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"Automation Systems for Locks and Dams Operating in Germany"

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Automation Systems for Locks and Dams Operating in Germany

By Erich Wirzberger[i] and David Fair[ii]

Automation systems for locks and dams are quite a big issue in the United States as well as in Europe. The contents of my paper explains what has been accomplished in Germany and the present state in the light of three examples:

a) Weir in Bremen on the river Weser
b) Ship locks Harrbach and Himmelstadt on the river Main
c) Seven ship locks on the river Neckar

Weir in Bremen

The new weir in Bremen was built with five weir openings, each of a width of 30 m.

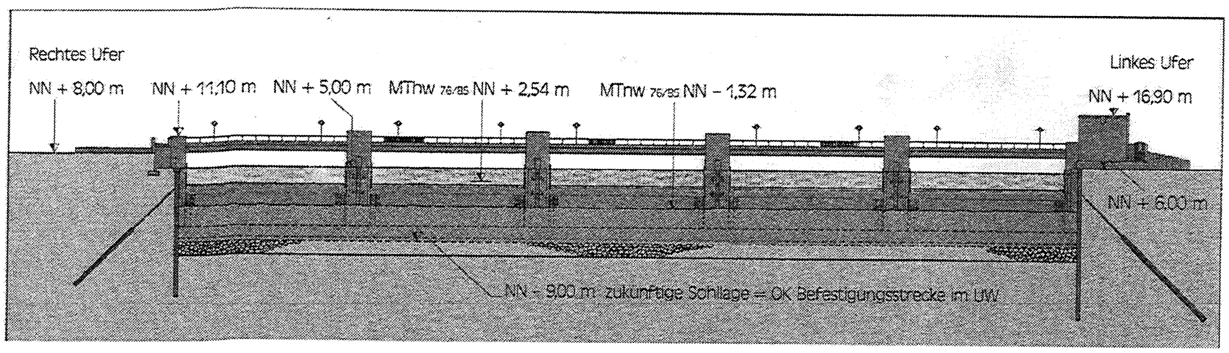

Fig. 1: Longitudinal section tailwater

This results in an entire overflow weir width of 150 m. Torsion-proof fish-belly flaps are used as regulating elements in the five weir sections to maintain the upstream water level.

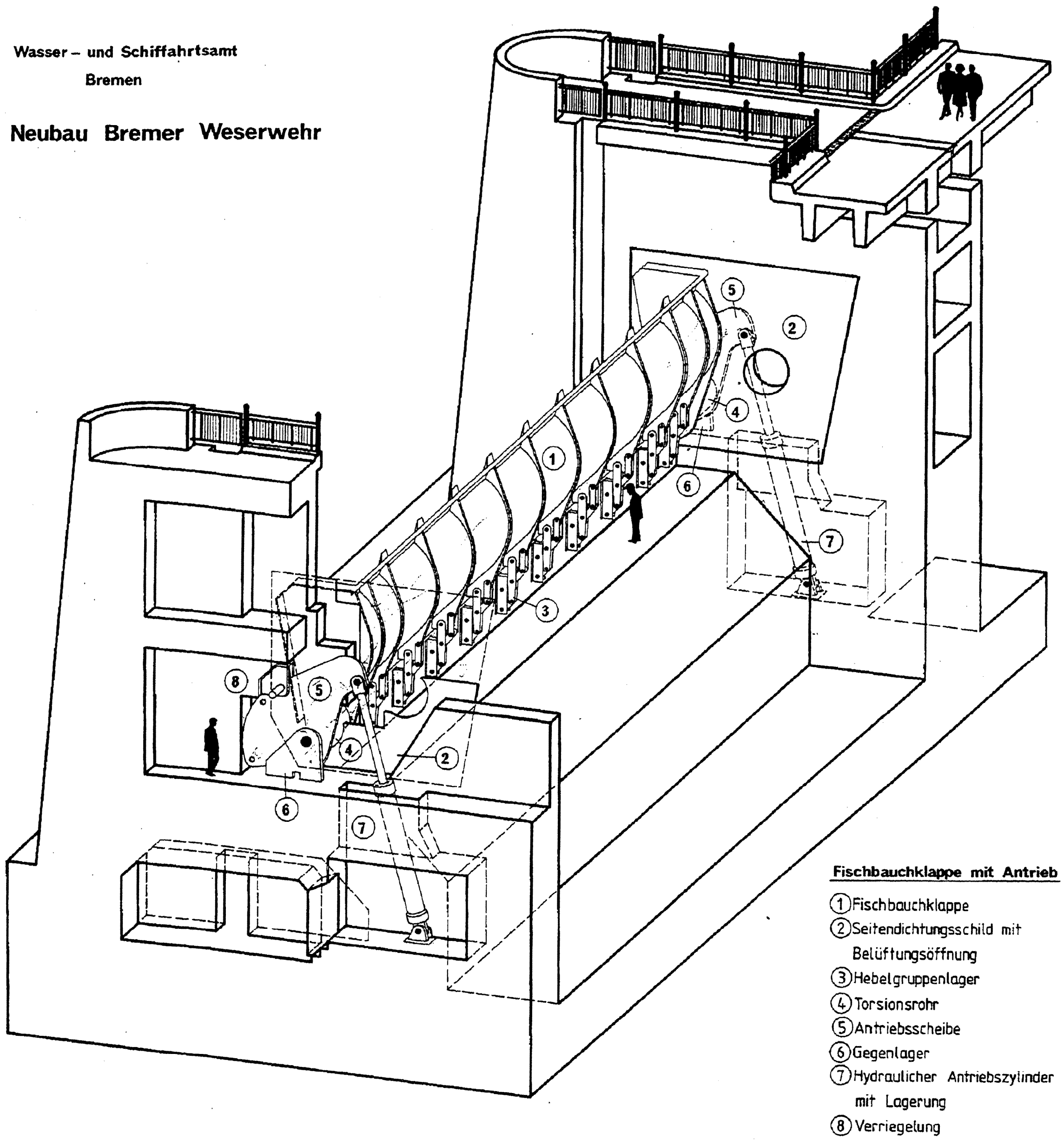

Fig. 2: Moveable weir flaps with drives

1 Fish-belly flap
2 Lateral steel plating with aeration opening
3 Lever group bearings
4 Torque tube
5 Lever disk
6 Counter-bearing
7 Hydraulic cylinder with bearing
8 Locking device

Operation of the Weir

The new Weser weir in Bremen is not operated by permanent staff but by means of an automatic weir control. The control station receives information on the flap position and the water levels, which is again processed by the computer system in order to optimize the individual weir flap positions. The initiation of a movement of the weir flaps is carried out by hydraulic power units, which receive actuating commands from the computer.

The weir flaps are driven on both sides by means of torque tubes with hydraulic cylinders, which are pressurized on both sides, applying force to the lever disks.

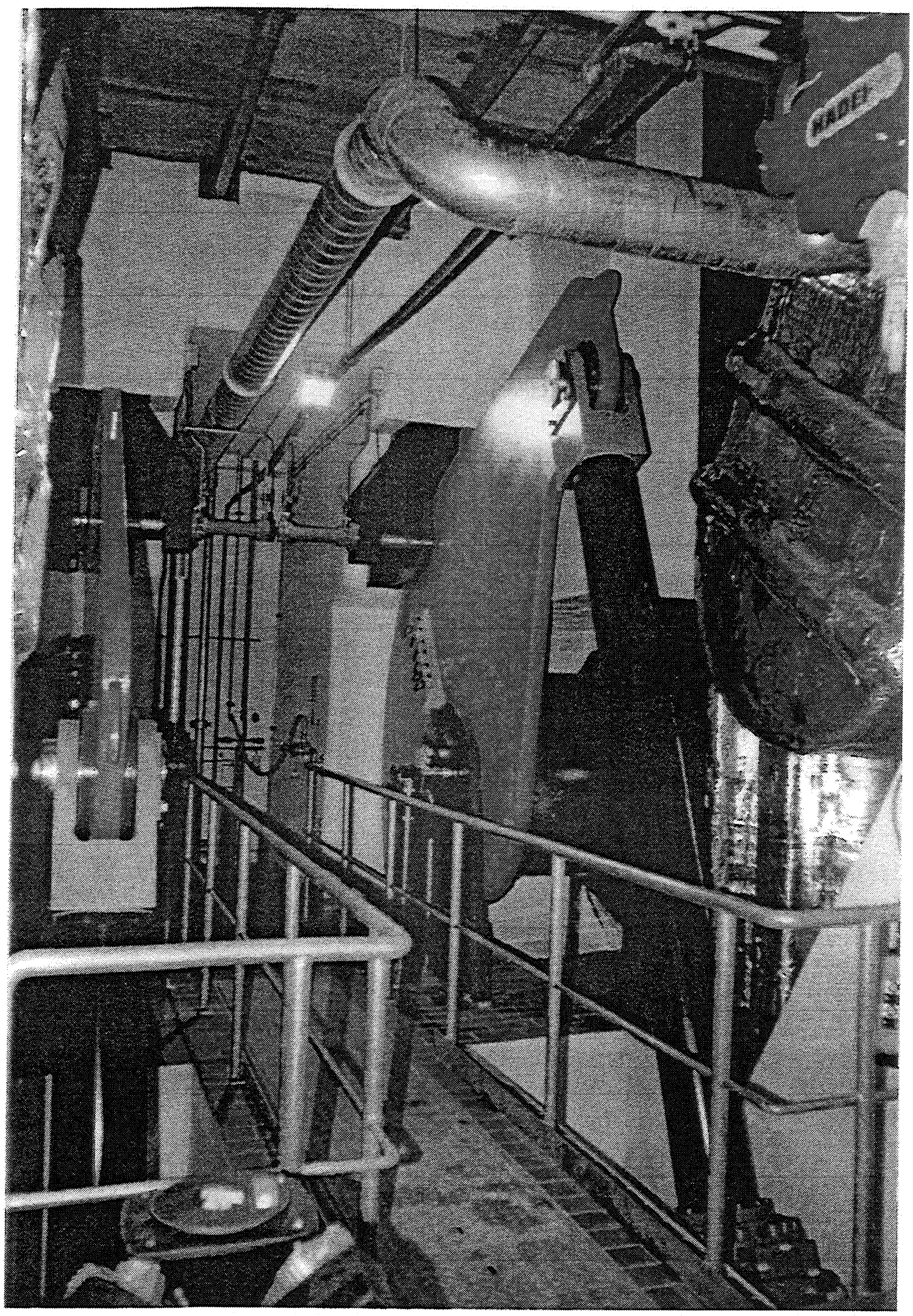

Fig. 3: Lever disk with drive cylinder

A drive power unit is assigned to each weir flap. These drives are of a uniform design.

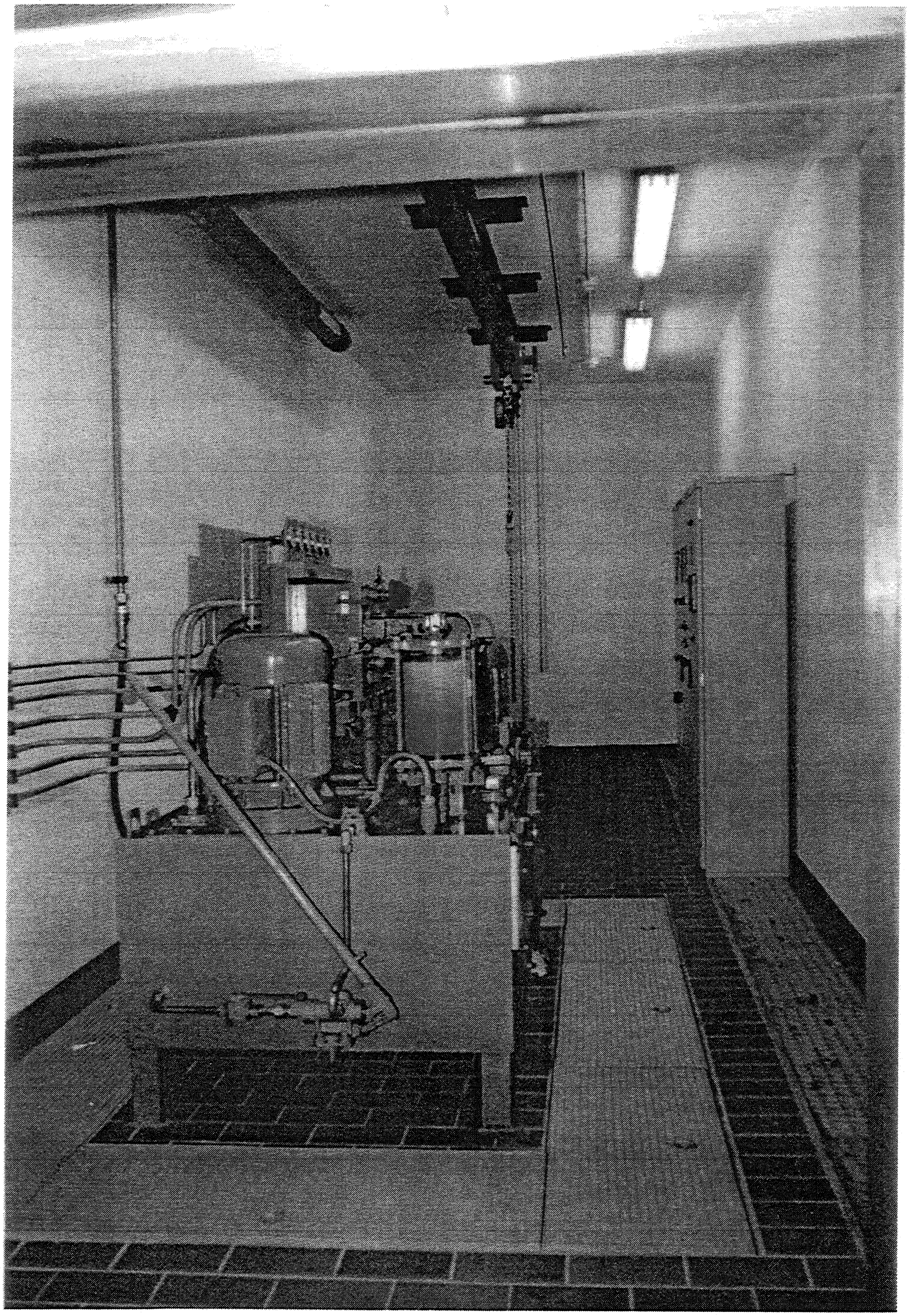

Fig 4: Hydraulic station with local control cabinet

The two drive cylinders are pressurized via a common pressure line up to the center of the weir and from the point of division through separate pressure lines, in the fine control range by means of one internal gear pump, in the coarse control range by means of two internal gear pumps. Thanks to the supply of oil to the middle of the unit, it is possible to achieve a synchronized movement of the drive cylinders.

The drive cylinders hold the weir flaps leak-free in any position. In order to guarantee a safe operation in the case of a drive cylinder failure, the weir flap is held in its current position by the other drive cylinder, or this cylinder assumes the motion sequence for lifting and lowering. This operating condition is controlled automatically.

When approaching the locking positions, the end positions of the weir flap are switched by means of contactless limit switches.

Rotary angle encoders are provided for position indication and monitoring of torsional stiffness of the weir flap.

When the upper edge is positioned at NN + 5.30 m and NN + 4.50 m, the weir flaps can be held manually in position, in the fully open position at NN +1,50 m they can be operationally locked by means of locking cylinders.

With a two-sided drive, the operating pressure is 90/130 bar (lifting/lowering), with a one-sided drive, this value increases to 230 bar.

A cross connection with the locking device drive ensures emergency operation in the case of a failure of both pump power units. The drive power units in the piers are coupled to each other by means of cross connections so that, in the case of a failure of the complete drive power unit, the relevant weir flap can be operated using another drive power unit.

1 Oil tank
2 Control plate „power unit"
3 Control „weir flap"
4 Control „locking device"
5 Control „cross connection"
6 Control plate „weir tunnel"
7 Drive cylinder 1
7.1 Control plate, piston side
7.2 Control plate, rod side
8 Drive cylinder 2
8.1 Control plate, piston side
8.2 Control plate, rod side
9 End position circuit „flap position NN + 5.30 m"
10 End position circuit „flap position NN + 4.50 m"
11 End position circuit „flap position NN + 1.50 m"
12 Locking cylinder 1
13 Locking cylinder 2
14 Lever disk 1
15 Lever disk 2
16 End position circuit locking cylinder
17 End position circuit locking cylinder
18 Pipes for cross connections
19 Filling and draining equipment
20 Concrete base with oil drip tray channel

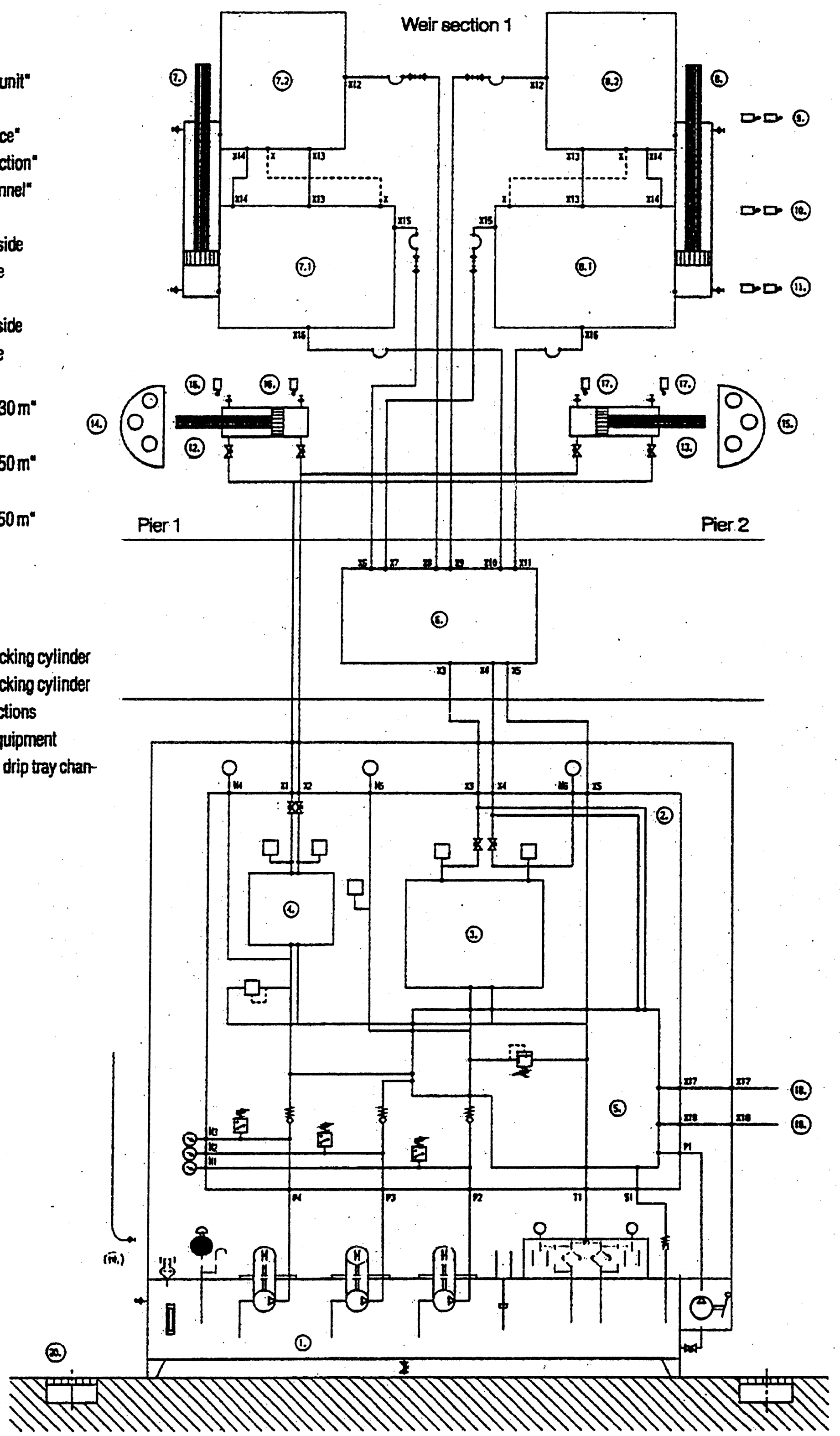

Fig. 5: Block circuit diagram: Drive of weir flap 1

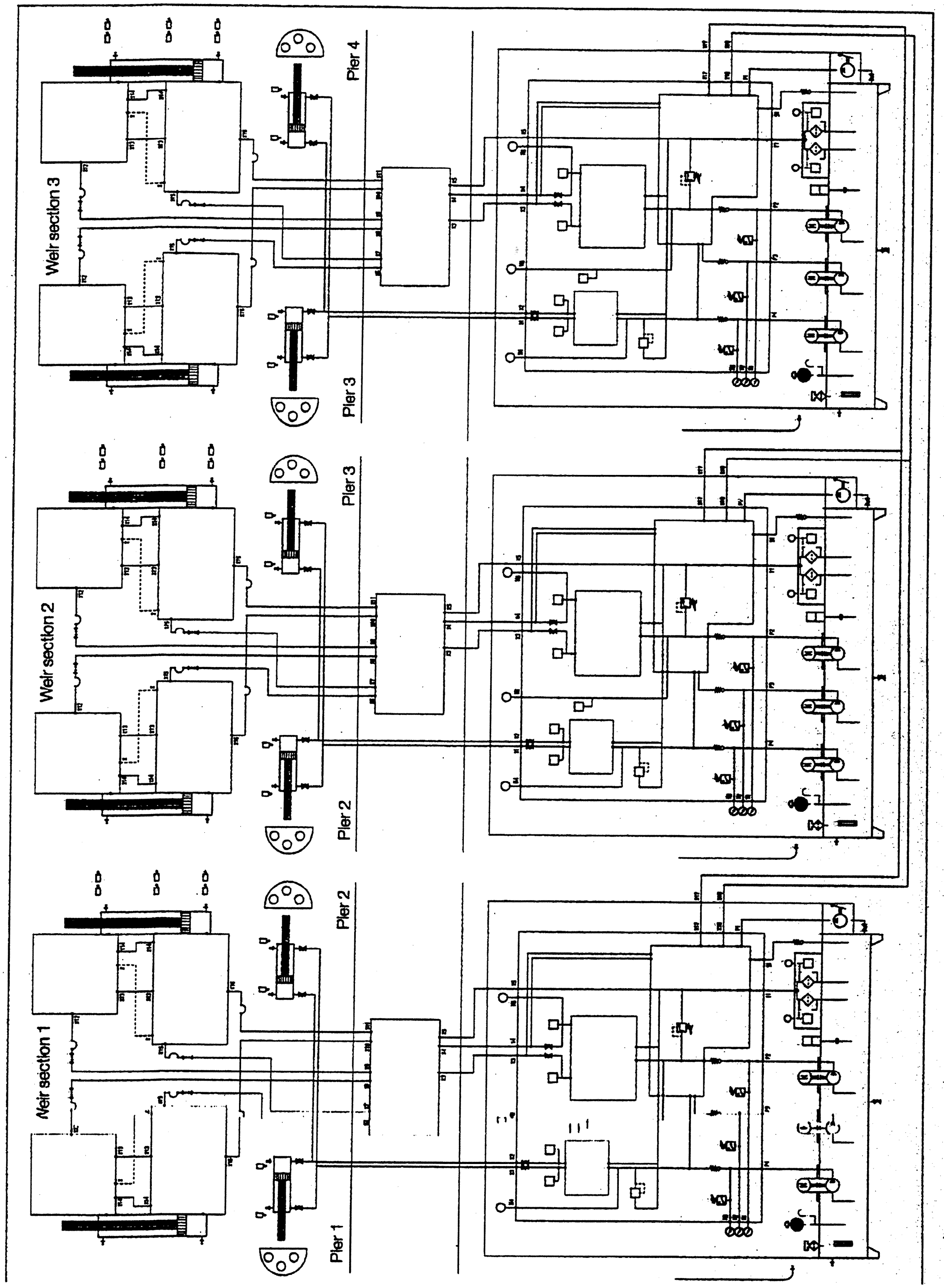

Fig. 6: Block circuit diagram: Drive of weir flaps 1, 2 and 3

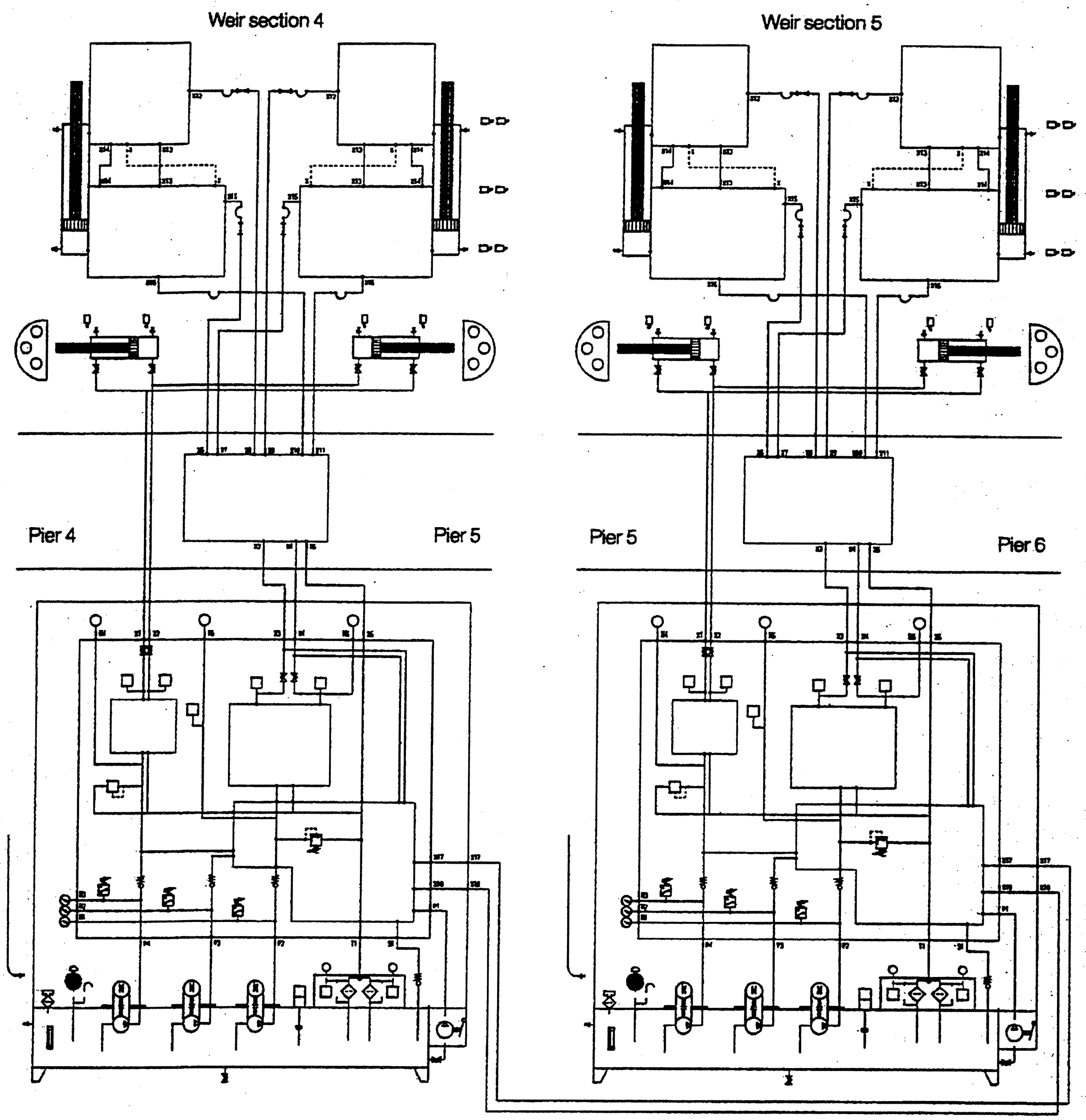

Fig. 7: Block circuit diagram: Drive of weir flaps 4 and 5

Unmanned, Automatic Water Level Regulation

The following requirements can be met by making use of a PLC:

- Unmanned weir
- Automatic headwater-dependent regulation (normal head NN +4,50 m+- 5 cm tolerance)
- Uniform water discharge through all five weir flaps
- Differences of the upper edges to adjacent weir flaps do not exceed +- 10 cm
- Extendable for further tasks if a hydroelectric plant were put into service
- Documentation of process events in the form of daily or status print-outs

The above requirements can be met thanks to a closed loop headwater/flow control (HW/Q control). Moreover, the closed loop control program is able to assume special control tasks, e.g.:

- After a failure of the weir flap (n – 1 case) or during regular maintenance work, the weir control must be able to keep the headwater level constant with the help of the remaining weir flaps

- In the case of increased tides, in which the head at the weir is eliminated, all weir flaps are moved to their lowest position, since a "barrage function" was not provided.

- Manual correction of the command value (Δh = 0 - 30 cm) for immediate improvement of navigational conditions. The conditions described here are stored as a program in the operating plans to be adhered to.

The weir control was designed as a so-called closed loop headwater/flow control. The closed control loop consists of a flow controller with a superimposed water level controller. The headwater controller responds to water level changes in the head. The time span between a flap movement and the measurable change in the water level depends on the storage capacity of the head (retention time). The headwater controller can therefore only react relatively slowly.

The dynamic control behavior of the flow controller is faster than that of the higher level headwater controller. The water flow is derived from the weir flap height, which is measured electrically. The relationship between flap height and water flow was determined in the form of a characteristic curve in hydraulic model tests carried out by the Federal Office for Civil Engineering – Department Coast – in Hamburg. This characteristics curve is stored in the control as a polygonal line. When inflow and outflow variations occur, the flow controller emits the adjustment commands to the weir flaps. The weir flaps are then carefully directed to their new position. In a stationary status, the water level adjusts to the available command value. The higher level headwater controller monitors variables, which are not registered, e.g. locking procedure, and carries out any required correction.

Increased tailwater levels at the weir further influence the discharge behavior of the weir flaps. The tailwater influence may be eliminated by a major flap adjustment.

In the case of increased headwater volumes (ca. 500 m3/s), an additional level (at Dreye) 7 km upstream of the weir is also taken into account for the water level control. If the limit water levels are exceeded here, the normal head at the weir is lowered to a level within given limits.

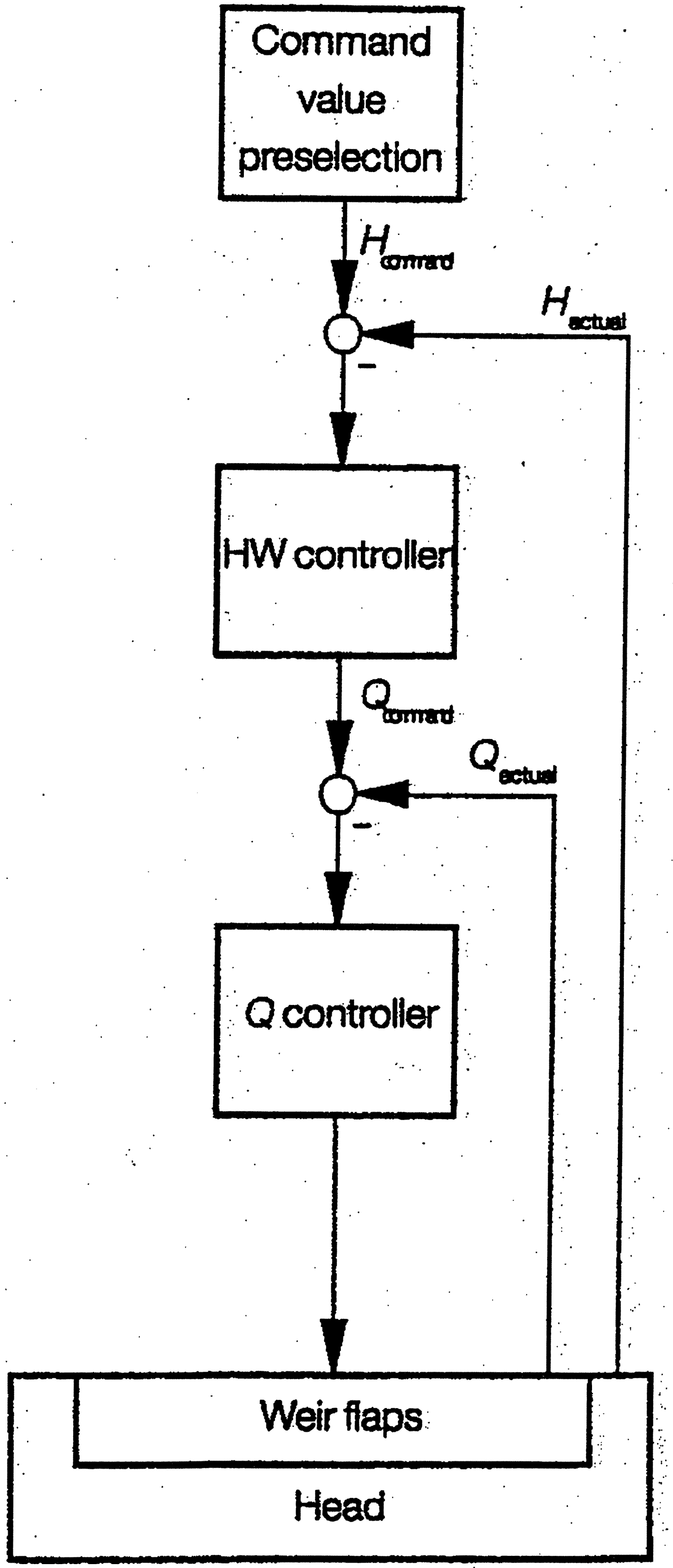

Fig. 8: Closed loop headwater / flow control

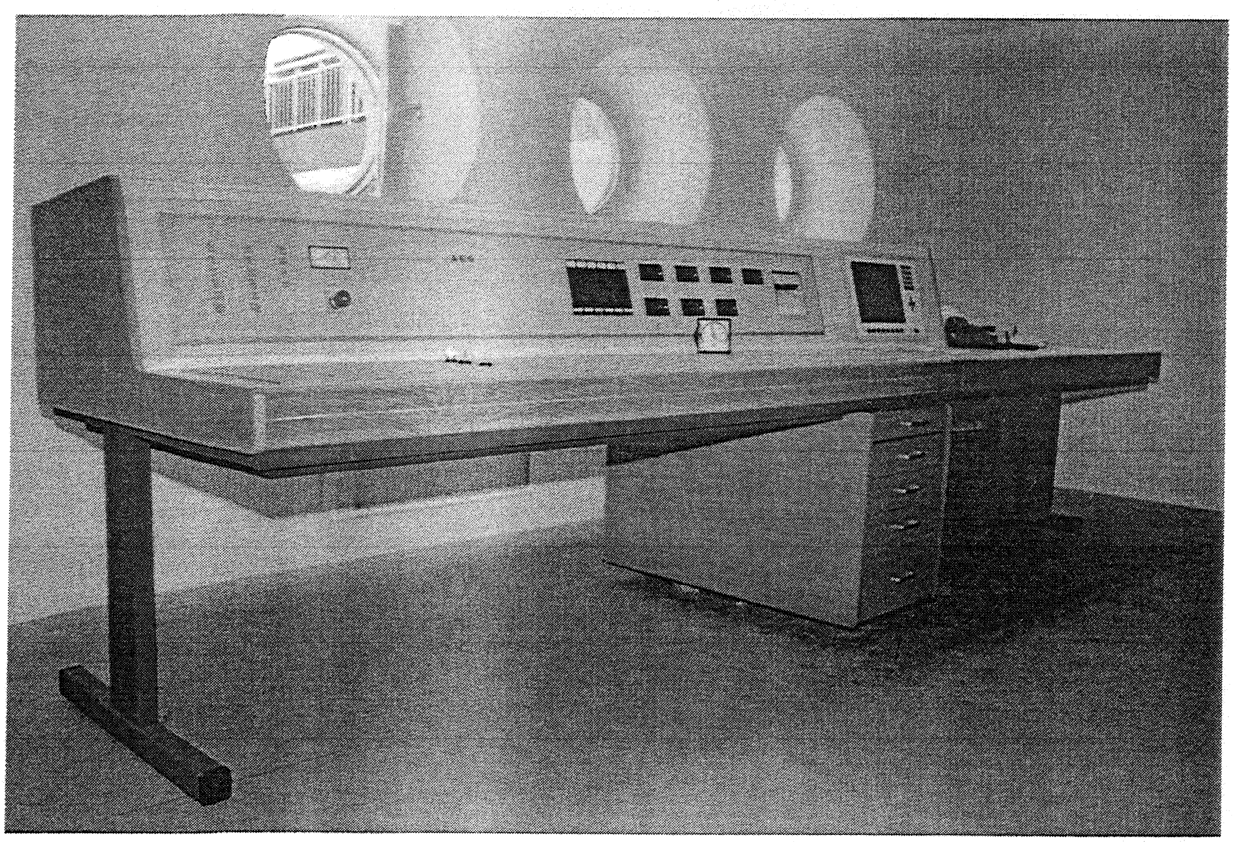

Fig. 9: Central control stand

The operating program for the weir control is located in the central control in the left pier of the Bremen Weser weir. PLCs, which are subordinate to the closed loop control (master/slave principle), are available in the relevant weir sections for the five hydraulic weir flap drives. These PLCs emit control commands to the hydraulic drives.

A data bus line (length approximately 300 m) enables a process data exchange between the central control and the five local controls for control commands and operating and fault messages. Individual flaps can be excluded from the automatic control and operated manually from a control panel at the left pier, e.g. for maintenance purposes. All fault messages and process data are documented and printed out, and important messages are immediately transmitted to manned departments of the WSA Bremen, e.g. the sluice control stand or the central department. Any measure, if required, will be taken from there.

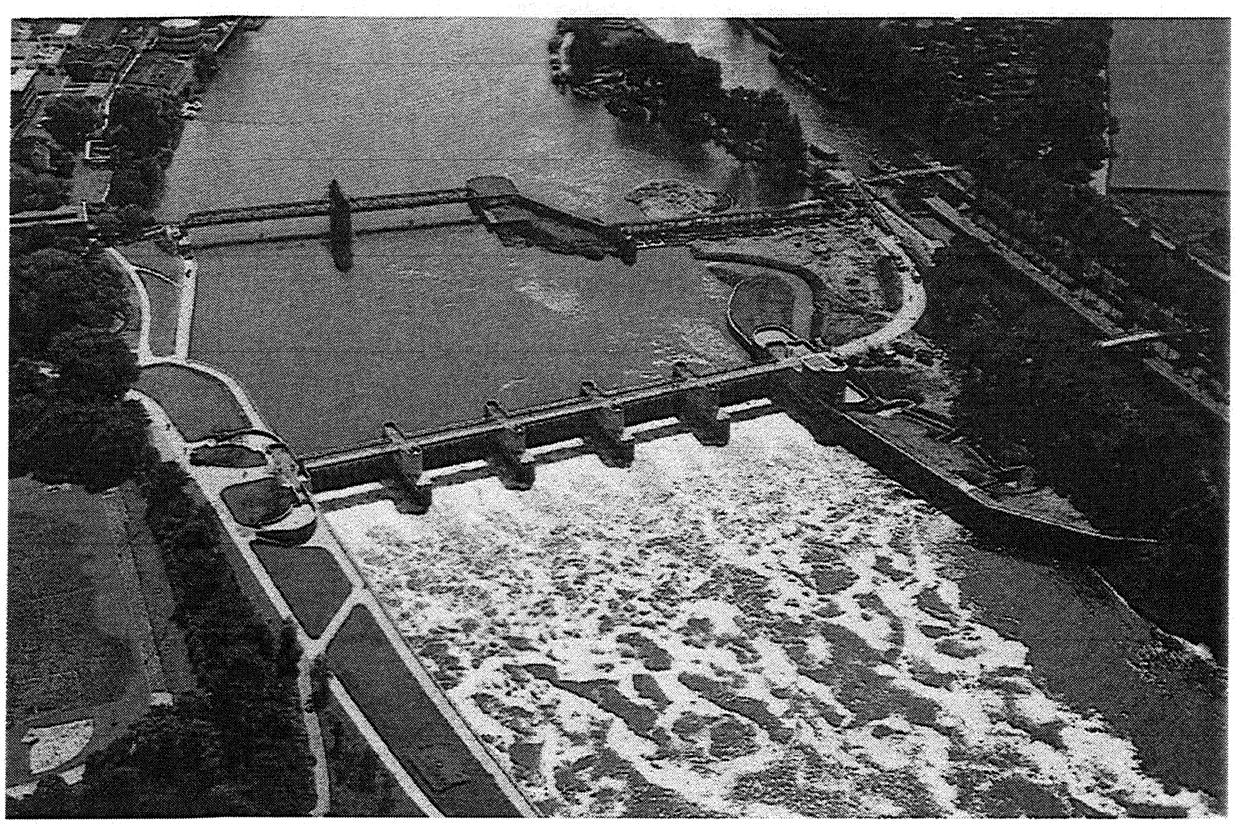

Fig. 10: Power plant with ship lock Bremen

Remote control of locks on the Main River

Automation of bridges, locks and dams in the United States is in progress. Many locations are or are considering repairing or replacing their mechanical equipment. In many cases old mechanical drives are being converted to hydraulics. In most cases the upgrade includes a modern control system with PLCs and computer-based operator consoles. Most of the control systems include a modern control network or two as the communications medium to allow for distributed control architechures and data sharing. The Panama Canal has been converting their miter gate drives to hydraulics including PLC based control systems. Their control desks in the control rooms are being converted to PLC-based controls. Computer-based Operator Consoles will eventually replace these desks. Fiber optic cables link the control desks with the individual machines' PLCs for control. However, for the most part the 'automation' of a facility has been limited to local control. The facility is still operated by an operator located at the site.

Automation of locks and dams has been progressing in Germany for many years. However, for the last six years 'automation' has expanded to also include remote control. Several sites are in operation while several sites are in the planning stages. In an effort to reduce operating manpower and extend the capabilities of the skilled workforce they have undertaken the automation of their locks and extended it to remote control of locks from locations kilometers away. I would like to describe one site that has been designed, installed and placed in operation and one site that is in the planning stages to show how the Germans have expanded the scope of automation to remote control and how even the scope of the remote control has expanded.

The first automation and remote control project that will be discussed is the remote control of the Himmelstadt lock on the Main (Mine in English) River. The control room of the lock at Harrbach serves as the operating station for its own lock as well as the lock at Himmelstadt. The two locks are located approximately 16 kilometers from each other and can not be seen from the other. Both locks are single chamber and, as are most locks in Germany, are hydraulically operated; both the gates and the valves

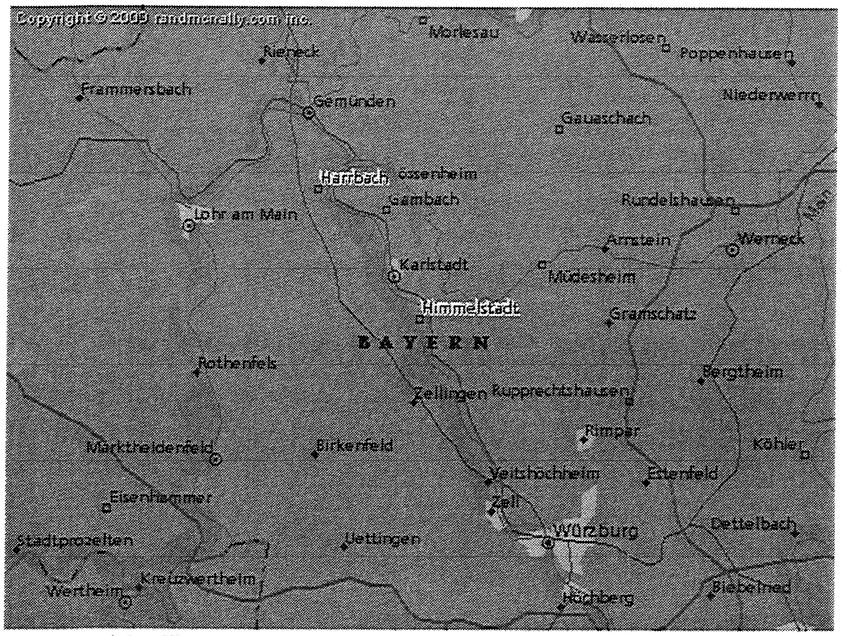

Figure 11 - Harrbach and Himmelstadt locks

In 1994 a working group for "lock automation" was setup by the Federal Minister for Traffic. It consisted of operational and technical specialists, members of local agencies and lawyers. They analyzed all functions and activities of lock operations including typical accidents. Their conclusion was that the automation of locks is feasible from technical, safety and legal points of view. The economic justification was:

- Remote control can make night navigation economically feasible on some waterways.
- The differential cost between the operating cost and the income from navigation can be improved.
- Calculations by the Ministry show a theoretical long-term savings potential of 40% in today's dollars.

It was decided that any lock maintenance or improvement project must be made with consideration for the future automation and remote control equipment at the selected locks. The drives for all of the equipment, doors, valves, etc., must be adapted to remote control. The heart of the remote control system is a programmable controller.

Figure 12 - Harrbach lock viewed from lower gates

Locks in the District of Water and Navigation South have only been repaired in the last few years with remote control operation in mind. The locks at Steinbach and Himmelstadt have been prepared to be controlled from Harrbach. Himmelstadt was revamped in the summer of 1999. It presently is controlled by the operator at the lock at Harrbach.

After a successful trial period of controlling the lock at Himmelstadt from Harrbach the nearby locks of Steinbach and Rothenfels will be added in a second step. Harrbach was the most convenient place to start the automation.

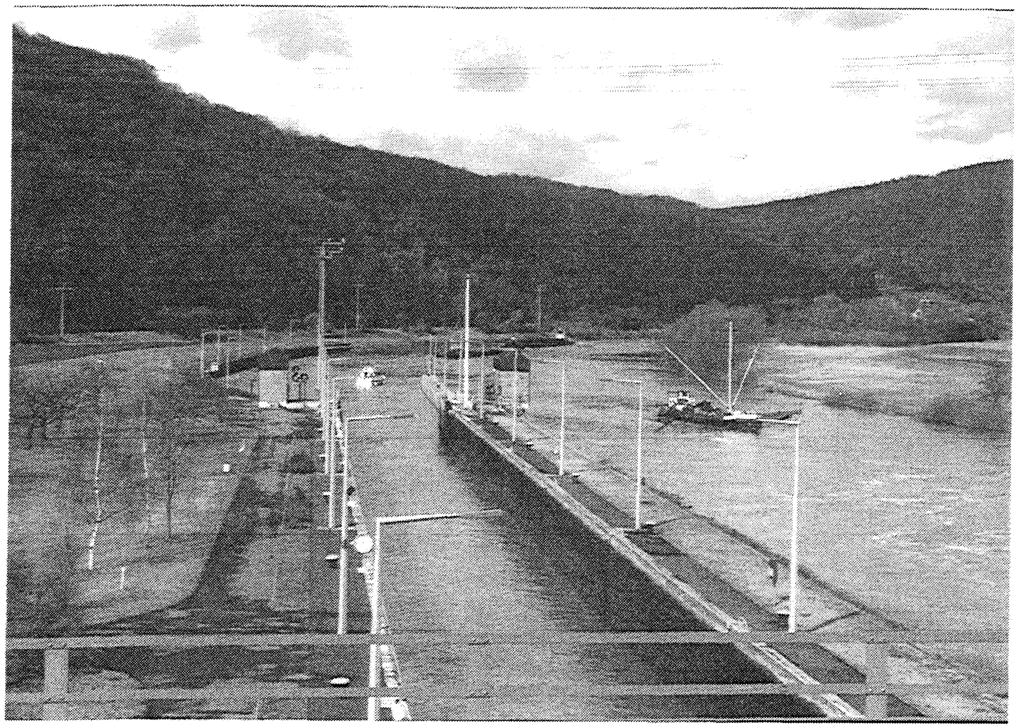

Figure 13 - Downstream gates of Harrbach lock

Remote systems

In order to control a lock from another lock one must have control of all of the services necessary to operate the lock. Control signals as well as audio and pictures must be transmitted from the remote lock to central station.

For the operation of the locks on the Main River the following communications systems also had to be serviced:

- Public Telephones
- KOM Telephones
- PA System
- Nautical Information radio
- Television monitoring
- Water Level Display

For obvious economic reasons it was desired that the existing long distance communications lines which are owned and operated by the WSD, refered to as the KOM network, be used. However, only a small number of wires within the cables are available in this network, parts of which are sixty years old. Because of this it was decided to use digital signal transmission methods.

In 1999, four PCM30 communications circuits were installed between the locks and WSD's Wurtzburg office building. The number of circuits was limited by the number of cables available in the KOM cables. PCM30 equipment allows 30 channels of 64Kbits/sec data streams to be transmitted on two pair of cables at 2Mbits/sec. The four circuits allow for 120 channels of data.

Existing underground cables were used. A multiplexer allows these channels to be used as desired.

The communications circuits to the locks were utilized as follows:

- Telephones in the public network and in the KOM network WSV

  The locks at Rothenfels and Himmelstadt are connected by a common TK/KOM system. The system has connections to both the public network and to the KOM network of the WSV. The telephones at the remaining locks are switched as needed over PCM30 channels.

- Public Address systems

  The control room at the Himmelstadt lock has a PA system for the use in the operation of the lock. When in remote operation all of its functions are duplicated over the PCM30 system. Two PCM30 channels are required for its operation.

- Nautical information radio (NIF)

  The NIF serves, among other things, as communications between lock operating personnel and the vessels. This system, made by AEG, was established in 1995 and established one system for communications. It consists of the transceiver, a duplex switch, UPS and the antenna. Normally it is operated from the control desk in Himmelstadt. In remote operation its functions are also duplicated on the desk in Harrbach.

  All signals were sent through one channel of the PCM30 multiplexer.

- Television monitoring system

  The television system is used to replace the operator's eyes. It's implementation has three major aspects, the placement of the equipment, the selection of the equipment and the transmission of the data.

Camera placement -
Placement of the television cameras was done with consideration of the 299.5m length and 12.00m width of the lock chambers. The following camera placements allowed for continuous monitoring of the critical areas with 18m high masts. Lower and upper approach areas, the chamber and the gate areas are monitored.

Camera assembly	place observation area	focal length
K1 on 18 m-mast at the lower gate	lower approach area	6,5 — 78mm
K2 on 18 m-mast at the lower gate	Lower gate operating area, impact protection chamber allocation marking	4,8 mm
K3 on 18 m-mast at the lower gate	upper chamber of lock	6,5 — 78 mm
K4 on the crossover	upper approach area	6,5 — 78 mm
K5 on 18 m-mast at the upper gate (installs in 8 mm height)	lower chamber of a lock; Entry area UH road bridge	6,5 — 78 mm
K6 on 18 m-mast at the lower gate	Upper gate operating area Allocation marking	4,8 mm

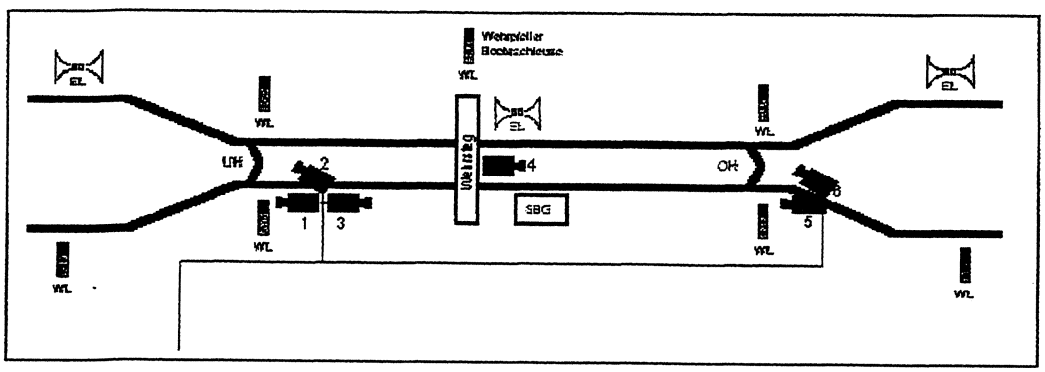

Abb. 1: Kamera-Montageorte

Figure 14 - Camera placement

From the crossover it was not possible to avoid the appearance of moving in opposite directions caused by cameras K3 and K4 as these are installed with the same viewing direction.

At the lock at Himmelstadt six weatherproof color television cameras with remote controlled heads. Four 13.8 TFT LCD displays are used. Because the Himmelstadt lock is constantly filled the two monitors that are used to view the upper and lower chambers are not installed.

At Harrbach the camera locations and objectives are identical except that the cameras at the lower and upper gates, K2 and K6, do not have remote control. The control desk at Harrbach also has six monitors.

Selection of equipment —

The color television cameras consist of CCD Image Converters, with bit mapped memory for improved luminous sensitivity with half image integration. The cameras are remote controlled by an RS-485 interface. All camera controls are adjustable and accessible from the control desk.

From experience gained at other locks it is very desirable to have swiveling control of the TV cameras. Despite the many advantages the CCD Image Converter has over other sensors it has two disadvantages, the Smaear effect and black light behavior. These effects appear in very low light situations as white vertical stripes which emanate from clearance lights or hatch covers from ships. Also reflections of the sun off of the water surface lead to large white marks on the entire display. Electronics alone can not eliminate these but the swiveling of the cameras can.

The selection of the flat displays has unique criteria. The background lighting s distribution determined the required brightness and picture-viewing angle. By trial and error it was determined that the background illumination distribution should amount to at least 200 cd/m^2 to ensure the naturalness and the uniformity of the color reproduction.

Data Transmission -

The video signals from the cameras at Himmelstadt require a special digital converter for transmission over the PCM30 system due to their large bandwidth. The graphic signals are digitized and compressed by the CODEC. The CODEC can be adjusted to provide a signal from 64Kb/sec to 2Mb/sec. The signals are multiplexed and transmitted to Harrbach. The data transmission rate can be adjusted from 64Kb/sec to 512 Kb/sec depending on the desired image quality. One PCM30 channel is needed for each 64Kb/sec of data. At Harrbach the digital signals are demultiplexed and restored to their original levels and displayed on the monitors. Control of the cameras, swiveling, tilt and zoom, is done in a similar fashion.

TV image quality strongly depends on the data transmission rate. Experimentation was done with different transmission rates in order to optimize image quality. Considering the transfer capacity of the PCM30 system the following recommendations were given:

Minimum requirements
- Middle and distant observations (approach areas) 256Kb/sec / 4 PCM30 channels are required for each camera
- Close range (gates) 384Kb/sec / 6 PCM30 channels are required for each camera

Average viewing
- Distant observations (approach areas): 256Kb/sec / 4 PCM30 channels are required for each camera
- Middle observations (chambers): 384Kb/sec / 6 PCM30 channels are required for each camera
- Distant observations (approach areas): 512Kb/sec / 8 PCM30 channels are required for each camera

Optimal picture quality
- All areas: 512Kb/sec. / 8 PCM30 channels are required for each camera

A further increase in transmission rates did not result in any noticeable improvement in image quality.

- Level display

The upper water, lower water and chamber water levels are available at Himmelstadt and are transmitted to Harrbach s PLC for use in the lock control.

Control Process

The control system for each lock is PLC-based. All of the functions of the lock are controlled by the PLCs. The PLC s at each lock communicate via Ethernet, 10BaseT, via the multiplexer. This requires 128Kb/sec / 2 PCM30 channels.

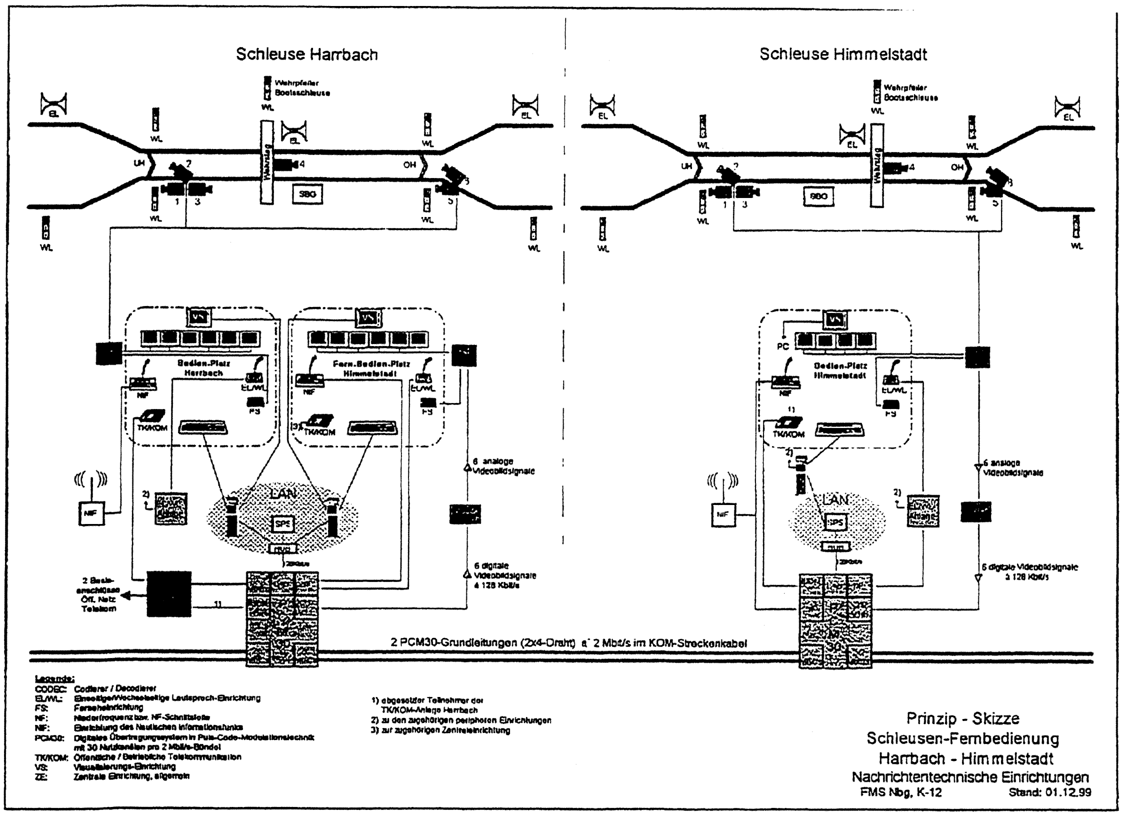

Abb. 2 : Fernübertragungsprinzip Himmelstadt - Harrbach

Figure 15 - Network layout

Operating Stations

Harrbach s control room was designed for two operators consoles each operating two locks (Himmelstadt/Harrbach and Steinbach/Rothenfels). Each console has six TV monitors and a control CRT for the two locks. The trial installation, however, is limited to only the remote control of Himmelstadt from Harrbach.

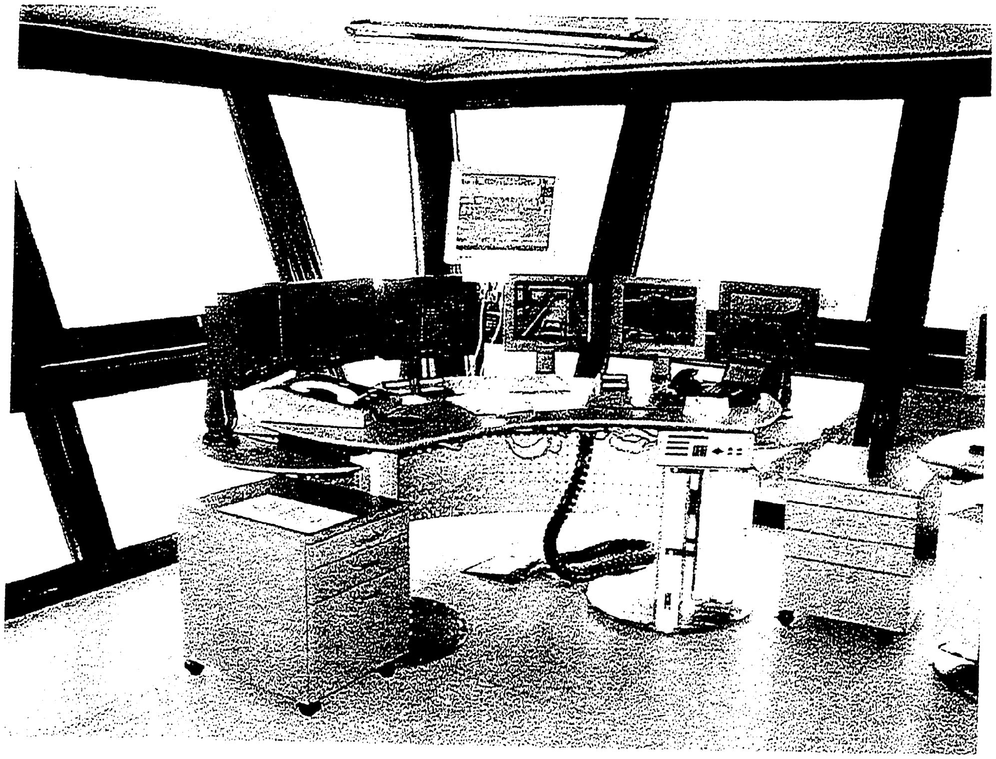

Abb. 4 : Bedienstand in Harrbach (Tisch in Sitzposition)

Figure 12 - Control Desk at Harrbach

It is intended that in day operation there are two operators, one for Steinbach and Rothenfels and one for Himmelstadt and Harrbach. In night operation one operator will handle all four locks. Each control console has six TV monitors and one display for operations. All operation is done with a track ball or mouse. The keyboard is only required for maintenance.

The picture monitors are arranged such that a lockage can be viewed as from the actual control room. Monitors are arranged from left to right views. The controls for each lock are also arranged in an identical manner at each lock to prevent mistakes by the operators.

Communications channels are also automatically switched when the control console is switched from the control of one lock to the other.

Remote control of locks on the Neckar River

The remote control of the locks on the upper Neckar River around Stuttgart in southwestern Germany is in the planning stages. The concept at present exists in draft form. The WSA s Engineering Southwest in Koblenz has prepared this draft in co-operation with WSA-Stuttgart. WSA-Stuttgart will be the future operator of these locks.

Locks from Heilbronn in the north to Deizisau in the south will be automated and connected to three remote central control centers.

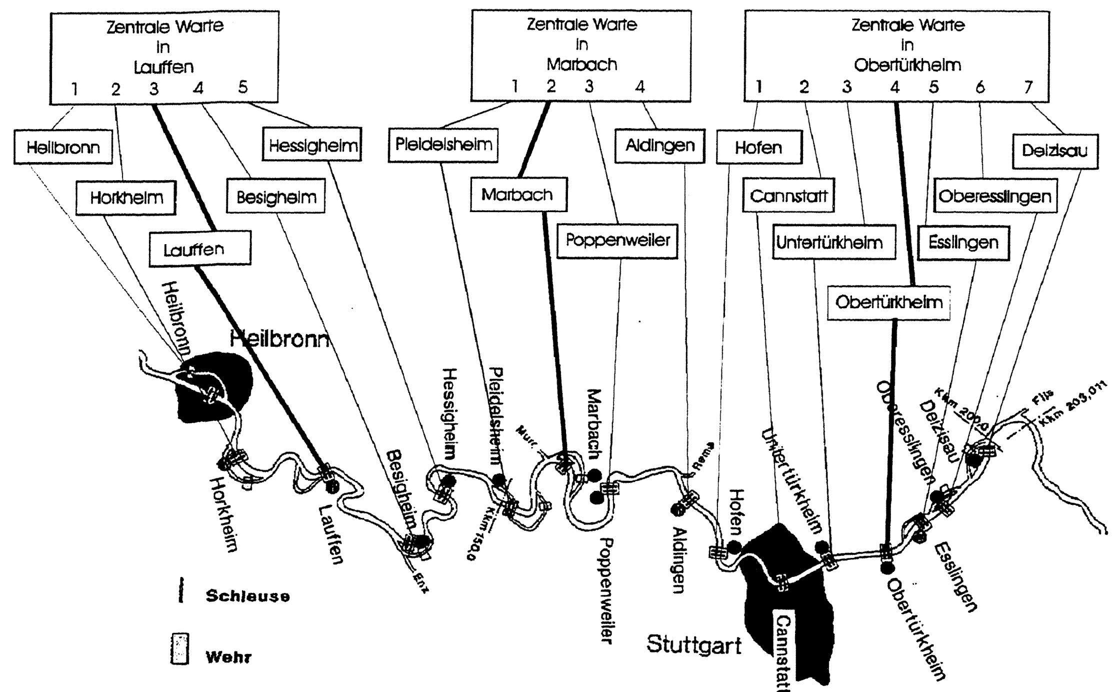

Figure 17 - Overview of Neckar locks

Overall a total of 16 locks with 29 chambers are involved. The first step includes seven locks.

The proposed schedule is

<u>Obert rkheim (1999 - 2002)</u>
Hofen, Untert rkheim, Cannstatt, Obert rkheim, Esslingen, Oberesslingen, Deizisau
<u>Marbach (2002 - 2005)</u>
Pleidelsheim, Marbach, Poppenweiler, Aldingen
<u>Lauffen (2006 - 2008)</u>
Heilbronn, Horkheim, Lauffen, Besigheim, Hessigheim

Design Criteria —

Based on the standards of the work group for the automation of locks, studies of the existing locks and controls and interviews with many operating personal the following standards were developed:

- The video monitors are arranged in a row above the visual display unit, (lower water level on the left to upper water level on the right).

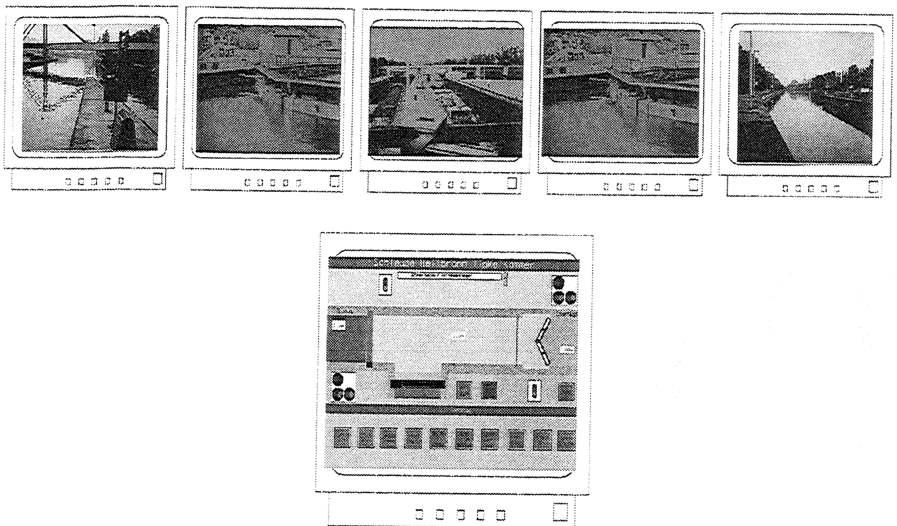

Figure 18 - Desired display layout

- One operator s station includes two lock control centers with all of the necessary controls including:
  - Data networks
  - Telephones
  - NIF radio
  - WS

- The remote control station at Obert rkheim must be able to perform six simultaneous lockages.

- Three operator s stations are required.

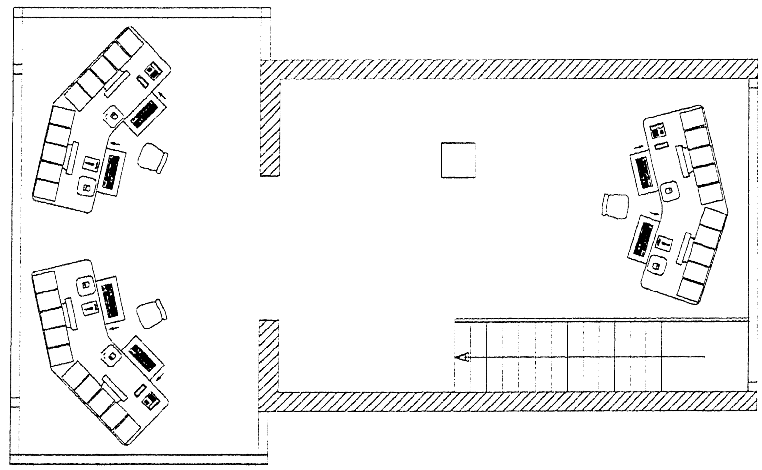

Figure 19 - Proposed console arrangement

Up to this point the design criteria has been very similar to the Main River locks. However, now the design considerations change partial due to physical constraints, not enough cables, and partial due to the avialability of newer technologies.

Data Transmission -

The important consideration, however, is the transmission of data. It was desired to use WF cable as was done at Harrbach/Himmelstadt. This, however, did not allow for the implementation of a proper network with redundant data paths.

The technology available is different on either side of the control center. Towards Deizisau a LWL (fiber optic cable) is available while toward Hofen only a standard copper telecommunications cable is available. In this cable only six pairs are available. If PCM-30 equipment is used then a data volume of 6Mb/sec is available.

The following list presents an idea of the type and volume of data transmitted between the central control station and the locks.

1 Chamber lock	**2 Chamber lock**
5 Video channels at 128 Kbit/s	10 Video channels at 128 Kbit/s
1 Control channel at 64 Kbit/s	2 Control channel at 64 Kbit/s
1 Security Video at 128 Kbit/s	1 Security Video at 128 Kbit/s
$\sum$ 7 Channels, 896 Kbit/s	$\sum$ 13 Channels, 1536 Kbit/s

The majority of the data is video data. Implementing a network based on the PCM-30 technology resulted in an unacceptably high use of resources (cables).

An IP based data network with dynamic bandwidth management offers a solution to the problem.

Time Multiplexed System | **IP-Network (Passport)**

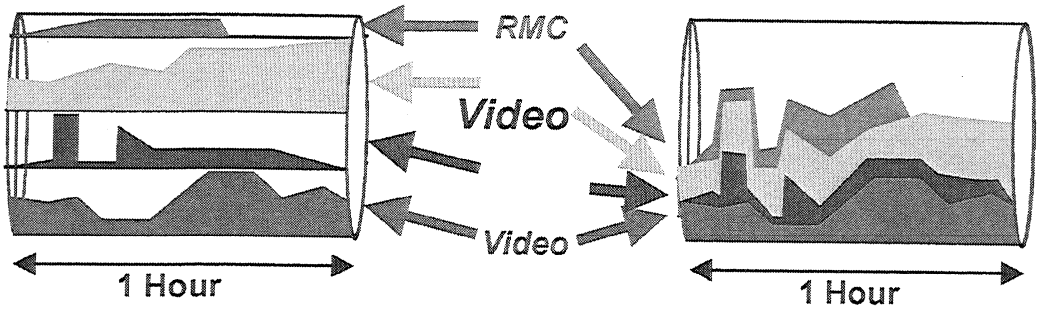

Figure 3 - Time multiplexed vs. IP Network

The left hand side shows a channel oriented system based on time multiplexers, such as the PCM-30. Each data source is allocated a channel with a defined bandwidth. This channel is reserved purely for this data source. This leads to a waste in transmission capacity as a low data flow still uses the entire bandwidth of the channel.

With dynamic bandwidth management in a planned IP network the data is split into blocks, identified, and then transmitted using an available channel. At the receiving end the data blocks are re-combined according to their ID and passed on to the recipient.

With this system there is now bandwidth available for the application.

Control System -

The control systems at each lock are still PLC-based each with their own local data networks. However, the Operator s Control Stations are no longer *dedicated* to control an individual lock. The new system is built on the *client-server* architecture. The control system is implemented on multiple computers. The major advantage to this system is that the required tasks to do have to run in one computer. These tasks are distributed over the entire network and run on different computers. A display client for lock X can be run on a computer anywhere in the system. Should one component fail a bumpless transfer to another computer is also possible. This system shows five tasks running independent of each other. Each of these tasks performs a specific function:

- The I/O server provides connection between the PLCs and the MMI system. Its task is to accumulate the data (I/O) and make it available to the other tasks.
- The Trend Server is to archive data and to display them as required.
- The Report Server periodically generates reports on the actual condition of the system and its components. It is not required for operation.
- The Alarm Server recognizes faults and unacceptable conditions.
- The Display Client is the actual process display.

In the beginning of the nineties a revolutionary new system was inroduced. The system is based on sensing serration's in the piston rod located just beneath the Ceramax layer. The sensor is located in the cylinder head just outside the pressurized area. It is fully protected from the environment and readably accessible. This implies that in case of service the sensor can be replaced without disassembly of the cylinder and thus guaranteeing the availability of the Ro-Ro. The CIMS system can be applied to all type of cylinders and is independent of length. As the accuracy lies within 1 millimeter it is an excellent input signal for a synchronization system. The only draw back to this system is that it is not absolute. This means that in case of power failure the position might be lost requiring manual reset of the system. Normally using a battery back up solves this problem, which however does not solve the problem in case of cable rupture.
Rexroth Hydraudyne recognized this draw back and is currently in the final stage of developing a new generation of this Ceramax Integrated measuring system. It is expected that in the beginning of 2001 an absolute CIMS system will be commercially available to the market.

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