22½ m extension w. 1½ ton

COMPUTER CONTROLLED CONCRETE DISTRIBUTION

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5-10 cm tolerance over 26m extension with full load

could this manipulator be used for other tasks? -yes

parking lot P13

-add total automated planning + control?

1 SUMMARY

After now five years of development the concrete pump with AMC control represents the first step towards computer-aided concreting on the job-site in the future. AMC results in an increase in productivity in placing concrete along with increased safety. The experience gathered here can be used to open up new possibilities for the precise and safe handing of components and tools over large reaches on the construction job-site.

1 joy stick for x-y
1 " " z
-19" rack computer casing in driver's cab

2. INTRODUCTION

For economical placing of concrete, truck-mounted concrete pumps are nowadays standard equipment in the building trade. The basic concept of a truck-mounted concrete pump comprises the concrete pump unit which is built into a frame construction. This frame construction also accommodates the concrete placing boom as well as the necessary constructional elements to support the unit. For concrete pumps with high delivery performance up to 150 m^3/h in connection with delivery pressures up to over 100 bar, hydraulically-driven double-cylinder piston concrete pumps are used nowadays /1/.

The main components and the functional diagram of a mobile truck-mounted concrete pump are illustrated in Fig. 1. The complete assembly unit is mounted onto a usual standard truck chassis. In order to increase the efficiency when the concrete pumps are in operation, a main demand is made for a maximum reach of the concrete placing boom utilizing the maximum permissible total weight and the respective axle loads of the truck-mounted concrete pump. Limits on the design are given by the vehicle registration regulations for trucks for the specific country in question. The result of this demand is a range of different reaches for truck-mounted concrete pumps from 24 m up to approx. 60 m (Fig. 2).

3. OPERATING CONDITIONS

Truck-mounted concrete pumps with placing booms are mobile working machines which can be used with full 360° slewing range with placing boom extended in horizontal position.

The operator of the unit is responsible for its correct setting up and support. All important functions of a truck-mounted concrete pump are carried out hydraulically, for example, the drive of the concrete pump, the support as well as the movement of the multi-sectional placing boom. The state of the art is the use of energy-optimising hydraulic systems, e.g. switching-over main hydraulic drives in closed hydraulic circuit directly to the drive cylinders of the double-cylinder concrete pump or Load-Sensing controls for the placing boom.

The latter are increasingly being used for long-reach concrete placing booms and the large volumes of oil which result from this.

The task of the concrete pump operator is to control the concrete pump and to position the concrete end hose on the last boom section of the multi-joint placing boom. Today radio proportional control for reaches over 30 m is provided for this. This development has asserted itself on the market during the last few years. The remote controls used before this - whether cable or radio, with direct black/white drive of the hydraulic valves - are increasingly becoming scarce for large units. This is especially the case with regard to the safety aspect with direct control of the total unit without the hindrance of a cable remote control.

The task of the machine operator is now to drive up to the six rotatoric degrees of liberty of the concrete placing boom. He must separately control the axes so that the end hose - out of which the concrete emerges - is positioned correctly on the job-site. A typical example of operation of a truck-mounted concrete pump is illustrated in Fig. 3. It is obvious that the unit can be moved in a non-structured three-dimensioned space when the job-site boundary conditions and safety regulations are observed. The use of the modern proportional radio remote control has considerably simplified this work of the operator. There is, however, still one hazard which must always be kept in mind: if one axis is overdriven this can lead to movements which are too quick at the end hose and consequently endanger the personnel working there. In addition, it is essential that the operator, due to safety reasons, always has the complete kinematics of the machine in his range of vision to make sure that the job-site or the close vicinity is not at all endangered by the concrete placing boom. Fig. 4 illustrates the kinematic constraints of the operator guiding when driving the multi-joint kinematics of concrete placing booms.

The signal processing on the concrete pump is usually carried out nowadays by relay technology. The signal transformation for the proportional valves used is carried out via the usual amplifier cards or proportional valves with integrated electronics.

4. DISADVANTAGES OF THE EXISTING SYSTEMS

Operator guiding

Conditioned by the single axis driving of today even trained operators find it extremely difficult to achieve a precise straight line for concreting in the co-ordinates of the job-site, i.e. for example in the formwork of the building. Constant corrections to the respective boom joints and the swivel movement of the placing boom must be carried out. Possible mistakes in operation can occure at all times, e.g. if quick horizontal swivel movements are carried out by mistake over the slewing unit. It is also extremely difficult to keep the end hose constantly at the same height above the surface to be concreted or area of placement (see Fig. 4)

The frequent demand made by users for a uniform meandering of the placing boom over a surface to be concreted, so that concreting is uniform, is very difficult to achieve due to the above reasons.

Conditioned by the system, with double-cylinder concrete pumps, pump vibrations from the concrete pump are transferred to the placing boom. Suitable concrete pump drives considerably reduce the induced vibrations /1/ caused by the pump drive. The vibrations of the placing boom, especially the dynamic reactions of the very elastic placing boom cannot, however, be avoided.

The vibration system consists of the respective single boom sections of the placing boom as well as the hydraulic linear drives, i.e. the hydraulic cylinders for the joints. If the vibration behaviour was improved by using proportional valves for the individual boom cylinders, then the vibration behaviour of the placing boom and thereby especially the amplitude at the end hose is a result of the operator driving the axis. The use of the hydraulic cylinders to actively damp the vibrating system is not provided nowadays.

Collision Avoidance

This keyword characterises a very dangerous situation when using concrete booms. The usual job-site demands of the operator that he constantly and carefully observes obstacles in the non-structured working space, and that he makes sure that no element of the kinematics, resp. of the placing boom fails to keep the prescribed safety distances. This is especially essential with, for example, high voltage lines or other energy-conducting structures.

Maintenance and operating notes

Due to the signal processing which is standardly provided nowadays, largely via relay technology, the diagnosis of a mistake in the system and its logical connection is not easy. Diagnostic systems of greater intelligence require additional investments in sensory mechanisms and signal processing. A coupling of these systems to the pump control is not the state of the art.

The representation of the operating status of the concrete pump necessitates extensive electrical equipment and complicates the electrical system. A central operating status monitoring requires special equipment not usually required and for which the complete integration into the system, e.g. for diagnostic systems, has not been introduced to date.

Signal processing and documentation of pump service performance, e.g. pumped cubic metre/time, resp. per order, require special equipment nowadays which cannot be integrated. Further peripheral functions can be covered nowadays by single solutions. A fusion under one complete system is not available.

5. COMPUTER-AIDED TRUCK-MOUNTED CONCRETE PUMP WITH CONCRETE PLACING BOOM M 24 - AMC

The truck-mounted concrete pump with four-section placing boom M 24 and AMC (Automatic Mast Control) was further developed as the base component of the BMFT project 'Highly flexible handling systems' /2/ as a continuation of the programme still running - Esprit II 'Large Handling Manipulator' /3/.

The truck-mounted concrete pump is a prototype for introducing computer-aided concrete placing on the job-site. In Fig. 5 in a block diagram, the essential components of the AMC technology are illustrated. As the central controlling unit a 'Robot Control 500' of the AEG company is used. This consists of a CPU from which in the main the following run off: the operating functions, the path planning, the co-ordinates transformation for the redundant degrees of freedom, and the calculation of the elastic system. Via a BUS-system the position control cards are integrated with the position control and pressure control. A communication-computer and a SPS to drive the peripheral functions are also integrated.

The operator controls the M 24 via a remote control unit (Fig. 6 a+b) which can be operated optionally either by cable or radio. What is important here is that the complete telegram communication of the robot control is ready on the remote control unit. This enables operation as well as the possibility for diagnosis and system monitoring of the machine.

The peripheral functions are driven via the robot control by the integrated SPS - independent of the driving of the boom. The support legs can, for example, be extended by computer and the stability monitored. Whilst designing the AMC great importance was attached to a fully-integrated extension. This guarantees that the system monitoring of all communicating components is safeguarded.

What are the practical advantages for the truck-mounted concrete pump operator when AMC is used?

An important result here is the **increased operating safety** of the employees on the job-site. The work of the concreting man at the end hose of the placing boom is simplified and can in some special cases even be done without. Risks of the individual driving of the rotatoric degrees of freedom are eliminated by the **computer-aided co-ordinated driving** of the individual axes by the operator by pre-setting X, Y and Z for the end hose. X, Y and Z pre-setting of the operator can either apply to the vehicle co-ordinate system or the job-site co-ordinate system. By **active damping** the vibrations of the boom structure are largely eliminated. A quiet end hose with which concrete can be continuously placed at a constant height is the result of the AMC (Fig. 7).

A further advantage of the computer-aided concrete pump is the possibility of achieving a **uniform placement of the metered concrete** over the whole surface by meandering programmes. What must be especially pointed out here is that for line formwork it is possible to drive this by just guiding a joy-stick after the co-ordinates system of the job-site have been taught. Overdriving of the concreting task is possible at all times, the direction of operation is optional.

Furthermore **quick readiness for working** of the concrete placing boom is guaranteed on the job-site. Folding in and out programmes which must be called up and monitored by the operator make work a lot easier.

The potentiality of the **Automatic Stability Control (ASC)** guarantees that the boom can only be foulded out, when the supports of the machine are all in correct position according to the regulations. If the pump leans over to the one side due to one of the supports sinking into the ground, boom movement is automatically halted before there is any danger of tipping over. The first step is an advice to the pump driver, then the boom can only be moved backwards, i.e. towards the safe side. This can be done manually as well as automatically. The safety advantages when using the concrete pump at the building site do speak for themselves.

For **special applications**, e.g. in pre-fabricated buildings, it is possible to transfer known geometries as CAD data as movement directions to the computer. A possible example of this is the pouring of sections of concrete precast slabs.

Apart from the increased efficiency in placing concrete via the placing boom, the increase in operating safety when using the concrete pump is an important marginal condition of the AMC development.

By **presetting collision space** via the computer, the operator does not drive into forbidden space. With the concrete placing boom, for example, the definition of a maximum height can be of a great help - no part of the boom structure is allowed to surpass it (Fig. 8). Worth mentioning here in this respect are concreting tasks in low-roofed buildings or tunnels.

The **extensive sensor equipment** give status information about possible safety-endangering error functions of components. We should mention here, for example, positional faults of proportional valves when maximum pressures are reached or when stability is endangered.

Standard information of the robot control and the SPS is given in the **notes on maintenance and the operating status of the machine**. By memorizing errors repeated interruptions can be recorded, evaluated and used for specific service measures.

Further possibilities with the AMC are the use of the electronics to match the performance requirement of the concrete pump to the performance of the drive system; in this case the diesel motor. Better **efficiency of the total unit** is thereby achieved. Guided increasing and reducing of speed of the drive motor via the SPS in a simple version or via a position-regulating structural component with regard to mathematical correlations is the key-word here.

It is necessary to point out here that the operation of the computer-aided concrete pump may only be intentionally released by the operator in accordance with the safety regulations.

All movements within the total working space are under the control of the operator and in accordance with the usual safety regulations; every movement is released intentionally for concrete placing booms. For the M 24 with AMC control we are not talking here about a robot but about a computer-aided manipulator.

Literature:

/1/ Benckert H.: Energiesparende Antriebshydraulik für 2-Zylinder-Dickstoffpumpen im geschlossenen Hydraulikkreis
O + P (1989) No. 4.

/2/ Hochflexible Handhabungssysteme
Förderungsprogramm Fertigungstechnik des BMFT
KFK - PFT, 153, February, 1990

/3/ Wanner, M.C:: Large manipulator for CIM (LAMA)
CIM-Europe SIG7 Workshop, Genua, 1990

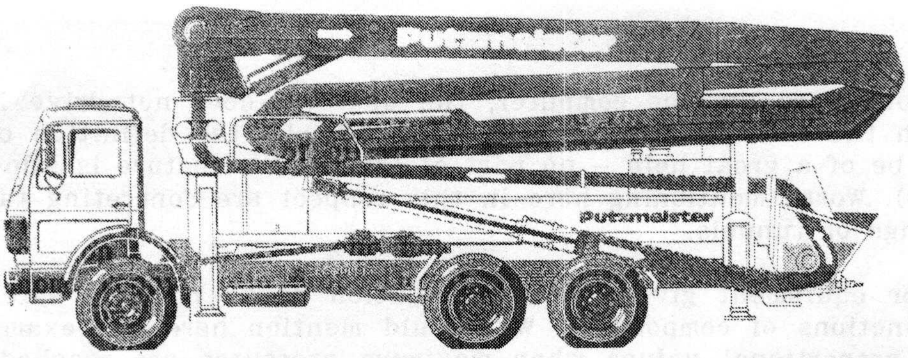
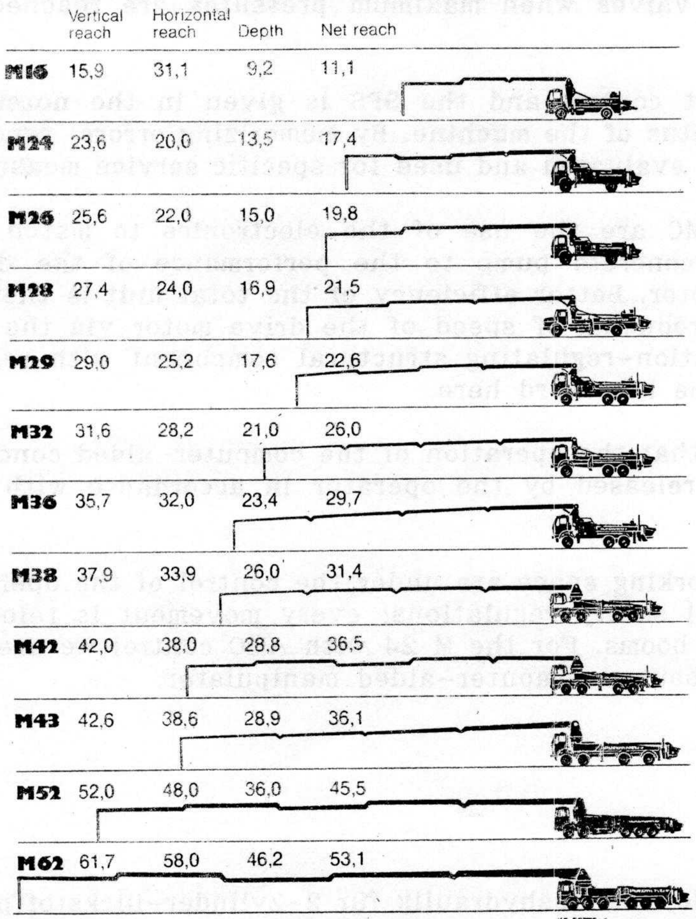


Fig. 1 Schematic system of a standard truck mounted concrete pump



	Vertical reach	Horizontal reach	Depth	Net reach
M16	15,9	31,1	9,2	11,1
M24	23,6	20,0	13,5	17,4
M26	25,6	22,0	15,0	19,8
M28	27,4	24,0	16,9	21,5
M29	29,0	25,2	17,6	22,6
M32	31,6	28,2	21,0	26,0
M36	35,7	32,0	23,4	29,7
M38	37,9	33,9	26,0	31,4
M42	42,0	38,0	28,8	36,5
M43	42,6	38,6	28,9	36,1
M52	52,0	48,0	36,0	45,5
M62	61,7	58,0	46,2	53,1

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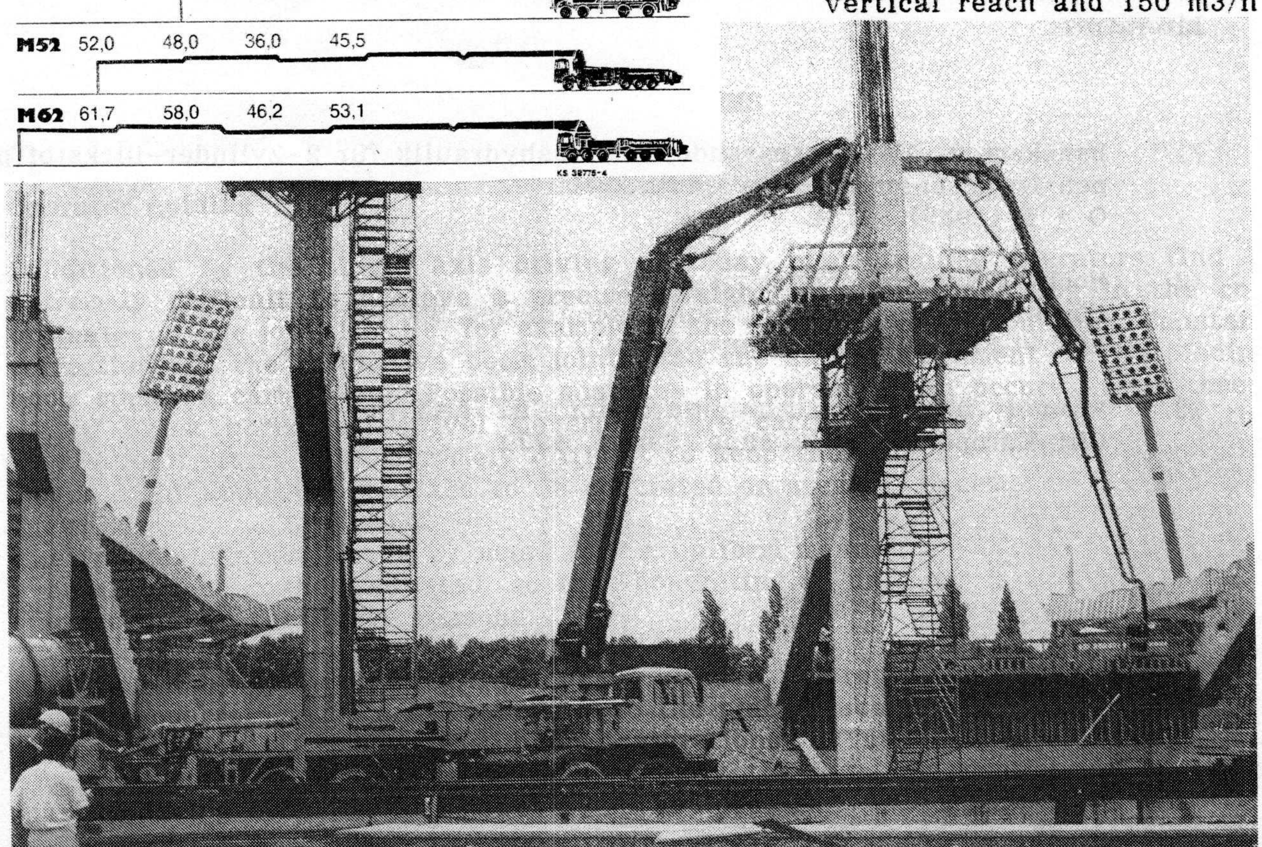
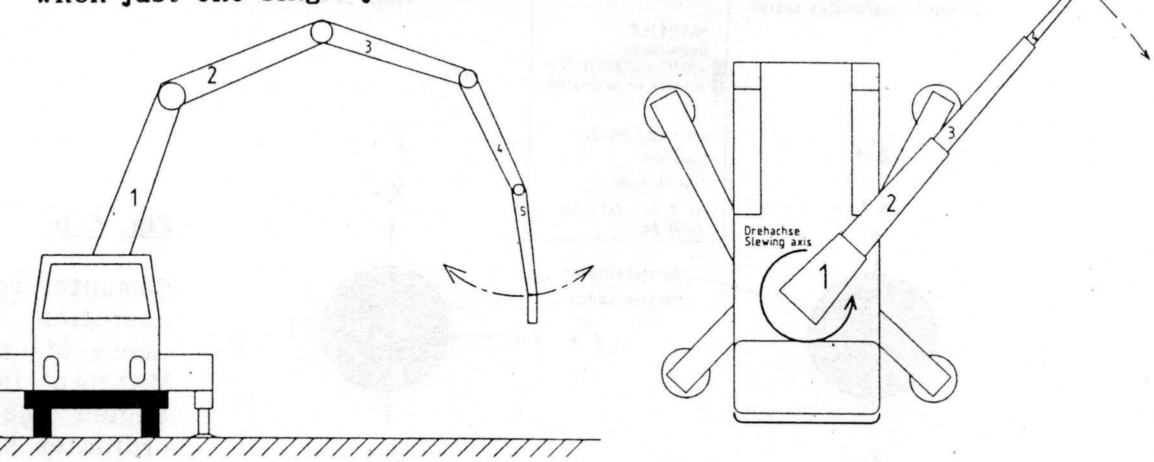
Fig. 2 Range of mobile concrete placing booms

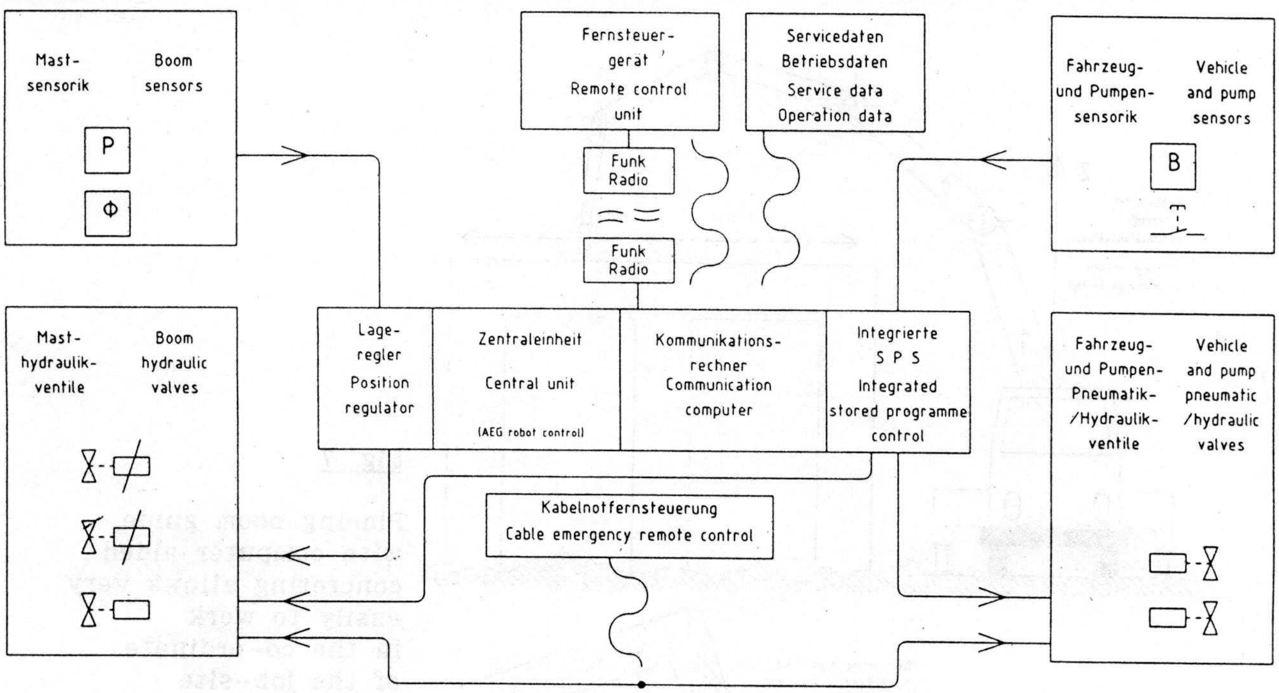
Fig. 3 BRF 42.15 H with flexible 5-section boom for 42 m vertical reach and 150 m3/h

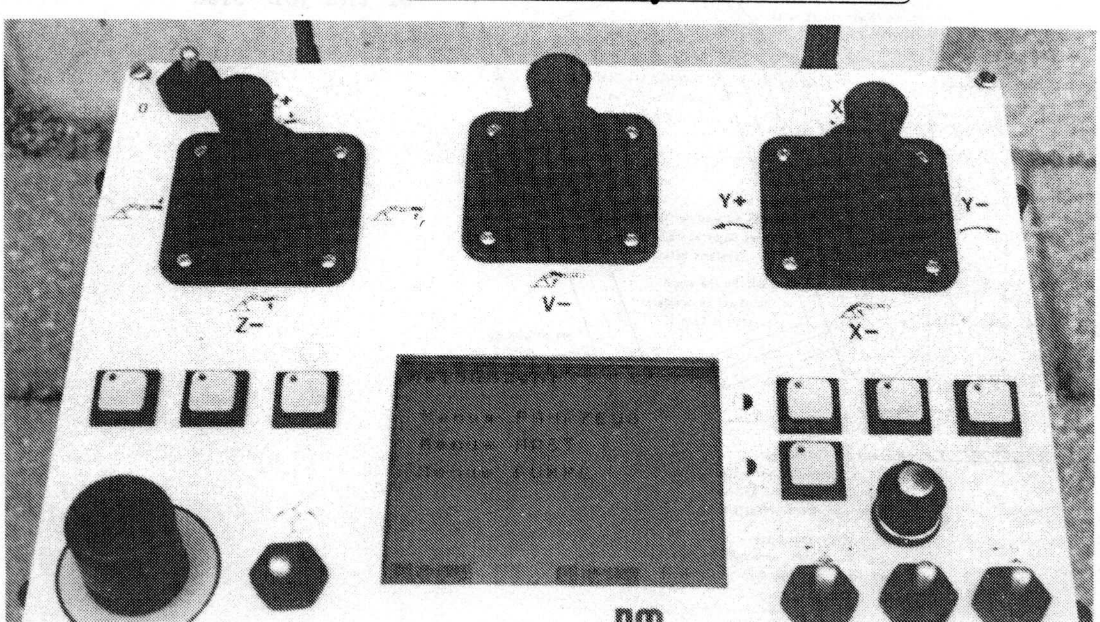


<u>Fig. 4</u> Conditioned by the multi-joint kinematics of the concrete placing boom, the top of the boom clears circular arc paths when just one single joint or the slewing axle is moved.



<u>Fig. 5</u> Block-schematic of a computer-controlled concrete pump with AMC





<u>Fig. 6 a</u>

Radio remote control with communication display

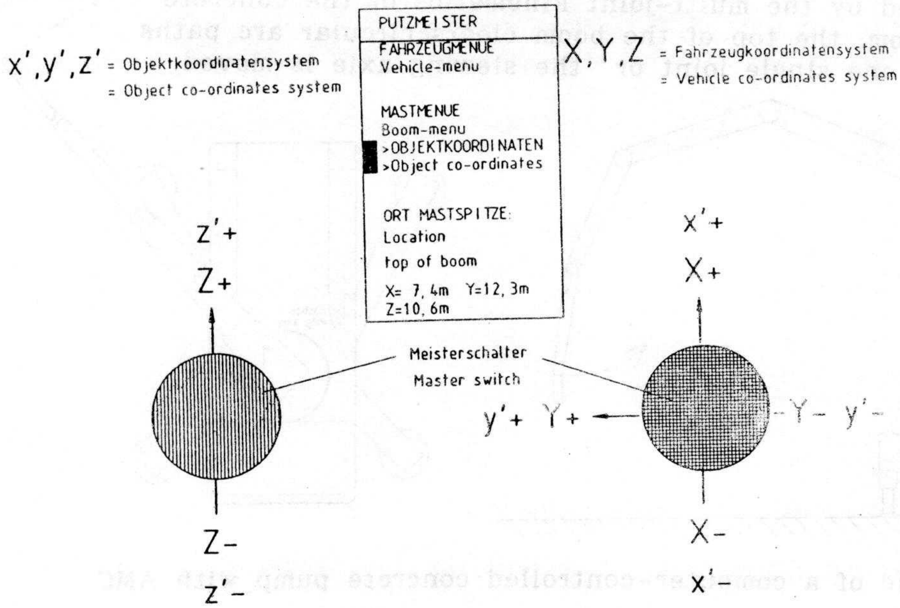


Fig. 6 b

Computer controlled operation (mode of operation: MANUAL) in right-angled object co-ordinates system

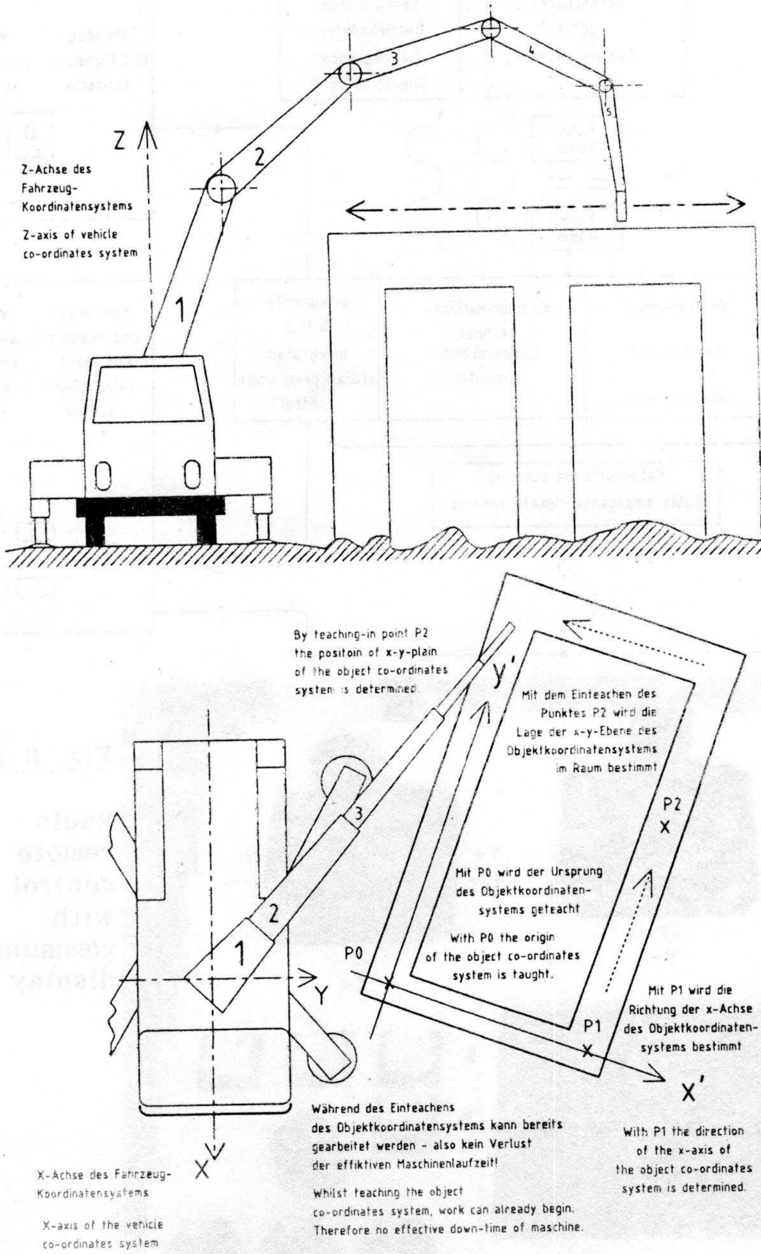


Fig. 7

Placing boom guide with computer aided concreting allows very easily to work in the co-ordinate of the job-site

still to be achieved?

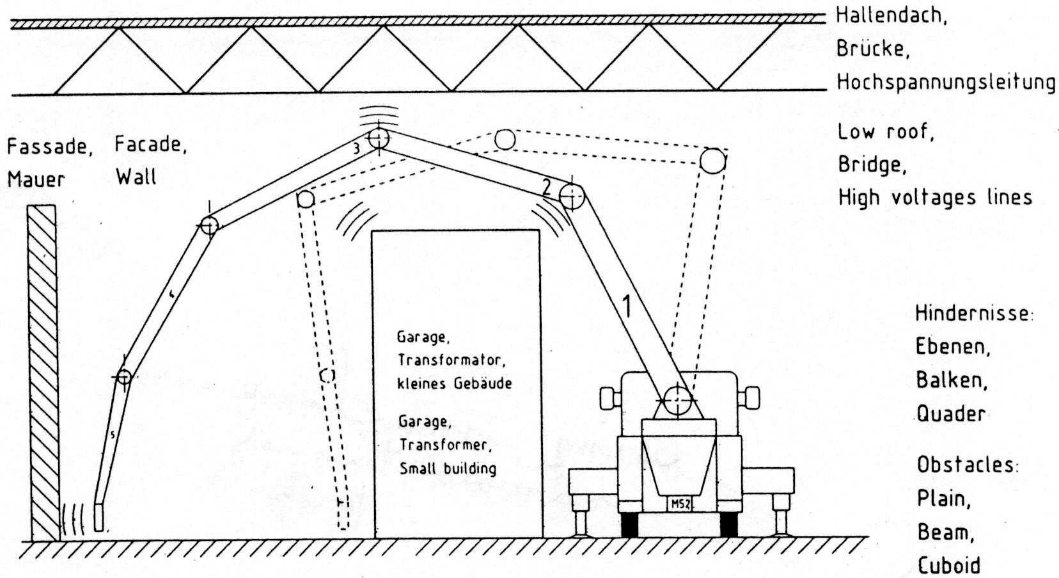


Fig. 8 Computer aided collision avoidance

Fig. 9 Computer aided concrete pump with 24 m 4-section boom in operation