But the assembling of the reinforcement cages or placement of the reinforcing elements on/in the formwork is, with few exceptions (Wilde, 1991), always done manually (Dolinšek and Duhovnik, 1995). As the part of the value and duration of work for the assembling of the reinforcement is essential, regarding the whole value and duration of work needed to build a reinforced concrete structure, each improvement of this process could be useful.

In this paper the functional design of a robot system for the assembling of the reinforcement cages for beams and columns is described. The robot system was developed using a graphic simulation program Workspace3 (Robot Simulation Ltd 1994). The aim of

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the work was to research the possibilities of the use of robots for assembling of the reinforcement, to study the kinematics of the proposed robot system, and to present the results to other interested sides, in the clearest way possible.

2. DESCRIPTION OF ROBOT SYSTEM FOR ASSEMBLING OF REINFORCEMENT

Among many possibilities (Dolinšek, 1996), the assembling process in which the prefabricated straight and bent rebars for longitudinal reinforcement and open stirrups for transverse reinforcement could be used, was chosen. When necessary, the stirrups are bent in the final form during the assembling process. The final shape of the reinforcement is the same as in the case of manual assembling. Using these types of the reinforcing elements, the reinforcement cages for beams and columns could be assembled as a prefabricated parts of the reinforcement of a reinforced concrete structure. The complete reinforcement should be assembled on the construction site by adding some particular rebars and by overlapping the prefabricated reinforcement cages. For prefabricated concrete beams and columns the complete reinforcement could be assembled in the manufacturing plants.

2.1 Robot cell

A robot cell consists of a frame structure, which defines the space, where the robots are moving, a supporting mechanism, two robots for moving and assembling of rebars and stirrups, a robot for bending of stirrups, a robot for connecting of rebars and stirrups, and a storage table for delivery of rebars and stirrups and laying down of manufactured reinforcement cages (Figure 1).

The beams and columns of the frame structure act as the rails of all four robots and supporting mechanism. For the simulation of the system the following dimensions of frame structure were assumed: length 12 m, width 5 m, and height 3 m. Although some parts of robots and supporting mechanisms stretch outside the frame structure, the whole process of assembling is carried out inside of the frame structure.

Four hanging robots are installed on the upper level of the frame structure. Two of them move the reinforcing elements and assemble them in the reinforcement cage, the third robot bends the stirrups in their final form, and the fourth one connects the reinforcing elements of a cage mutually. Each robot can move in any horizontal direction inside the robot cell. The robots for moving and assembling have grippers to grasp rebars and stirrups. The robot for bending of stirrups has a special tool on its top, and the robot for connecting has a usual tool for connecting steel parts. This arrangement of robots was chosen because of great working space of each robot. The frame structure enables a more uniformly distributed loading of robots and reinforcing elements. All robots can reach each point in the robot cell (Leyh, 1995).

The supporting mechanism is installed on the rear outer side of the robot cell. Its task is to support the longitudinal reinforcement in the appropriate relative distance during the assembling process.

On the front side of the robot cell floor a storage table is moving out and in the cell. Its task is to provide the prefabricated rebars and stirrups to the assembling robots and to transport the manufactured reinforcement cages outside of the cell. In the simulation the table is represented as a one-degree-of-freedom mechanism.

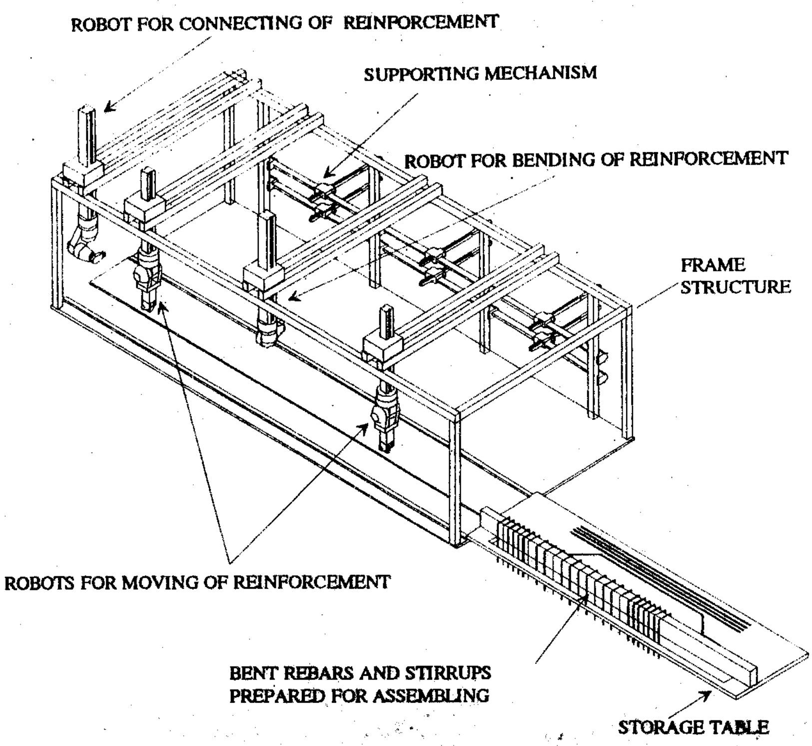


Figure 1 *Robot cell for the assembling of the reinforcement*

The whole assembling process is divided in four subprocesses:

(a) transport of rebars and stirrups in the robot cell and reinforcement cages out of the robot cell

(b) moving of the longitudinal rebars from the storage table to the supporting mechanism and manufactured reinforcement cages from the supporting mechanism to the storage table.

(c) positioning and final bending of the stirrups

(d) connecting of stirrups to the rebars

The common characteristics of each particular subprocess is the use of the same part (robot or supporting mechanism) of robot cell or the same combination of different parts.

In the particular subprocesses the following parts of robot cell are involved:

(a) the storage table

(b) both robots for moving the rebars and the supporting mechanism

(c) one robot for moving and the robot for bending

(d) the connecting robot

To carry out the anticipated tasks the parts of the robot cell should have the characteristics, described in the further subsections.

2.2 Supporting mechanism

The supporting mechanism consists of level beams, supports of cantilevers, cantilevers and supports (Figure 2).

Each longitudinal rebar is supported during the assembling by at least two supports. This is needed due to the large flexibility of rebars. The supports are installed on the cantilevers and can move horizontally along the longitudinal axes of the cantilevers. The connection between a particular cantilever and a level beam is made by a support of the cantilever, which enables the horizontal moving of cantilever along its and level beam's longitudinal axis. Level beams move mutually independently in the vertical direction.

The cantilevers should be as slender as possible to minimize the hindering of the assembling process and the limitations for the arrangement of reinforcement.

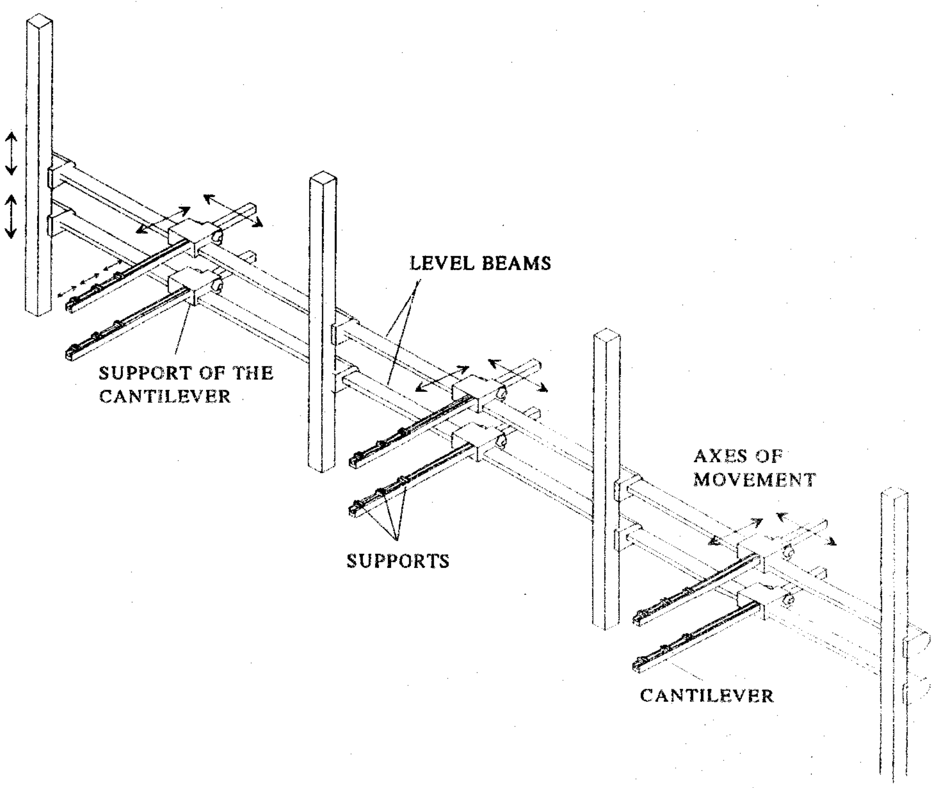


Figure 2 *Supporting mechanism for the longitudinal reinforcement*

Due to the limitation of the program Workspace3, which enables 9 degrees of freedom at the most, the possible degrees of freedom of the supporting mechanism were reduced, taking into account the needs which depend on the usual arrangements of the reinforcement.

2.3 Robots for moving rebars

The robots for moving the longitudinal rebars should grasp them in at least two points. The reason is the large flexibility of longitudinal rebars which requires more space for manipulation to avoid the striking against the other parts of the robot cell or reinforcement. The position of the grasping points should be defined regarding the position of the supports on the supporting mechanism.

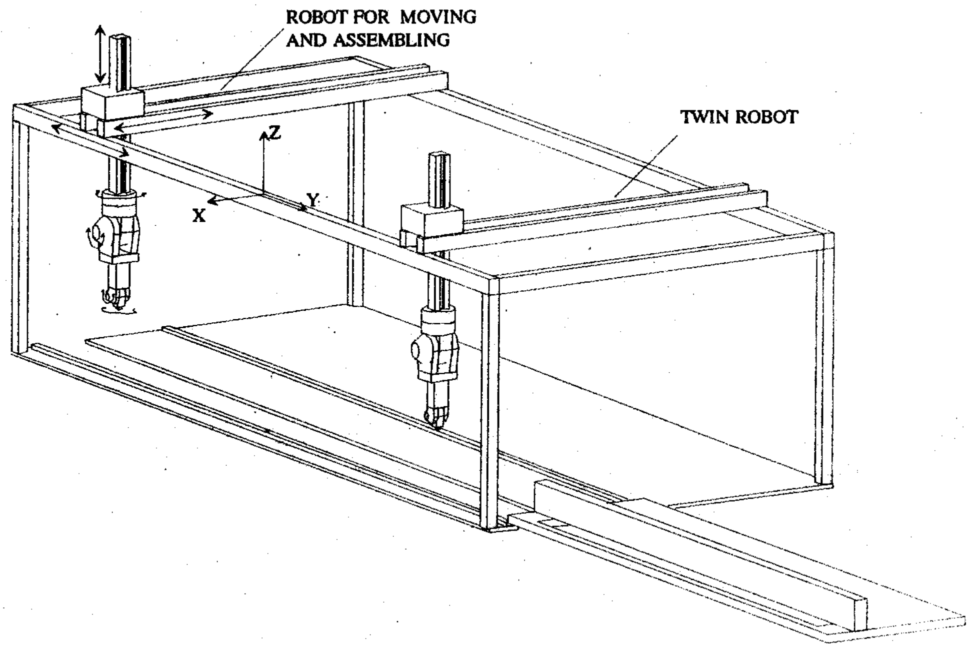


Figure 3 *Robots for moving and assembling of rebars and stirrups*

The robot has five degrees of freedom. Both robots act as twin robots.

The grippers have two steps. The first step enables to grasp the rebar without avoiding the rotation of the rebar around the axis through the center of both grippers. The second step of the grasp should be so strong that this rotation is avoided. This characteristic is needed for the bent rebars, which lay on the storage table in the position rotated for 90 degrees regarding the final position of the bar (See the position of a bent rebar on the storage table in Figure 1).

When the robots move the manufactured cage from the supporting mechanism to the storage table the weight of the load is many times greater than in case of moving a particular rebar. Therefore the robots stretch the arms and the moving of the robot top in the vertical direction is carried out only by translatory moving.

2.4 Robot for bending of stirrups

The most demanding part of the robot cell, regarding its kinematics and the tool used on its top, is the robot for bending of stirrups. On one hand, the tool for final bending of the stirrups requires comparatively large power, and, on the other hand, the tool should carry out complicated operations in bending process. As the robot for bending works together with one robot for moving and assembling, its kinematics is demanding as well. The distance between two neighbouring stirrups is sometimes very small. Additional hindrance between two stirrups is also the cantilever of the supporting system which holds the longitudinal rebars. To enable the work of robot in this limited space, the last two segments of robot arm are installed in the eccentrical position regarding the vertical axis of the robot (Figure 3).

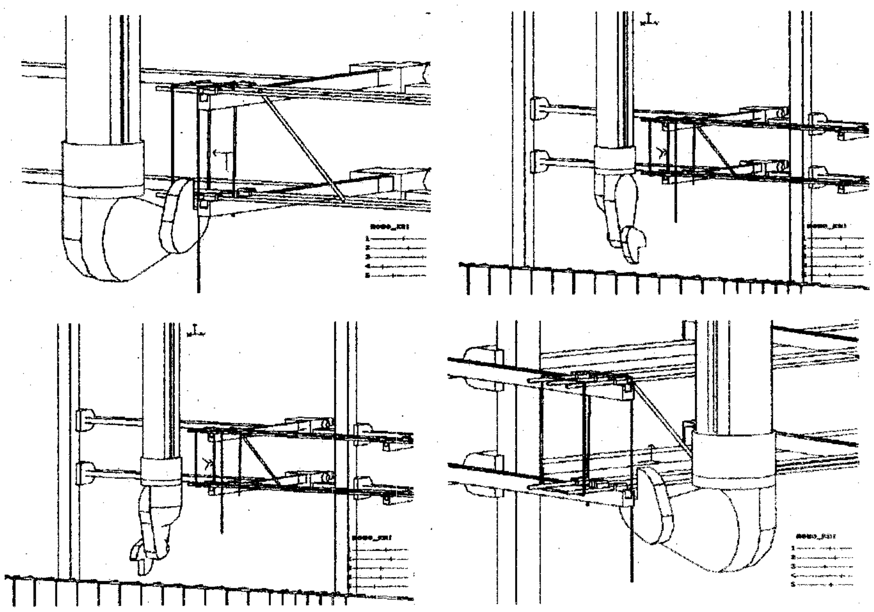


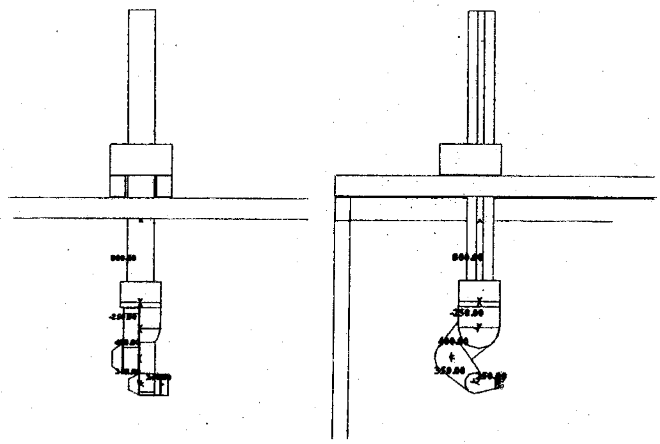
Figure 4 *Kinematics study of robot for bending of the stirrups close to the cantilever of the supporting system.*

The robot has six degrees of freedom. Three of them are translational and three rotational.

In the prefabrication a particular shape of the open stirrups should be produced. The last legs of stirrups shoud be temporarily a little bit more open than in the final shape. This enables the slipping of the stirrups over the longitudinal rebars on the supporting mechanism. Each stirrup should be bent in two points. In the first, the longest leg is bent and in the second one the hooks on both free ends of stirrup are made. The tool for bending should be able to carry out operations in both points. The detailed description of the tool is presented in a particular annex (Dolinšek, 1996). In the design of the tool kinematics the allowed minimum radii of bending and the return elastic deformation of the rebars should be taken into account.

2.5 Robot for connecting rebars and stirrups

Taking into account that several systems for connecting of steel parts have been used in the industrial praxis, only the kinematics of the robot for connecting was studied. A part of the results of this study is shown in Figure 5.



joint	ϑ	d	a	α	rotation (R) or translation (T)	range of movement (mm or °)	home position
1	0	800	0	-180	T	-800 - 1200	0
2	-90	-250	0	90	R	0 - 180	0
3	-90	0	400	0	R	-100 - 100	-45
4	0	0	350	0	R	-150 - 150	90
5	0	240	250	0	R	-150 - 150	45

Figure 5 *Kinematics of robot for connecting of rebars and stirrups*

3. CONCLUSION

Construction industry all over the world has been steadily faced with the nonuniform amount of work and the lack of skilled workers in the time of conjuncture. Therefore, the construction companies have been always forced to employ unskilled and unexpensive workers. This is the main reason that several procedures in building process have been unchanged for a long time and a general opinion is present that new and modern technologies have nothing to do with construction. To overcome these obstacles for further development of this important human activity, one of the possibility is to replace some workers with robots. This is particularly suitable for the tasks, which could be characterised as difficult, dangerous, and dirty (3d phenomenon).

The classic procedure of the development of a device usually includes the building of several prototypes, which enable to estimate the functionning of the designed device. This is a very expensive and longlasting way. A modern development approach replaces the building of the physical prototypes with the simulation on computers.

The production of the reinforcement includes, as the last phase, the assembling of the reinforcement. This phase has been, with few exceptions, always done manually and an essential progress, regarding costs and time, could be made, if this phase is modernised by using modern technologies.

The graphic simulation of the assembling of the reinforcement using computer program enables to estimate the suitability of the designed procedure. Although a relatively inexpensive software was used, a clear presentation of the ideas for the particular operations of robots could be prepared and demonstrated to the interested sides.

ACKNOWLEDGEMENTS

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