# Automation and Robotics in Construction
## - State of the Art in Germany -

**Wolfgang Poppy** - Technische Universität Berlin
Construction Machinery Design and Engineering
Jebensstraße 1, D-1000 Berlin 12

**Summary**

Automation and robotics in Germany are concentrated on concrete and asphalt mixing, concrete block and pipe making, precast concrete units and masonry prefabrication, control of mobile construction machinery, tunneling and renewing of buildings and sanitation. The development has been going at a measured pace, because not all prerequisites to the introduction of these new technologies are fulfilled in the construction industry. But extensive need for construction works, lack of workers and new demands and tasks stimulate the development performed by manufacturers, construction companies, universities and institutes.

### 1. Introduction

The construction technique in Germany is - as in all industrial countries of the world - characterized by a wide mechanization. The transition from manual working methods to mechanical work went off very differently in the individual construction areas so that the prerequisites for automation and use of robots vary considerably, too. While important advance with the automation of concrete and asphalt mixing was already achieved in the sixties, the development of the necessary prerequisites for mobile construction machinery first began with the introduction of microelectronics in the beginning of the eighties. Essential impetus resulted from the change of the personnel situation and the production conditions in the construction industry as well as from new tasks and fields of activity, which could not be managed with conventional methods and machines.

### 2. Conditions of development

The decisive personnel, technological and economic conditions for the automation of construction machinery and plants in Germany are characterized by

- an extensive lack of qualified workers and a growing average age of the staff,
- demands for effective humanization of nearly all construction works,
- increased requirements on the quality of the execution of work,
- a need for works in dangerous and inaccessible areas of operations,

- an increase in performance and reduction of costs for improvement in rentability,
- a permanently extensive need for construction works, especially in East Germany, as well as
- by the competition on international markets of construction machinery.

That the development to a higher degree of automation in the construction industry of Germany has been going at a measured pace so far has to be attributed to costs, unsolved technical problems, special conditions of use in construction plants and sites and essentially to inadaquate acceptance by users and operators of construction machinery.

For years the German construction industry has not succeeded in covering the need for qualified junior members of the staff for machines operation and maintenance. As a result of that

- the construction machinery often get under too great a strain - unconciously and conciously,
- men and machines get endangered by carelessness and exessive demands and
- the maintenance costs on the construction site go up.

As a countermeasure more and more electronic components and systems are used in construction machinery and equipment. That development shall help

- to make use of the machines efficiency without overstrain,
- to simplify the operating of the machines,
- to ensure safe working of the machines,
- to optimize work processes,
- to relieve and protect the operators,
- to prevent consequences of operating errors,
- to minimize power consumption,
- to limit emissions of the machines,
- to monitor the condition of the machines,
- to signal usual and unusual need for maintenance and
- to simplify maintenance.

Characteristic is the fact, that there is always a possibility to switch over to conventional working of the machines. That takes into account the reservations of the users, who have a sceptical attitude towards reliability und lifetime of microelectronics. They are afraid of failures, work interruptions, resultant costs and loss of time.

So far electronic controls are mainly brought in selectively in addition to and modification of the conventional technique. For the creation of basicly new conceived flexible automated machines and systems fundamental prerequisites are not fulfilled yet.

## 3. Automation and development of robots

In view of automation and robotisation, stationary machines and plants on the one hand and mobile machines for the construction-site service on the other hand have attained a very different state of the art in Germany. A representative cross-section of the current development is given by the German papers in the programme of the 8th ISARC. Examples from the following fields of machines and process development will be presented:

- fabrication of precast concrete units,
- bricklaying machines,
- control and monitoring of mobile construction machinery,
- expert system for planning and controlling,
- computer controlled equipment,
- tunneling and
- renewing of buildings and sanitation.

### Fabrication of precast concrete units

A high degree of automation is attained with stationary concrete and asphalt mixing plants and with the series production of standardized concrete blocks and pipes. However the prefabrication of large concrete units went through a changeable development in Germany. After a gradual increase of automation up to the early seventies a beginning recession caused a general return to conventional construction techniques. Prefabrication plants with higher degree of automation had to be closed. Some years ago a new development began and has in individual cases already resulted in computer aided manufacturing (CAM) and in initial stages in computer integrated manufacturing (CIM) of precast concrete units. For qualitiy control in the automated production a measuring robot was developed.

The degree of automation of large element series production in the former GDR was relatively high. Since the political turn in 1989/90, that kind of construction method is not practicable any longer.

### Bricklaying machines

Besides the fabrication of precast concrete units the prefabrication of masonry elements in stationary plants gains growing importance in Germany since the middle of the eighties. The German's preference to bricked residential buildings on the one hand and the high dependence on weather of this construction method on the other hand have lead to the development of a number of bricklaying machines. Some of them are already in practicle use. In other cases neither a systematic market analysis has been done nor a ripened design principle has been developed. Therefore they are not marketable yet. With bricklaying

machines a higher output can be achieved. They make possible great lightening of work and the saving of workers.

For bricklaying at construction sites handling aids are used to distrain the bricklayers of handling heavy bricks and blocks. Most of the construction companies hesitate to use these handling aids, because they make the bricklayer's equipment much more expensive. But on longer terms these devices will become a necessary and useful investment.

Control and monitoring of mobile construction machinery

So far mobile machines are characterized less by automation and robotization than by a growing penetration with microelectronic components and systems for following tasks:

* monitoring, diagnosis and maintenance,
* safety aspects,
* operator's information and guidance,
* quality control and
* measuring and recording of machine data.

The machines of some manufacturers are already equipped with large systems, which inform the operator constantly about the state of the machine, which signal inadmissible changes optical and acousticaly and which are able to give instructions to clear faults. Such systems contain control devices to optimize the use of the machines and to suit them to the conditions of use.

Only in single cases the next step of the development has been gone to automize or robotize work processes. That would allow works in inexessible areas, e.g. microtunnel, and in uncomfortable, unreasonable and dangerous areas, e.g. in case of hazardous influence of temperatures, dusts, steams, gases, liquids or radioactivity as well as in case of danger falling or collapsing).

Only exact knowledge of the operating principle of the machines allows the development of control systems that are suitable for practical use. Prereqisite is a detailed analysis of the controlling behaviour of the machines in use. That analysis can be managed by a mathematical model and by computer simulation of the decisive parameters. The needed basics are mainly acquired at several universities. Thus the so far predominant empirical kind of development of construction machinery could be improved by systematical structural design. That has had a positive effect both on the design and production of the machines and on their use and quality of work.

Expert systems for planning and controlling

For the use of construction machinery on sites an exact choice and planning of work is necessary. Due to many exogenous conditions on construction sites the execution of work

has mostly stochastical nature. To take these conditions completely into account, planning systems have been developed, which make it possible

- to determine optimal combinations of machines,
- to ensure preparation of the machines on the construction site just-in-time and
- to gain continual and high use of capacity during the whole operation time.

By the aid of an expert system the organization of the construction site can permanently be adapted to changing conditions.

Computer controlled equipment

So far the working processes of mobile machines has to be controlled by operators. An important decision in every development is to split control tasks between men and technique, especially in case of machines, whose movements of working equipment have to be adapted to a permanently changing working process, e.g. hydraulic excavators and concrete pumps with distributor boom. To develop an concrete distributor boom to a manipulator with large reach the boom and his drive have been modified and a robot guidance and a 3-d sensor system have been installed.

The basic experiences of such manipulator development are also useful to develope handling systems for related areas, e.g. for work in contaminated areas of nuclear power plants or in coal-mining with working conditions similar to construction sites.

Tunnelling

For years underground construction methods have been of growing importance in Germany, i.e. tunnelling with large and small cross-sections. The shotcrete technology for the lining of tunnels makes great demands to the operators. To improve the working conditions, the shotcrete technology and the quality of work a shotcrete robot has been developed on the base of an industrial robot.

To stay on the exact tunnelling axis, for shield tunnelling in Denmark an automatic direction control of the shield machine has been developed, which corrects every deviation.

In many centres of population in Germany it is not possible to do service works with open trenches. Therefore the number of trenchless working laser-controlled machines for microtunnelling with small cross-sections increased considerably.

To put down the continental deep boring in the Oberpfalz (up to 10 km depth) an automated deep drilling system has been developed, which corrects all deviations from the vertical direction. In an depth of 5 km the system has to stand a pressure of 600 bar and a temperatur of 120 °C.

Renewing of buildings and sanitation

A special problem in many German cities and towns represent the sanitation nets. Already in World War II they have suffered exessive damages and now they reach the end of their normal lifetime, too. Urgent need is given both for robots to inspect the sanitations and for renewing the damages with trenchless methods. Several robots to coat old pipes, to renew pipes and to point bricked sanitation have been developed.

In East Germany many buildings are in an extraordinary bad state. For their renewing a milling attachment for hydraulic excavators has been developed to remove plaster of exterior walls with high performance. Other methods to remove old parts of buildings use high pressure jet of water.

## 4. Tasks of research and development

The prerequisites to that development are not alone fulfilled by the availability of new technologies, especially of microelectronics. Of significance is the suitablility of electronic components for construction machinery. High load and heavy use of the construction machinery, extreme changes of weather and climate, influence of building materials and dirt as well as poor operating and maintenance require the use of extremly robust automation components, which must be available in low cost/heavy duty-version.

That components, e.g. sensors, actuators, microprocessors, on-bord computers, bus systems, process in- and output units and power modules, must have - with care to very different combined machine pools - the feature of machinery components: standardized, with well-known use and quality characteristics, simply to handle and generally available.

On this base the manufacturers can use cheeper serial products of component suppliers and the user of construction machinery can organize a simplier keeping of replacement parts and maintenance.

Those tasks require theoretical basics, which make possible a systematic new design of products and construction processes under integral aspects, i.e. with tuned fusion of mechanical, hydraulic, electric and electronic components (mechatronic). That fusion cannot be achieved by an empirical development of machines and systems, where an electronic component is graft on to an existing product. Rather the development must start with a complete system analysis, which includes machines, operating, construction methods, building materials and all conditions of use. Such an integral reflection on the system men-machine-construction technique-site-environment and the consideration of all interactions is possible as a rule only by modelling and simulation of all important system parameters.

Some month ago several instituts, manufacturers and users have been starting to prepare a programme of main points of emphasis. It shall create the prerequisites to the development and application of new technologies in construction machinery and processes on an

scientific founded base and involve the test and the modification of microelectronic components in accordance with all demands.

In view of the develoment of the production techniques in other branches of industry the application of C-techniques with the aim "CIM in construction" are to take into account to avoid interface problems, characterising current developments in other areas of technique.

For years relevant research work has been done in construction and mechanical institutes of following universities:

* Techische Universität **Berlin** - Prof. Poppy:
  - Development of a test stand for sensors and microelectronic components,
  - Compaction control of vibratory rollers,
  - Analysis and optimization of hydraulic excavator drive according to the need of power for the eqipment.

* Ruhr-Universität **Bochum** - Prof. Maidl:
  - Shotcrete robot for tunnelling,
  - Integrated distance measure system for shotcrete robots,
  - Robot for construction and renewing of pipe lines.

* Hochschule für Verkehrswesen, **Dresden** - Prof. Schuszter:
  - Partial automation of a multi-purpose earth moving machine,
  - System for monitoring, diagnosis and maintenance of hydraulic drives.

* Bergakademie **Freiberg** - Prof. Höffl:
  - Optimization of concrete mixers,
  - Radiometric scoring of characteristic particle sizes.

* Universität **Karlsruhe** (TH) - Prof. Bock and Prof. Gehbauer:
  - Control of an autonomous tranportation vehicle,
  - Development of a portal robot,
  - Control of vibratory rams,
  - Remote controlled collecting vehicle for manganese nodule.

* Technische Universität **Magdeburg** - Prof. Prusseit and Prof. Vogt:
  - Control of compactors for building materials,
  - Automated vibratory cutting of soil,
  - Measuring robot for precast concrete units,
  - Use of microcomputer in hydraulic excavators.

* Universität **Stuttgart** /IPA/FhG - Prof. Warnecke and Prof. Schraft:
  - Programmable mobile concrete distribution boom,
  - Robot for renewing of bricked sewers,
  - Flexible automated fabrication of precast elements.

These instituts are open to companies, that are interested in cooperation - national and international. Several of their works will be presented on the 8th ISARC.

## 5. Conclusions

Compared with similar branches of industry the German construction technique is characterized by an enormous delay - in spite of several encouraging examples of automation and robots. In face of the extraordinary need for construction works, above all in Eastern Germany, that delay has to be made up as fast as possible to improve the working conditions and safety in construction, to increase performance and quality and to reduce costs.

The manufacturing of construction machinery in small series and the machine pools of the construction companies with many different kinds and sizes of machines suggests the development of a standardized concept of measurement, control and automation for mechanized construction processes. On the one hand that will create better prerequisites for developing a suitable range of components. On the other hand that will simplify the use and the maintenance of construction machinery and equipment in the construction companies.