RADIO CONTROLS FOR GATED PIPE IRRIGATION SYSTEMS

BY

HAROLD RICHARD BLUME

B. S., Kansas State University, 1976

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

Approved by:

Harry L. Manges

Major Professor

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INTRODUCTION

There is increasing usage of water by domestic, industrial, recreational, and agricultural users in the United States. This increase in water usage has caused a decrease in the undeveloped water supplies. As irrigation is one of the low efficiency users of water, there needs to be a way to increase its efficiency so as to make better use of the available water.

Reasons for the inefficient use of water in surface irrigation systems has been the high cost for labor, the lack of good labor, and the inexpensive plentiful water supplies of the past few decades. Farmers are reluctant to use additional labor just to conserve water. Rather, farmers adjust water application time to labor patterns dictated by general farm operations, rather than crop needs. Twelve-hour and 24-hour sets used by many farmers often result in excessive percolation and runoff losses, particularly where soils are coarse textured and intake rates are high. Excessive use of water usually leads to drainage and salinity problems that are costly to alleviate.

Some reduction in labor for surface irrigation has been accomplished in the last two decades by the increased use of siphon tubes, gated pipe, lined ditches, and improved structures. However, well-trained labor is still required to operate most of these systems effectively. Further reduction of labor is needed. Automatic operation of properly designed irrigation systems can eliminate most of the labor connected with irrigation and at the same time insure high irrigation efficiencies.

Sprinkler irrigation has led the way in automating irrigation systems with the sophisticated solid set and self-propelled sprinkler systems where labor requirements are minimal.

Development of automated surface irrigation systems has lagged behind sprinkler systems because of the difficulties involved in converting irrigation water control structures to remotely operated devices. Also, surface irrigation automation has not been used on a large scale because of the lack of economical equipment and design criteria to satisfy the practical requirements of an automatic system.

Furrow irrigation systems are more difficult to automate than border and other surface flooding systems and therefore have received less attention in automatic irrigation development. Gated pipe is extensively used in surface irrigation and has a number of advantages for delivering and controlling irrigation water to furrows. Progress has been made in automation of gated pipe systems over the last few years, but a better automated system is needed to reduce labor and increase irrigation efficiencies.

REVIEW OF LITERATURE

Automation of surface irrigation began back in the 1950's with the use of time clocks to activate motor-control equipment to start pumping plants. Also, at a preset time, time clocks would energize electric or hydraulic-control valves to turn on or shut off water in ditches or pipelines (Pair, 1961).

Haise, Kruse and Dimick (1965) developed a pneumatic valve that was the first big step in the automating of gated pipe irrigation systems. The automated system consisted of (1) a pneumatic valve or closure, (2) 3-way solenoid control valve that permitted the flow of air into or out of the pneumatic valve, (3) a source of air pressure to inflate the valve, and (4) a centrally located remote control system with timing device to actuate the 3-way solenoid control valve by means of a signal transmitted by radio or carried by wire.

The pneumatic valve was an inflatable rubber O-ring mounted in an alfalfa valve between the alfalfa valve seat and the alfalfa valve lid. Alfalfa valves were mounted on top of risers and controlled water coming out of the riser from an underground pipe. Air supplied by a buried plastic tube was used to inflate the pneumatic valve which closed the alfalfa valve and shut off the flow of water from the riser.

Haise and Kruse (1966) tested two remote control systems in the field using the pneumatic valve. System 1 was a radio transmitter. The time clock was programmed for different time intervals and activated a 12-channel citizen's band transmitter at the end of each interval. Three watts of power were radiated from the transmitter on a frequency of 27.235 MHz. Twelve receivers were used, with each receiver tuned to a different transmitter channel, to receive the signal from the transmitter and activate a momentarily energized latching relay air control valve. Power for the equipment was 110 volt AC for the programmer-time clock and transmitter, with 12 volt DC and 67.5 volt DC battery packs for the receiver and solenoid valve, respectively. Radio signals were transmitted over .5 miles to operate the solenoid valves.

System 2 used wires to send the signal to the solenoid valve. An industrial timer and switching relays were used in place of the time clock and transmitter. One common wire and one wire for each of the solenoids was required. The same type of solenoid air valves and latching relays were used with the wires as with the radio signal. This system did not use batteries because all power came from a central location. A plastic enclosed cable of three wires, inside the buried plastic air line, provided the current needed to operate solenoids at distances up to 1.5 miles.

Both systems used tone telemetry components consisting of encoders and decoders and both have been tested successfully in the field.

Haise and Kruse (1966) contend that multifrequency signals transmitted by a pair of wires appear to offer the most practical method of control, because radio control requires a license and when operated in a contiguous block of irrigated farms could conceivably result in unintentional operation of valves on an adjacent farm.

In the spring of 1966, two separate but similar pipe distribution systems were automated with the Haise et. al. (1965) pneumatic valves at Wiggins, Colorado and at Mead, Nebraska (Haise and Fischbach, 1970). Both systems used gated pipe to deliver the water to the furrows and the gated pipe was connected to a hydrant which was placed over the alfalfa and pneumatic valves.

The principal difficulties in operating the Wiggins and Mead systems were initially associated with the activation of the 2-way pilot valve using tone telemetry transmitted by wire. At Mead, a small drop in voltage from the main power source caused the telemetry system to change sets. The transmitter was redesigned for the Wiggins system, but difficulties in keeping oscillators properly adjusted to activate the tone receivers resulted in automatic shut-downs when all pneumatic valves closed.

An automated surface irrigation valve was developed and used at Mead, Nebraska (Fischbach and Goodding, 1971). This valve sat directly over the riser without using an alfalfa valve. A rubber diaphragm was located inside the valve and was between the pipe that attached to the riser and another small piece of pipe. When the diaphragm was inflated with air, the pipe from the riser was sealed off and all water flowing from the riser was stopped.

The controls for the Fischbach valve (Fischbach, Thompson and Stetson, 1970) consisted of, a controller, wires from the controller to each valve, an air line from each valve to an air compressor, a 3-way solenoid air valve, and a surface irrigation valve to control the water from the riser. The controller started the irrigation, controlled the irrigation time for each set, sequenced the irrigation water from one set to the next, and shut the system off. Tensiometers placed in the field would sense the need to irrigate and would turn the controller and pump on. A reuse pit was also used and the reuse pump was hooked into the controller to be operated when desired.

Haise and Payne (1972) developed a diaphragm pipe valve which was similar to the other surface irrigation valves mentioned, except the pipe valve used water from the pipeline instead of air to inflate the diaphragm. The advantage of the pipe valve was that it could be used in remote places where electric power was not available.

Humphreys and Stacey (1975) used the idea of Haise and Payne (1972) to use water from the pipeline to inflate a diaphragm in a valve and made further modifications. The Humphreys and Stacey valve consisted of a diaphragm mounted in a housing that was placed directly in a pipeline. Water came into the valve and flowed around the diaphragm, and out the other side. To inflate the diaphragm, water was brought in through a pitot tube, mounted on the upstream side of the valve, through a

3-way pilot valve and into the diaphragm which inflated and stopped the flow of water. To allow the water to flow again through the valve, the 3-way valve was turned to allow the water in the diaphragm to leave and the diaphragm deflated to allow water through the valve. Water velocity closed the valve and water pressure kept it closed.

Controls for the Humphreys and Stacey (1975) automated valve included a 3 volt DC motor to operate the 3-way valve and a 24-hour timer to activate the motor and to time the irrigation. To close the valve after being opened, the motor could be reversed by two different ways. One way was for water to fill a container which closed a switch and reversed the motor. Another way was to have another timer to reverse the motor after a certain time. The motor/3-way valve unit was tested using mechanical timers, electronic timers, and a commercial irrigation controller and could have been used with radio transmitter/receiver units.

Edling, Duke, and Payne (1978) used electronic timers to actuate pneumatic irrigation turnout devices that had been developed (Haise, Kruse, and Dimick, 1965). The timers were run by a crystal controlled clock chip which was very accurate. Current clock time, as well as the desired times to begin and end an irrigation, were entered through a pair of five-digit thumbwheel switches. When the clock reached the preset time for irrigation initiation, a momentary pulse was sent to a 3-way magnetically latching solenoid valve. This valve exhaused the pneumatic actuator to atmosphere through the upper solenoid valve port, and the turnout was forced open by the water pressure beneath. Upon reaching the preset time to end the irrigation, a second pulse of opposite polarity switched the solenoid valve, inflating the pneumatic pillow from an air tank.

Electronic timers were also devised and tested by Fisher, Humpherys, and Worstell (1978) to replace old alarm clock timers. The electronic timers were used in controlling a cutback irrigation system. The time base for the controllers was a crystal oscillator. A control circuit monitored two irrigation valves and determined the position of the valves to see if they were opened or closed. Three banks of thumbwheel switches were used to set the timers.

Another timer-controller was developed for use in a buried lateral distribution system. The system used a matrix of toggle switches and two thumbwheel switches to activate 24 VAC solenoid pilot valves. The time base for the control circuit was the 60 Hz line frequency.

Fisher, Humphreys, and Worstell (1978) used a microprocessor controller for a multiset irrigation system. The controller ran two programs simultaneously, one for semi-automatic and the other for automatic operation. In the semi-automatic mode, the operator programmed the time of day and the duration of irrigation for each valve. At selected times, the controller sequenced the valves. The operator could program only the duration of irrigation in the automatic mode since the time to begin irrigation was determined by two or more moisture sensors calling for irrigation. The automatic program turned on the pump and operated the irrigation valves assigned to it. The valves could be assigned to either type of operation through the keyboard.

Both manual operation of the system and power outages override the execution of both programs. The system could interrogate pipeline pressure sensors or other feedback elements and modify the program execution accordingly.

The primary input device of the controller was a hexadecimal keyboard enabled by a hardware interrupt command. The operator could enter timing information through the keyboard or, with the correct security codes, alter system parameters, such as valves assigned to each program.

Duke, Payne, and Kincaid (1978) developed and tested a controller which used a microprocessor to control the irrigation of a field. The micro-processor measured the amount of water that flowed to the field and was programmed to let a pre-set amount of water through each valve before switching to the next valve. To program the controller, the valve number was entered in through the keyboard along with the amount of water needed for the plot, and the valves were entered in the order that they were to open for irrigation. The desired irrigation program, which could contain as many as 61 turnout addresses, was stored in random-access-memory (RAM) for later reference. All downfield control was accomplished over two wires. An address decoder was installed between the signal and common wires at each downfield turnout control point. A large capacitor was located at each decoder to store energy for switching. When the correct address for a particular turnout came down the wire, a momentary connection of the large capacitor to a 3-way magnetically latching solenoid valve resulted. The solenoid valve then either opened or closed the pneumatic closure device.

Bowman (1969) used a radio control system for control of a border irrigation system. A transmitter was placed at the end of the border and beside the transmitter was a sensor that would activate the transmitter when water reached it. The transmitter used coders, discriminators, and a modulator, while radiating 300mW of power at a frequency of 27 MHz to the receiver. Three different channels on the receiver could be activated by the transmitter and the receiver activated a servo-motor to operate a flood gate to control water. Batteries were used to power all of the equipment.

Fischbach and Somerhalder (1971) claimed that irrigation distribution efficiencies of 92% and irrigation application efficiencies of 92% were obtained with an automated gated pipe irrigation system with a reuse system. These efficiencies were large improvements over conventional surface irrigation system efficiencies and were just as good as sprinkler irrigation efficiencies. The amount of labor required to operate the automated system was very low.

Humpherys and Stacey (1975) stated that the use of automatic irrigation controls may be the most feasible way to achieve better on-farm water control without increasing labor inputs. It had been shown that the labor requirement for irrigation could be reduced and irrigation efficiencies could be increased using an automated gated pipe irrigation system.

The use of radio controls and irrigation valves inflated by water seem to offer a better type of control system for an automated gated pipe system. A radio control system run by batteries offers a system completely independent of outside power sources and still allows control of the irrigation system without going into the field.

INVESTIGATIONS

Objectives

The objectives of this research were:

1. to control an existing gated pipe irrigation system using radio control, and,

2. to evaluate performance of the radio control system.

Previous Work

A small irrigation project had been carried out during the summers of 1977 and 1978 on the Herschel Webber farm of Sublette, Kansas. The project was sponsored by the Southwest Kansas Groundwater Management District No. 3 at Garden City, Kansas, and the Kansas Agricultural Experiment Station at Kansas State University. Irrigation equipment was loaned by Hastings Irrigation Pipe Co., Inc. of Hastings, Nebraska, for use on the project.

Objectives of the project were to irrigate with gated pipe controlled by flow control valves, and to test different types of irrigation practices. The flow control valves were similar to the valve developed by Humphreys and Stacey (1975). Hastings Irrigation Pipe Co., Inc. manufactured the flow control valves which used water to inflate the diaphragm.

The flow control valve consisted of 8-inch aluminum pipe on each side of a bell shaped cast aluminum housing containing a diaphragm. Access to the diaphragm was gained by unbolting and taking the valve apart in the middle. Connectors on the 8-inch pipe allowed connecting to gated pipe. Water flowed into the flow control valve, hit the diaphragm, flowed around it, and out the other end. The diaphragm was held in place by a cast aluminum plate connected to the valve body at four places. The 8-inch pipe upstream from the diaphragm protruded into the bell shaped housing a few inches. That allowed the diaphragm, when expanded, to seal off the water coming through the pipe. Water to inflate the diaphragm was obtained from the water flowing through the valve.

A pitot tube in the upstream section of the 8-inch pipe directed some water through a ½-inch ID plastic pipe to a 3-way brass valve located on the outside of the flow control valve. The water passed through the 3-way valve, into the flow control valve, and to the diaphragm. The pitot tube, 3-way valve, and inlet to the diaphragm were located on the side of the flow control valve. Water was directed into and out of the diaphragm by turning the 3-way valve. When the 3-way valve was in the open position, water passed into the diaphragm which expanded against the aluminum pipe and shut off flow through the flow control valve. In the closed position, the 3-way valve shut off the water flowing to the diaphragm and vented the diaphragm to atmosphere. This caused the diaphragm to collapse from the pressure in front on it. The water was then able to flow through the flow control valve.

The field that was irrigated consisted of 47.75 acres with 1/2 and 1/4 mile long rows. In the summer of 1978 only 35.75 acres were irrigated as 12 acres of the poorest short rows were not planted. The soil was mostly Richfield silt loam and Richfield and Ulysses complexes, where level benches had been located, with some Randall clay at the lower end of the short rows. The field had been regraded to a .3% slope, the benches were eliminated and a tailwater pit was build below the short rows. Water for the field was supplied by the tailwater pit and was pumped to the upper end of the field through underground pipeline.

The same basic irrigation system was used both summers with the test plots being different. The irrigation system consisted of 10-inch gated pipe connected to a riser and layed along the upper end of the field. A flowmeter, to measure the amount of water applied, was placed in the pipeline at the riser. Inline tees directed the water from the 10-inch pipe through the flow control valves to 8-inch gated pipe which delivered the water to the field. A Parshall flume measured runoff from some of the test plots.

The flow control valves were in the developmental stage and no automatic controls had been developed to activate them. In the tests that were run, the valves were activated by manually turning the 3-way valves. Considerably less labor was needed to turn the 3-way valves, to change the water from one set to the next, than to open and close a number of slide gates. Only a few seconds were required to turn on one 3-way valve and turn off another 3-way valve. It took one to five minutes for the valves to open and from three to ten minutes to close, depending on the water velocity and pressure.

The only operational problem with the valves was that sometimes when the water was changed from one set to another set, the valve that was turned off would not close completely. The reason was insufficient water flow through the valve and the valve that would not close was always upstream from the point where water was being used. The upstream valve did not have sufficient velocity of flow through it to force water into the pitot tube, through the 3-way valve and into the diaphragm. A moderate rate of flow was needed to shut the valve and exert sufficient pressure to keep the valve shut.

The problem could have been avoided by having smaller pipelines, larger flows in the existing pipeline, or some type of reservoir to fill the diaphragm when the 3-way valve was in the off position. The overall operation of the flow control valves was good and they could be used in any automated gated pipe irrigation system with the proper controls.

The irrigation tests that were run were:

1. 24 hour irrigation sets versus shorter irrigation sets,
2. Small furrow streams versus large furrow streams,
3. Conventional irrigation versus cut-back irrigation.

Results of the irrigation tests showed that the 24-hour irrigation sets (control plots) yielded more bushels per acre of corn than the shorter irrigation sets (test plots), but the shorter sets yielded more bushels per inch of water applied (Table 1). There was no difference in runoff between the small furrow streams and the large furrow streams. Also, there was no difference in runoff between conventional irrigation and cut-back irrigation. Overall, the results were not conclusive and more tests were needed to properly evaluate the irrigation treatments.

Table 1. Results of Summer 1977 Irrigation Tests.

Plot	Area (ac.)	Time of Irrigation Season (hr.)	Time of Irrigation Per Irrigation (hr.)	Water Applied Season (in.)	Water Applied Per Irrigation (in.)	Yield (bu./ac.)	Yield (bu./ac./in)
Control 1A	7.16	70.5	23.5	20.28	6.76	100	4.93
Control 1B	7.16	76.2	25.4	26.71	8.90	100	3.74
Test Plot A	7.16	48.5	16.2	13.40	4.47	93	6.74
Test Plot B	8.95	66.0	22.0	14.21	4.74	90	6.33
Control 2A	5.97	72.0	24.0	22.20	7.40	107.5	4.84
Control 1B	5.37	72.0	24.0	25.11	8.37	107.5	4.28
Test Plot C	5.97	52.0	17.3	16.09	5.36	85	5.28

Initial System Design

Permission was obtained from Mr. Webber to irrigate a 160 acre field using a radio control system. Funding was provided by the Department of Energy of the United States Government and the Kansas Agricultural Experiment Station.

The radio control irrigation system consisted of the existing gated pipe irrigation system plus radio control equipment (Figure 1). The existing gated pipe system included a well, underground pipeline, riser, and gated pipe. The well was located at the southwest corner of the field and was connected to a .5 mile long, 14" diameter concrete underground pipeline, which ran along the west or upper end of the field.

Connected to the underground pipeline through risers was .5 mile of 10 inch aluminum gated pipe which diverted the water to furrows in the field. Ten risers were located across the field but the gated pipe had been connected to only two of the risers during the past irrigation seasons. A flowmeter at the well measured the amount of water pumped. All runoff from the .5 mile long field was diverted to a tailwater pit and used to irrigate other fields.

The radio control equipment included radio transmitters, receivers, servos, controllers, batteries, and solar panels. Three-way valves and flow control valves connected the

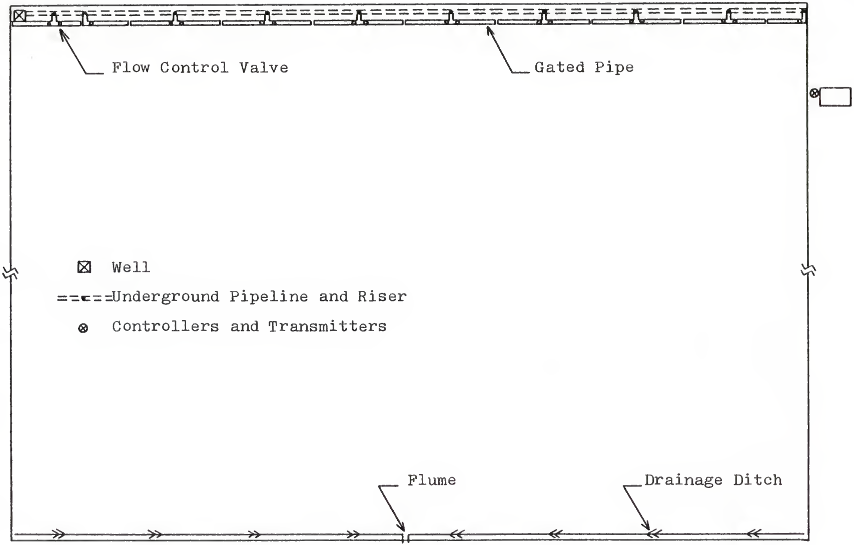

Figure 1. Gated Pipe System and Radio Control Equipment.

existing gated pipe system with the radio control equipment.

Radio Controls

The most important component of the radio control system was the transmitter. A Heathkit Model GDA-1205-D 8 Channel Digital Proportional Radio Control Transmitter from Heath Company, Benton Harbor, Michigan was selected for the system (Figure 2). The signal sent out by the transmitter was in digital form. Digital signals have an advantage over regular radio signals in that several different devices can be operated separately on the same radio frequency. Up to eight different devices could be operated at the same time with the Heathkit transmitter. Several frequencies were available for use by the transmitter and frequency changes could be made with the use of plug-in frequency modules. The frequency used for the radio control system was in the 72 MHz frequency band and was selected to keep away from interference caused by Citizen's Band radio and Amateur or Ham radio. Power radiated by the transmitter was 500 mW while it drew 100 mA. The power supply provided by Heath Company for the transmitter was an internal 9.6 volt DC 500 mAH Ni-Cad battery that could be recharged. However, the battery could not be recharged while the transmitter was operating, so a fully charged battery would run the transmitter for only 5 hours. As the transmitter had to be on continuously during an irrigation of the field, a separate power supply was required.

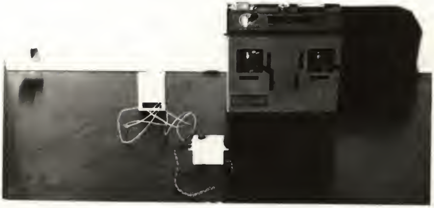

Figure 2. Transmitter, Receiver and Servo for the Radio Control System.

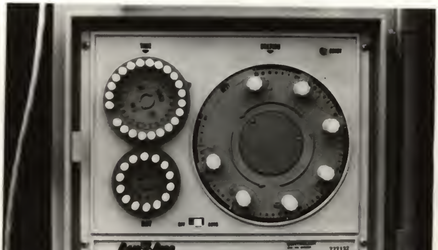

Figure 3. Front View of Controllers Showing Timers.

The separate power supply transformed 120 volt AC to 13.5 volt DC. Diodes and capacitors were used to drop the voltage to the 9.6 volt DC needed at the transmitter. The transmitters were rewired to bypass the on-off switch and allow the batteries to charge continuously while the transmitter was on. The battery charger that came with the transmitter was not modified and used because the charger could not charge the battery as fast as the battery discharged.

The transmitter could not change channels by itself so some type of external means was needed to do this. Also, a timer was needed to control the length of time that each channel was on. Both of these were accomplished by using a Model AG-7 Automatic Controller from Rain Bird Corp, Glendora, California (Figure 3). The controller controlled up to 7 stations when used by itself and up to 6 stations when two or more controllers were connected in series. A timer was available for each of the stations and could be set for up to 24 hours. Also on the controller was a time clock which turned the station timers on and could start an electric pump. Power requirement was 120 volt AC.

In order for the controller to operate the transmitter, wires were run from the controls at each channel in the transmitter to an external connector jack. Also, wires were run in the controller from the stations to an external plug. The transmitter was connected to the controller by plugging the connector plug into the connector jack. The resistance at each of the channels in the transmitters was changed to set the digital signal from each channel to a long pulse. Resistance in the form of resistors was added to each station in the controllers to shorten the length of the digital pulse for the channel being used.

The signal from the transmitter, as purchased from Heath Company, was sent out with a telescopic whip antenna that collapsed into the transmitter case. Preliminary tests run at the University showed that the whip antenna did not send the signal a sufficient distance. The whip antenna transmitted a sufficiently strong signal 0.2 mile but signal transmission up to 0.5 mile was needed. Instead of boosting the power radiated by the transmitter, a larger antenna was used. A channel 2-13 VHF antenna was able to send the digital signal 0.4 mile but a channel 4 VHF, model 1544, Channel Master Challenger could send the signal more than 0.5 mile. In order for the transmitters to use external antennas the trainer button was removed and replaced with an external antenna jack. Coaxial cable was used to get the signal from the external jack to the external antenna.

Another vital part of the radio system was the receiver. The receiver used for the system was a Heathkit Model GDA-1205-2 8-Channel Modular R/C Receiver (Figure 2). Power consumption was 10mA and the receiver had to be on the same frequency as the transmitter in order to receive any of the signals being sent. Frequency of the receiver was controlled by plug-in frequency modules that could be changed quickly. The receiver required 4.8 volt DC to operate.

A servo was used to change the radio signal to useful mechanical output. Servos are devices which use motors and electrical feedback to control the position of a lever arm or wheel. The servos used in the radio control system were Heathkit Model GDA-1205-8 High Torque Digital Proportional Servos (Figure 2). Power consumption for the servo was 20 mA when idle, 1000 mA when stalled, and 150 mA when turning with no load. Power needed to operate the servo was 4.8 volt DC.

The signal that was sent out by the transmitter through the transmitter antenna was a pulse modulated crystal-controlled RF (Radio Frequency) carrier that permitted remote control of 8 separate devices when the transmitter was used with a digital receiver and servos. A radio wave was sent out that had a frame of 9 pulses that was repeated every 25,000 microseconds (μsec) in a continuous train. Each pulse in the frame was 350 μsec wide and the time interval between the first pulse and the next pulse in the frame was 1500 μsec. The time interval between any 2 successive pulses within a frame could be increased or decreased as much as 500 μsec. It was this variable width between individual pulses that was used to position the servos. One of these variable segments was used to control each servo.

The receiver circuits received, amplified, and detected the RF carrier to reproduce the pulse modulation wave-form.

The pulses were then shaped for proper triggering of the decoder circuits that control the servo units. The first pulse started a new pulse frame and began passing a pulse to the channel 1 servo. The time interval between the start of the first and the start of the second trigger pulse determined the length of the pulse that was sent to the channel 1 servo for positioning.

The decoder passed the second pulse to the channel 2 servo, and the next pulse to the channel 3 servo, etc. Therefore, each servo received one pulse from each frame, or one pulse every 25,000 μsec (.025 sec.), and the length of the pulse determined the position of the servo.

A 4.8 volt DC, 500 mAH Ni-Cad battery was supplied with the radio control equipment to power the receiver and servo. The battery could run the receiver and servo only 16 or 10 hours depending on whether one or two servos were used. A larger battery was found that could power the equipment for more than a week. The battery was a Ni-Cad storage battery with a rating of 14 AH and was manufactured by the Sonotone Corp. of Elmsford, New York. (Figure 4).

Even though the battery could run the receiver and servo for more than a week, this was considerably shorter than the two to three month irrigation season. An AC powered battery charger to recharge the batteries was not feasible because the receiver and servos were located in the field. The answer to the problem was a silicon solar panel. Solar panels, Model

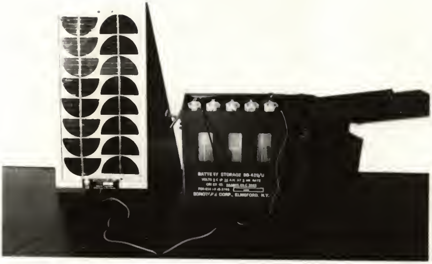

Figure 4. Ni-Cad Battery Used to Power the Receiver and Servos and Solar Panel for Recharging the Battery.

Figure 5. Ten Inch Flow Control Valve.

615-D manufactured by the Solarex Corp., Rockville, Maryland, and rated at 6 volt DC and 300 mA output, were selected (Figure 4). Calculations showed that a solar panel would have sufficient capacity to run the equipment in the daylight and recharge what was used during the night.

Flow Control Valves

Flow through the gated pipe was controlled by flow control valves of a design similar to the valves used during the summers of 1977 and 1978. The valves were manufactured by Hastings Irrigation Pipe Co., Inc. (Figure 5). The new valves had 10 inch pipe instead of 8 inch and had a small reservoir which stored water that was used to help inflate the diaphragm. The reservoir was located between the inlet pitot tube and the diaphragm and was refilled while water flowed through the flow control valve to the field. An aluminum box was mounted on the valve to house servos and batteries. The pitot tube, 3-way valve, and inlet to the diaphragm were located on top of the valve.

The 3-way pilot valve was part of the flow control valve and connected the irrigation equipment with the radio control equipment. Water was directed into and out of the diaphragm in the flow control valve using the 3-way valve. A brass 3-way valve had been used on the 8-inch valves, but the servo could not turn it. A slide valve was made in the Agricultural Engineering Shops out of aluminum and teflon. The 3-way slide valve uses the same principles as a high pressure hydraulic valve, but was low pressure as the fittings were not as tight. The valve was made from an aluminum block (2.5" x 2.0" x 1.2") with a .75 inch hole drilled most of the way through the center of it. Three .25 inch holes were drilled in the block for the inlets and outlets; one hole was at the end of the .75 inch hole with the other two holes on each side of the .75 inch hole.

A .75 inch teflon rod, 2 inches long, was used to direct the water to the proper holes in the aluminum block. The teflon rod was trimmed down to leave 4 washer-like protrusions, which seal against the water moving the wrong way, and a handle to connect with the servo. In between the center 2 washers, a .25 inch hole was drilled half way into the rod, and another .25 inch hole was drilled in from the end opposite the handle to meet the first hole in the middle of the teflon rod.

With the rod in the aluminum block placed in the down position, the water flows in through the bottom side hole of the block, into the rod, and then out the end of the rod and block. Moving the rod .50 inch to the up position causes the water to flow back up through the end of the block and rod, through the rod and out the top side hole of the block.

The 3-way valve was mounted to the bottom of the aluminum box on the flow control valve (Figure 6). A small wire was connected to the handle at the teflon rod and to the arm on the servo. The movement of the servo arm caused the teflon rod to move up and down.

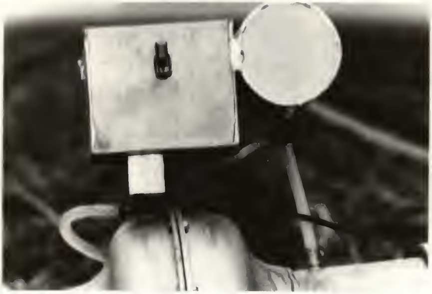

Figure 6. Three Way Slide Valve Mounted at Base of Flow Control Valve Box.

Figure 7. Plywood Box Housing the Controllers and Transmitters.

System Layout

The field was divided into 18 sets to be irrigated separately. To irrigate the field 18 flow control valves and 18 segments of gated pipe were used. Eighteen 3-way valves and servos directed flow through the flow control valves. Ten receivers, one at each riser, operated the servos. The 18 flow control valves were controlled by 3 transmitters, each on a different frequency, and 3 controllers. Each transmitter was connected to a different controller and the controllers were wired in series to operate as one large controller.

The transmitters and controllers required 120 v AC power and the nearest AC outlet was at a metal building north of the field. Plans were made to use a different antenna for each transmitter. A channel 4 TV antenna for the furtherest receivers, a channel 2-13 TV antenna for the middle distance receivers, and a whip antenna, supplied with the transmitters, for the closest receivers. As the transmitters were being placed at the building, it was found that the transmitter with the whip antenna was able to send a strong signal to the south side of the field. As the two external antennas were very bulky, they were discarded and whip antennas were reinstalled on all transmitters. The whip antennas were used for all field tests of the radio control system.

Transmitters and controllers were mounted in a plywood box installed on two pipes driven into the ground on the south side of the building (Figure 7). The controllers were mounted to the back of the box and the transmitters were mounted one on each side of the box and one in the middle. The transmitters were mounted upside down so their antennas, which were longer than the box, would extend through the bottom. This arrangement reduced the chance of moisture entering the box and damaging the electronic equipment. Theoretically the antennas should have been located one wavelength apart (4 meters) to lessen interference between signals from the different transmitters. The actual distance between transmitters was 1.5 feet but tests showed that, although there was interference, it was not enough to hinder the signals being sent to the receivers. The power supply for the transmitters sat on top of one of the controllers (Figure 8).

Electrical power was delivered to the box by an electrical cord that was plugged into an electrical outlet inside the building. A four receptacle electrical outlet was installed in the box to plug the controllers and power supply into (Figure 9).

Gated pipe was layed out starting on the south side of the field (Figure 10). Hydrants were placed on the risers with end tees and flow control valves connected to the hydrants (Figure 11). Short segments of gated pipe were connected to the flow control valves (Figure 12). Irrigation soks, to

Figure 8. Inside View of Plywood Box Showing the Controllers, Transmitters, Power Supply and Electrical Outlet.

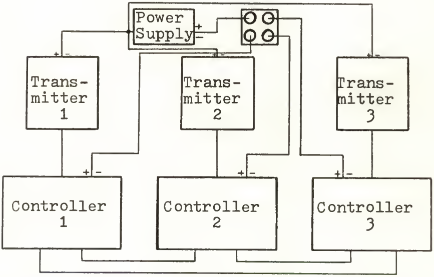

Figure 9. Schematic of Wiring for Controllers, Transmitters, and Power Supply.

Figure 10. Gated Pipe Layed Out on the Upper End of the Field.

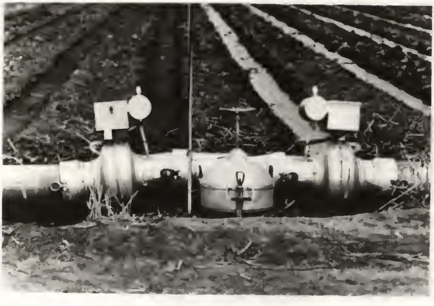

Figure 11. Hydrant Mounted on a Riser and Connected to Two Flow Control Valves.

Figure 12. Segment of Gated Pipe Connected to a Flow Control Valve with Soks in Place.

Figure 13. Receiver Mounted under Bracket Supporting the Solar Panel.

hold down on erosion at the gates, were placed on the gated pipe. The gates in the gated pipe were opened to a predetermined setting at installation of the pipe and remained open all the time. One riser was missing from the field because it had been damaged and removed. To irrigate the sets at the missing riser, a feeder line of 10-inch gated pipe was attached to an adjacent riser and ran along the edge of the field. Inline tees placed in the feeder line branched the water off into 3 8-inch flow control valves and 8-inch gated pipe for these sets. The aluminum boxes and reservoirs were taken off the unused 10-inch flow control valves and mounted on the 8-inch valves. Slight modifications were needed to make the reservoirs work. Seven risers watered two sets, one riser watered three sets and one riser watered one set.

Before being placed in the field all of the receivers, servos, solar panels, wiring cords, and batteries were tested. One servo developed a short circuit during testing. No cause for the short circuit was found. Each servo had to be matched to a selected channel in the transmitters. The controls in the transmitters were adjusted so the servos were normally in the off position. The resistance in the controllers also was matched to the servos to give 180° rotation of the servo arm. Once the servos are matched to a given servo, they must be used at the same place in the field for the entire irrigation season.

Transmitter 1 (72.320 MHz) and transmitter 2 (72.960 MHz) operated properly and their servos were matched and properly positioned. However, transmitter 3 (72.160 MHz) did not respond properly and it was sent to Manhattan for repairs. An extra receiver and 3 servos were sent along to check out the transmitter. The problem with transmitter 3 was a burned out transistor, but it was not fixed and returned until the field tests were about completed.

Ten receivers, 10 solar panels, 15 servos, 10 batteries, and 16 3-way valves were placed in the field to start the test. The remaining 3-way valves were installed during the test as they were assembled. Three servos were moved around to test all of the receivers and irrigate all of the sets.

The receivers were mounted under a bracket on top of 10 foot long poles (Figure 13). This placed the receiver antenna high enough to receive the radio signals. The original wire receiver antennas were discarded and replaced with sturdy aluminum rods which were mounted to the side of the bracket. Solar panels were on top of the brackets, tilted at a 20°-25° angle, and faced south (Figure 14). The poles were placed beside the risers and held in place by sliding them inside a larger diameter 2 foot long pipe that had been driven into the ground. The solar panels were 8 feet above the ground and the top of the receiver antennas were 11 feet above the ground.

All of the receiver modules were tuned for maximum signal

Figure 14. Solar Panel Mounted on a Bracket Supported by a Pole 8 Feet above Ground.

Figure 15. Inside of Flow Control Valve Box Showing the Servo and Ni-Cad Battery.

strength at the furtherest receiver. The maximum signal strength varied from 3.5 to 4.5 where the scale was from 0 to 5.0 with 5 being the strongest. A signal strength of 3.0 was required to operate a servo.

At risers with two flow control valves, the battery and one servo was placed in the box of one flow control valve and only a servo was in the box of the other flow control valve (Figure 15). A battery and a servo were in the box of the flow control valve at the risers with only one valve.

A four wire cord was used to run power from the solar panel to the battery and also to run control wires from the receiver to the servos (Figure 16). The servos and receivers were powered by the batteries which were recharged by solar panels. A switch on the receiver allowed it to be turned on and off. A three wire cord ran from the battery in one box to the servo in the other box. It carried power and the signal from the receiver.

The 3-way valves which were mounted on the bottom side of the aluminum box were connected to the servos with a small wire rod (Figure 17). Connections to the pitot tube and diaphragm were through plastic hoses.

A safety device was installed to prevent damage to the underground pipeline if the radio control equipment failed and all the flow control valves closed. The device was placed at the first riser on set 2 and consisted of a long plastic hose connected with a tee to the hose going from the 3-way valve to

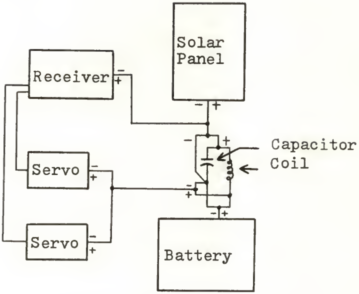

Figure 16. Schematic of Wiring for the Solar Panel, Receiver, Battery and Servos.

Figure 17. Three Way Slide Valve Mounted on a Flow Control Valve Located in the Field.

the diaphragm of the flow control valve. The long hose was held up by a clamp on the solar panel pole that was higher than the normal head at the flow control valve. The hose siphoned the water out of the diaphragm when the head at the flow control valve exceeded the high point of the hose. This drained the diaphragm and allowed water to flow through the flow control valve.

Results of Initial Design Field Tests

The radio controlled gated pipe irrigation system was layed out and used to preirrigate the 160 acre field in the spring of 1979.

Preirrigation of the field started as soon as the gated pipe was layed out. The well at the southwest corner of the field was started and water was delivered to set 1 at the south end of the field. Set 1 was watered 36 hours, but the water advanced only about one-half the length of the furrows. All the other sets were watered only 24 hours because after that the water almost stopped advancing. A few days later the well at the northwest corner of the field was started and water was delivered to set 18 on the north end of the field. The second well was used because there was not sufficient time before corn planting to complete preirrigation with one well. Most of the sets were watered twice before the preirrigation ended.

By the time the receivers, servos, and the other radio control equipment were set up in the field, the preirrigation had been going on for a week. The radio control system was used to make the next change of water. When it became time to change the water, the receiver at riser 4 was turned off and controller 2 was moved to station 2. The receiver was turned back on causing the servo at set 6 to turn off and the servo at set 7 to turn on, thus, changing the water. This procedure was followed because the controller was not ready to change when the time came and the servos had to be watched closely. No problems developed in the changing of water from set 6 to set 7. The radio control system was left on during the day and everything but the controllers were turned off at night. The controllers were left on to run their timers. The transmitter that was used for the switching was transmitter 2.

During the daytime while the radio system was operating, one thing that was very noticeable was the chattering of the servos. The further the servo was from the transmitter, the more it would chatter (move back and forth). It was determined that the servos were too sensitive and at long distances, the transmitted signal was not exact. This caused the servos to move around trying to match the signal. The chatter caused excessive wear on the servos and a large drain on the batteries. In order to alleviate the chatter on the most affected servos, timers were installed on the five furtherest receivers. The timers controlled the power to the receivers and turned them off for 20 seconds, on for 2 seconds, off for 20 seconds, etc. By turning off the receivers, no signal went to the servos and they stopped chattering.

The water was changed from set 8 to set 9 by again shutting off the receiver and moving the controller. When the receiver switch was turned on there was a 20 second wait for the timer to turn on the receiver. The water changed sets with no problems.

Using two wells to irrigate the field caused some difficulties. The north half of the field had its sets changed manually going north to south. It had been planned to change all sets south to north and the radio control system was set up that way. A part of the north half could have been changed to allow the radio control equipment to run it, but it would have involved running two controllers at the same time and it was simpler to change the north sets manually.

When set 9 had been irrigated, the water from the southwest well was changed back to set 1. This was done manually. The radio control system was now ready to change the water on the entire south half of the field.

During the day while set 1 was being watered, a small thunderstorm passed over the field causing some gusty winds, a little rain, and some lightning. During the storm the controllers, transmitters, and servos were on but the receivers were turned off. After the storm had passed it was noticed that set 2 had been turned on. While changing the water on the north half of the field it was also noticed that a servo at one set being changed was turned around to the off position and was trying to turn further. The control arm of the servo was against a plastic stop which caused the motor in the servo to stall. Up to 1 amp of current was being drawn by the servo from the battery, causing the servo to overheat. The receivers and transmitters were not controlling the servos. To keep the servos from being damaged further, all of the servos were immediately disconnected from their power supply.

The servos were checked to determine how many were damaged and what was wrong with them. In the initial check, 7 of the 15 servos were found to be damaged. The 7 damaged servos all acted the same with the motor running in one direction and not stopping. Nothing appeared physically wrong with the servos. However, tests showed that the integrated circuit and one transistor were not functioning properly.

Only one of the receivers was damaged having its channel 4 output burned out. No solar panels, batteries, wiring cords, transmitters, nor controllers were damaged by the thunderstorm.

The cause for the damage to the servos was either static electricity or the flash from lightning which caused a voltage surge at the solar panels to travel to the batteries and servos. The lightning flash was the most logical answer. There was no particular pattern to which servos were damaged and which were not damaged. All three radio frequencies had damaged servos. Some of the receivers had both servos damaged, some receivers had one servo damaged, and some receivers had no servo damaged.

Also, the position on the field did not matter as servos were damaged all across the field.

After set 1 had been watered for 12 hours of its second irrigation the number of gates that were open were decreased from 30 to 20. Number of gates per set were reduced because water was not getting to the end of the furrows and more water was needed per furrow. All of the sets for the second irrigation were reduced to 20 gates with the number of sets increased to 26. The smaller sets caused problems in that the flow control valves could not control 20 furrow sets. The sets had to be changed by opening and closing slide gates. Since some of the servos were damaged and inoperative, irrigation of the field was continued without the radio control system.

A few days after the servos had been damaged, the north well shut down for the third time since preirrigation started. The water was still not making it through on most of the furrows but time was becoming a factor in preirrigation of the field as planting time was approaching. As the root zone was at about three-fourths of field capacity irrigation was discontinued.

After the preirrigation had been stopped, additional tests were run with the radio control equipment. Six servos, each located at a different receiver, were placed across the field and the radio control equipment was turned on with the controllers positioned on rest. Three servos received signals sent by transmitter 1, two servos received signals sent by transmitter 3, and the remaining servo was not sent a signal. Transmitter 2 was not in use because it had been removed to help conduct tests on the damaged servos.

The six servos were on for six days in which time the weather was fair except for one small thunderstorm on the last day. The storm did not damage any of the servos which had survived the first storm. However, another servo, which had not been in the field before, stalled in the off position like the damaged servos. The batteries at two of the servos had discharged completely because of the excessive current drain caused by chattering servos. The other four batteries which had timers on their receivers, to turn off the servos, were fully charged. The timers help extend the life of the batteries, but it was hard to tell if the servos were working because they received their signals for a very short length of time. The transmitters, controllers, receivers, and solar panels were still operating properly.

The aluminum-teflon 3-way valves worked fine during the preirrigation in directing water from the reservoir to the diaphragm and from the diaphragm to the atmosphere. Water moved through the 3-way valves rapidly with little head loss. There was some problem in transporting air from the diaphragm through the 3-way valve to the reservoir for release by a relief valve to the atmosphere. On some flow control valves, the 3-way valves had to be opened and closed to allow the air to be released through the exhaust port of the 3-way valve and allow water to fill the diaphragm. Most of the trouble with air occurred when the flow control valves were being closed for the first time.

Leakage from the 3-way valves was of some concern. The leakage did not affect the performance of the flow control valves but it was a nuisance. Leaks were caused by nicks in the teflon washers that occurred during manufacture and assembly. Under pressure the water seeped through the nicks. About half of the aluminum-teflon valves leaked water at a faster than acceptable rate.

Temperature also affected the 3-way valves. Cold temperatures caused the valves to be loose and leak excessively. Hot temperatures caused the valves to be tight and the servos could not move them.

The safety device did not work properly and was not used during the preirrigation. The long hose could not be placed high enough to get above the normal operating head and the water overtopped the hose. A siphon was created and drained the water out of the diaphragm and the flow control valves opened. When the siphon was broken the diaphragm filled back up with water and closed the valve which caused the head to go up and overtop the hose again. The high head was the result of having two wells pumping into the same underground pipeline and having the safety device located beside a well. A taller pole to hold the hose would have been necessary to allow the safety device to function properly.

All of the 10 inch flow control valves operated properly in controlling flow of water to the gated pipe. However, their reservoirs had to be filled with water before the first irrigation so their diaphragms would expand and close the flow control valves. This was done by hand. After the first irrigation, the reservoirs refilled themselves as the head in the gated pipe reached them.

Final System Design

Some changes were made in the radio control system after the preirrigation had been completed. These changes included, different 3-way valves and modification of the servos.

The new 3-way valves were modified brass 2-way gas valves. The 2-way valves had a 1/8 inch hole through them with 1/4 inch pipe thread connectors. A spring and screw on the stopcock determined tightness of the stopcock in the valve. The 2-way valve was very difficult to turn and so the screw was taken out and replaced with a longer one to loosen the stopcock. The longer screw provided adjustable tension on the stopcock to tighten or loosen as the need may be. The stopcock was tightened sufficiently to keep it from leaking water but loose enough for the servo to turn it. A 3/16 inch hole was drilled into the side of the valve and stopcock to make a third port. Also, the 1/8 inch hole was drilled out to 3/16 inch. The valve was soldered onto a steel bracket which had been bent at a 45° angle and was mounted on the box in place of the old 3-way valve (Figure 18). A small hole was drilled into the handle of the 3-way valve and a wire rod connected the handle to the servo arm. When the servo arm moved 180°, the handle moved 90°. With the handle in the down position, water from the reservoir was directed to the diaphragm and in the up position, water was directed from the diaphragm to the atmosphere through the port in the side of the valve.

The servos were modified by replacing the original circuit

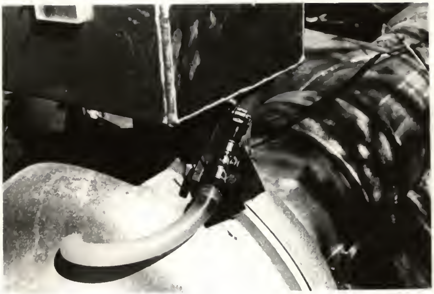

Figure 18. Three Way Brass Valve Mounted at 45° Angle.

Figure 19. Modified Servo Mounted in Flow Control Valve Box.

board with a new circuit board designed and built in the Agricultural Engineering Department at Kansas State University. The new circuit board compared the incoming radio signal pulse with a standard pulse and directed the motor to turn the servo arm one way or the other. The 1500 ohm control that told the position of the servo arm to the circuit board was modified so that only the ends of the control were usable. The ends corresponded to the two extreme positions of the servo arm. As the servo arm moved to one end of its rotation, it came in contact with the 1500 ohm control end and feedback to the circuit board shut the motor off to stop the arm.

The new circuit board could not be placed in the servo housing because it was too large and so it was placed in a plastic box mounted on the servo. Wires ran from the circuit board through the lid of the box and top of the servo to their correct places on the motor, 1500 ohm control, and power and control wires from the battery and receiver. The servos were mounted in the aluminum boxes of the flow control valves as before (Figure 19).

Other changes in the radio control system included adding a capacitor and a coil to the batteries to protect the servos from voltage surges caused by lightning, and rewiring the four wire cords to allow easier connection to batteries and servos.

Results of Final Design Field Tests

The radio control system was used in the summer of 1979 to irrigate the 160 acre field after it had been planted to corn. The system used during the spring preirrigation with its design changes, was used for the summer irrigation.

The transmitters, controllers, and power supply were placed in the plywood box at the building. All 18 of the flow control valves and 1/2 mile of gated pipe were placed in the field for the 18 sets. The missing riser had been replaced and 10-inch flow control valves and gated pipe were used throughout the field. The poles supporting the solar panels, receivers, and receiver antennas were again positioned at the riser. The new 3-way valves were placed on the flow control valves with the servos and batteries in the boxes.

Irrigation started with the first set on the south side of the field and water was delivered from the well at the southwest corner of the field. Each set was irrigated approximately 12 hours per irrigation and each complete irrigation of the field took 9 days. The field was irrigated 6 times during the summer and the water was diverted to another field for a few days between the earlier irrigations.

The original servos, the ones that had not been damaged during the preirrigation, were used until the electronic equipment arrived to modify them. The old servos still had the chattering problem and a storm early in the summer damaged a few more of them. Addition of the capacitor and coil to the batteries did not protect the servos from damage. One servo was damaged when there was no storm and so the reason for the servos being damaged was not completely clear.

The closer the servos were to the transmitters, the less they would chatter. Interference caused by touching the receiver pole or walking by the receiver antenna would make the servos chatter more. The chattering servos discharged some batteries in 3 to 5 days, even with solar panels operating.

By the time the 2nd irrigation started there were only 4 old servos operating out of the 9 installed at the start of the irrigation and the 19 available at the start of preirrigation. Some of the new servos were placed in the field at the start of the second irrigation and at first they chattered, but less than the old servos.

Most of the chattering of the servos was due to interference at the transmitters. The interference was not in the transmitters themselves but in their power supply. Feedback between transmitters was going through the power supply. To eliminate the feedback, the transmitters could have been put on separate power supplies. Instead, one power supply was used and the voltage from it was dropped, to the required voltage of the transmitters, several different ways. The diodes and capacitors which had dropped the voltage during preirrigation were removed and replaced with 3 1.2 VDC batteries. The 1.2 VDC batteries were each in series with a different transmitter and dropped the voltage to 12 VDC.

After a few days the 1.2 VDC batteries were removed and replaced with a 10 VDC regulator which dropped the voltage of the power supply to 10 VDC. The regulator did more harm than good as it caused the servos to chatter even when they were placed beside the transmitters. The interference from the regulator was so bad that the RF meters in the transmitters were jittering. Placing a large 10 VDC Ni-Cad battery between the regulator and transmitters filtered out most of the interference.

Another problem was feedback through the controllers connected to two of the transmitters. It was caused by improperly connected power wires from the transmitters. Later evaluation showed that most of the problems with the transmitters were caused by the improper wiring.

The two transmitters that were sending signals the furtherest distance were turned around so their antennas were pointing upward. The antennas protruded through the top of the box. This action was taken to insure sufficient signal strength reached the receivers through the growing corn. The other transmitter was left as it was with its antenna pointing down.

The 10 VDC regulator did not charge up the 10 VDC Ni-Cad battery because it did not provide a large enough voltage differential between the regulator and the battery. When electricity was shut off, the battery was discharged by the transmitters in a few minutes. To allow the battery to be recharged, the regulator was replaced with a 7 ohm resistance. The resistance dropped the voltage of the power supply from 13.5 VDC to 10.4 VDC at the battery. A voltage of 10.4 VDC was sufficient to operate the transmitters so they sent out precise strong signals, and also keep the transmitters batteries charged.

Solving the power supply and transmitter problem helped tremendously with the equipment in the field. The new servos did not chatter at all except for the two by the well and the old servos chattered very little. The chatter at the well was traced to the engine which powered the irrigation pump.

The new servos did not need the resistance in the transmitters and controllers to be perfectly matched with each individual servo. Each servo was adjusted to set its standard pulse width midway between the on and off pulse widths sent by the transmitter. When some of the new servos were first placed in the field, their pulse widths had not been set correctly. They were very sensitive and sometimes would not operate. A design error was found in the new circuit board which caused it to not compensate for the distortion of the radio signal by the 4 wire cord. Correcting the design error and setting the proper pulse width allowed the new servos to operate properly.

Sometimes it was hard to determine if the new servos were getting a signal from their receivers. The servos move to one of their two positions when connected to power and the position may be correct but the servo may not be receiving a signal. An old servo was used to determine if the signal was being received by the new servo.

The receiver antennas had been causing problems for the old and new servos alike. The problem was not in the antennas themselves but in the insulators that insulated the antennas from supporting brackets. The insulators were made from a material which deteriorated with exposure to sunlight and moisture. With the bad insulators, the poles and cords from the receivers to the servos acted as antennas. This altered the signal being received and sent to the servos causing some of the chatter. The antennas were insulated from their supports with plexiglas.

The radio control system changed the water in the field zero times the first irrigation, 1 time the second irrigation, and 3 times the third irrigation. Only 2 of the 4 radio controlled changes were made without problems. On the other 2 changes, one of the two servos changing did not work. Several factors were involved in why the servos did not work. Reasons for not having more radio controlled changes were either no servos, servos not working, or power supply not operating properly.

To eliminate the effect of the interference from the engine, the four wire cords at the two risers nearest the engine were replaced with shielded cable. The shielded cable reduced the chatter at the first riser but did not eliminate it completely.

By the time the 4th irrigation was starting, most of the problems in the radio control system had been found and corrected. The transmitters and controllers were working properly and the transmitters had a reliable power supply. New insulators were installed for the receiver antennas, new servos were installed at all the flow control valves and shielded cable was placed on the furtherest two receivers.

The radio control system operated the flow control valves for all of the 4th, 5th, and 6th irrigations. Twelve hours of irrigation for each set infiltrated enough water to meet the water needs of the crop until the next irrigation and this amount of time was set on the controllers. The 12 hour sets also made it convenient to observe the system as it changed water. At the start of the 4th irrigation, all of the servos but one had their 3-way valves open and flow control valves closed. The other servo had its 3-way valve closed and flow control valve open.

Controller 1 was set on station 2 which correlated with the first set in the field. The well delivered water to set 1 through the gated pipe. After the first set had been irrigated for 12 hours, the controller automatically sequenced to station 3. The servo at set 1 closed and the set 2 servo opened which caused the set 1 flow control valve to close while the set 2 flow control valve opened. The water was then directed through set 2 and delivered to the field.

When the time for irrigation of each set had elapsed, the controller changed to the next station and the water changed to the next set. When controller 1 reached station 7, controller 2 moved to its first station. Station 7 of each controller was used to turn on the next controller in the series and after a short time the controller would move from station 7 to rest, to be ready for the next irrigation. Each controller automatically sequenced to the next controller and each controller controlled one transmitter and 6 sets.

After the entire field had been irrigated, controller 1 moved from station 1 to station 2 and the water was changed from the last set back to the first set to start the next irrigation. Although the irrigation sets were 12 hours in length, each set could have been of any duration between 1.5 and 24 hours, or the set could have been completely eliminated from irrigation by setting its timer to zero. The timers on the controllers were not exact as the time of an irrigation set varied by as much as 20 minutes from irrigation to irrigation.

Out of the 54 changes made by the radio control system for the 4th, 5th and 6th irrigations, 9 changes were not made properly. Reasons for the servos not changing properly included a bad contact in one controller, a damaged electronic component in two servos, and two receivers with damaged servo outputs. No reason was found for the damaged electronic components and receiver outputs. There were 4 receivers that had damaged servo outputs so the receivers were changed around to different risers to allow the servos to operate and the irrigation to continue.

Most of the time the radio control system was observed when it changed water from one set to the next, but a few times the water changed unobserved. When the water changed and the radio control system did not work properly causing all of the flow control valves to close, the safety device was activated.

The safety device was set up the same as during the preirrigation for the regular irrigation season. It was located on the riser furtherest from the well to keep height of hose setting above the ground to a minimum. When the pressure in the underground pipeline exceeded the height of the hose, the safety device activated. All of the water was siphoned from the diaphragm of the flow control valve and the safety device had to be reset by breaking the siphon. Siphoning all the water out of the diaphragm when the safety device activated was bothersome in that even a momentary increase in head above the hose setting required resetting of the safety device. The need for resetting the safety device was eliminated by shortening the length of plastic hose. The end of the plastic hose was clamped at the height which represented the operating pressure in the underground pipeline. When excessive pressure developed, either due to a momentary increase in pressure or closure of all flow control valves, water discharged through the hose and the flow control valve opened. As pressure receeded to the operating pressure, the flow control valve closed and the gated pipe system continued to operate with flow through the valve opened by the radio control system. The safety device operated properly several times during the irrigation season.

Various heights of receiver antennas were tried. Two of the solar panel poles were shortened and the receivers, receiver antennas, and solar panels were lowered to half of their original height above the soil surface. Three poles were completely eliminated with their receivers placed in the boxes with the batteries at the flow control valves, the receiver antennas mounted on the boxes, and the solar panels eliminated (Figures 20 and 21). The other five poles were left at their original height of 8 feet.

During the 4th, 5th, and 6th irrigations of the field, the receiver antennas were at the different heights. The lowered antennas were scattered across the field with two of the original height receiver antennas at the furtherest two receivers from the transmitters. Antenna height did not affect reception of the radio signal from the transmitter. All of the lowered antennas were shorter than the corn and the radio signals had to pass through the corn to reach them. The antennas at the middle height were more susceptible to interference caused by working around them or driving by with

Figure 20. Flow Control Valve Box with Battery, Receiver, Servo, and Receiver Antenna.

Figure 21. Hydrant and Flow Control Valves without a Solar Panel and Receiver Antenna Mounted on Flow Control Valve Box.

a motor vehicle.

The batteries recharged by the solar panels stayed fully charged except for those with chattering servos. The 3 batteries not recharged by solar panels had varied lengths of life. One of the batteries ran its receiver and two servos over 3 weeks and was still going strong when the irrigation ended. The other two batteries, after some problems, ran their receivers and servos over a week and were still near full charge at the end of the irrigation season. Calculations indicated a fully charged battery should operate a receiver and two servos for up to 2 months before it becomes discharged.

Problems encountered with the flow control valves involved the diaphragms. On one valve, the clamp which held the diaphragm in place slipped and the valve would not close. A second valve opened slowly when the head in the underground pipeline dropped, even through the 3-way valve was set for the valve to be closed. The valve acted as if there was a small leak in the diaphragm and a slit was found in the diaphragm when the valve was dismantled.

The flow control valves opened or closed 3 to 5 minutes after the 3-way valves were activated. This time span was adequate to prevent a pressure build up in the underground pipeline. Although the stopcocks in the 3-way valves tended to stick as their grease became dry the servos had sufficient torque to turn them.

DISCUSSION

Radio control of a gated pipe irrigation system was accomplished during the 1979 irrigation season. As each phase of the testing and system modification was completed, the radio control system became more reliable.

The flow control valves were the only equipment used that was made especially for automated gated pipe systems. The controllers were developed to operate sprinkler systems and were rewired to operate the radio control system. The radio equipment, which was developed to fly model airplanes, was modified extensively.

Many problems were encountered during preirrigation. This was to be expected as the radio equipment had not been used before to control this type of system. Much was learned during preirrigation about the radio control equipment and how it operated under field conditions. The servos were the biggest problem during preirrigation and no conclusive reason was found to explain why they became damaged. It must have been because they were not built sturdy enough for the conditions encountered. The transmitters, receivers, and servos had been manufactured to be operated for only a few hours at a time. Continuous use in a hot, dusty environment may have led to the servo problem.

The receiver antennas were placed on the box at the flow control valves to determine if the radio control system could operate with the antennas lowered and without solar panels. There was less damage to the servos when they were not connected to the solar panels. Without solar panels, the servos and receivers ran off large batteries which will require periodic recharging. Replacing the circuit board in the servos with low power electronic components increased the life of the battery between charges from 10 to 50 days and rebuilding the receiver with low power components could further increase the interval between charges.

Even with labor savings and increased irrigation efficiencies, a big factor in deciding whether or not to automate a gated pipe system will be cost. The cost for the automated gated pipe irrigation system has to be competitive with the cost of sprinkler systems in order for the irrigators to buy them.

Equipment costs for two automated gated pipe irrigation systems were determined, with system 1 being the equipment that was used to automate the existing gated pipe system at the Webber field and system 2 being the complete system that includes the underground pipeline and gated pipe (Table 2). The estimates are for this field only as each field will be different.

The gated pipe system that had been used on the field last year and during previous years consisted of the underground pipeline with risers and .5 mile of gated pipe. Only

Table 2. Equipment Costs for Two Automated Gated Pipe Irrigation Systems.

Item	Cost per Unit	Total Cost
	SYSTEM 1	
3 Rain Bird AG-7 Controllers	$379.00	$ 1,137.00
3 Heathkit Model GDA-1205 Transmitters	$139.95	$ 419.85
10 Heathkit Model GDA-1205-2 Receivers	$ 59.95	$ 599.50
10 Sonotone Model BB-429/U Storage Batteries	$ 19.95	$ 199.50
18 Heathkit Model GDA-1205-8 Servos	$ 26.95	$ 485.10
18 3-way Valves	$ 10.00	$ 180.00
18 Hastings Flow Control Valves, 10 in.	$203.00	$ 3,654.00
10 Waterman Hydrants 12 in. x 10 in.	$138.05	$ 1,380.00
8 End Tees, 10 in.	$ 44.30	$ 354.40
18 End Plugs, 10 in.	$ 13.01	$ 234.18
520 Irrigation Sok, 10 in.	$ 1.75	$ 910.00
10 Solarex Model 615 D Silicon Solar Panels	$ 90.00	$ 900.00
	TOTAL FOR SYSTEM 1	$10,453.53

Table 2. (Continued)

Item	Cost per Unit	Total Cost
	SYSTEM 2	
1/2 mile Underground Pipe (installed) 14 inch	$ 2.80/ft	$ 7,392.00*
1/2 mile Gated Pipe 10 inch, 30 foot lengths	$ 2.60/ft	$ 6,864.00*
10 Risers, 14 inch to 12 inch	$115.00	$ 1,150.00*
Miscellaneous		$ 350.00
System 1		$10,453.53
	TOTAL FOR SYSTEM 2	$26,209.53

* Estimates furnished by Delta Irrigation, Garden City, Kansas

two risers were used with .25 mile of gated pipe connected to each riser. All gates in the gated pipe were closed at the start of the irrigation season. To irrigate, a certain number of gates were counted out and opened manually. The sets were changed once a day when it was the most convenient for the farmer.

By automating the existing system, the operation of the gated pipe system was changed. Ten risers were used, the gates in the gated pipe were open all the time and the water was changed automatically using flow control valves, servos, receivers, transmitters, and controllers. The water could be changed at any time of day and several times per day.

With the radio control system changing the water there was no labor needed to change water while irrigation was in progress. Only labor needed was for maintainence of the irrigation well and for setting up and taking down the system at the start and end of the irrigation season.

The radio control system can help increase irrigation efficiencies. Water application and water distribution efficiencies are influenced by rate of flow into the furrow and time of irrigation.

With the radio control system the application duration can be easily changed, thereby applying only the quantity of water needed in the soil. There will be less water wasted due to excessive runoff and deep percolation. Water application efficiencies can be determined by measuring the amount of water applied with a flowmeter at the pump and measuring runoff from the field with a flume and water level recorder at the drainage ditch.

High distribution efficiencies can be obtained by running large streams of water down the furrows and collecting the runoff in a tailwater pit (Fischbach and Somerhalder, 1971). Distribution can be measured with either gypsum blocks or gravimetic readings taking from soil samples. Readings are taken throughout the field to determine how well the water was distributed.

Shorter, more frequent irrigations can be made with the radio control system, in which the moisture level in the soil does not change drastically.

Cutback irrigation is another way to irrigate more efficiently (Garton, 1966). With cutback irrigation, water will be turned into one flow control valve and its gated pipe for a sufficient length of time to allow the flow to reach the end of the furrows. Flow will then be diverted to an adjacent flow control valve and gated pipe for the same period of time. Then flow will be allowed through both flow control valves giving a cutback flow of one-half of the initial flow in an individual furrow.

Cutback irrigation increases irrigation efficiencies, but labor requirements are high for conventional gated pipe systems. Automated and radio controlled systems make the labor requirement for the cutback system almost zero.

CONCLUSIONS

1. An existing gated pipe irrigation system was controlled with radio control equipment and flow control valves.

2. The performance of the radio control system was very good once the system became operational.

3. A 160 acre field was irrigated successfully several times using the radio control system.

4. The flow control valves were a vital part of the radio control system and worked very well.

5. A compact controller with accurate timers is needed to control the transmitters.

6. Labor requirements to irrigate the field using the radio control system were low.

7. The safety device was very important in the radio control system since there was always a chance that the flow control valves would all close.

SUMMARY

There is increasing usage of water by domestic, industrial, recreational, and agricultural users in the United States. Irrigation is one of the low efficiency users of this water.

Reasons for the inefficient use of water, particularly in surface irrigation systems has been the high cost for labor, the lack of good labor, and the inexpensive plentiful water supplies of the past few decades. Farmers are reluctant to use additional labor just to conserve water.

Automatic operation of properly designed irrigation systems can eliminate most of the labor connected with irrigation and at the same time insure high irrigation efficiencies. Irrigation distribution efficiencies of 92% and irrigation application efficiencies of 92% had been obtained with an automated gated pipe irrigation system with a reuse system. Automation of sprinkler systems has resulted in systems where the labor requirements are minimal.

Progress has been made in automation of gated pipe systems, over the last few years, but a better automated system is needed to reduce labor and increase irrigation efficiencies. The first big step in the automation of gated pipe irrigation systems was the development of a pneumatic valve placed in an alfalfa valve. The pneumatic valve was

used in an automated system that was tested using both radio control and a timer with wires. Field tests of the system were made at Wiggins, Colorado and Mead, Nebraska. Later, another flow control valve was developed with a pneumatic valve mounted inside a housing. Controls for this valve consisted of a controller with airlines running to each flow control valve.

The next development in automated gated pipe irrigation was a flow control valve that used water instead of air to inflate the diaphragm. The diaphragm was mounted in a housing that was placed directly in a pipeline. To inflate the diaphragm, water was brought in through a pitot tube, mounted on the upstream side of the valve, through a 3-way pilot valve and into the diaphragm which inflated and stopped the flow of water. Water was released from the diaphragm by moving the 3-way valve. Controls for the flow control valve consisted of a motor to operate the 3-way valve, and a 24 hour timer.

Another development was the use of radio transmitters and receivers to control a border irrigation system.

The use of radio control and irrigation valves inflated by water, seem to offer a better type of control system for an automated gated pipe system.

The objectives of this research were to control an existing gated pipe irrigation system using radio control, and to evaluate the performance of the radic control system.

Permission was obtained from a farmer to irrigate a 160 acre field using a radio control system. Funding was provided by the Department of Energy of the United States Government and the Kansas Agricultural Experiment Station. The radio control system consisted of the existing gated pipe irrigation system plus radio control equipment.

The existing gated pipe irrigation system included the well, underground pipeline, risers and gated pipe. The radio control equipment included radio transmitters, receivers, servos, controllers, batteries and solar panels. Flow control valves with 3-way slide valves connected the existing gated pipe system with the radio control equipment.

The transmitters, receivers and servos used in the project were radio control equipment used for flying model airplanes. Digital signals emitted by the transmitter allowed the separate control of up to 8 different devices on one frequency. For the radio control system, 3 transmitters were used each on a different frequency and each one controlled 6 servos.

Standard sprinkler irrigation controllers were used to control the transmitters with each transmitter run by a separate controller. The controllers were operated by 110 volt AC power and were located with the transmitters in a plywood box at a building north of the field.

The receivers and servos were placed in the field and were powered by large batteries that were recharged by solar panels. Receivers were placed with the solar panels on top of poles located at the risers. The signal that was sent by the transmitters was decoded by the receivers and the proper responses were sent to the servos. One servo was mounted on each of the 18 flow control valves in the system. The servos controlled the 3-way slide valves which controlled the flow control valves. Water was delivered to the field through gated pipe and the flow control valves controlled the flow through the gated pipe.

The radio control system was set up to preirrigate the field in the spring of 1979. To start the radio control system 24 hours were set on each of the timers in the controllers and the transmitters, receivers and servos were turned on. Water was changed from one set to the next set by shutting off the receiver in the field, moving the controller to the correct station, and then turning the receivers back on to allow the servos to operate. The water that was being delivered to the field through the first set was changed to the second set. The servo in the first set had opened its 3-way valve and closed it flow control valve while the servo in the second set closed its 3-way valve and opened its flow control valve.

Two changes of water had been made before a thunderstorm damaged about half of the servos. The storm had caused some sort of an electrical charge to be induced to the servos, and this electrical charge damaged some of the circuits. No more changing of the water with the radio control system was attempted because of the damaged servos and also the preirrigation was discontinued a few days later.

One problem encountered during preirrigation was that the servos were too sensitive and would move about and chatter because the radio signal they received was distorted and they tryed to match it. Some type of interference was affecting the transmitted signal. Another problem was the 3-way slide valves built in the Agricultural Engineering Department. They leaked excessive amounts of water and were affected by temperature.

The radio control system was used in the summer of 1979 to irrigate the field after corn had been planted. Two major changes were made in the system. The 3-way slide valves were replaced with small 3-way brass gas valves and the servos were modified by replacing their circuit boards. The changes in the servos caused them to be less sensitive so they would not chatter and more rugged so they could not be damaged easily.

The radio control system was set up in the field in the same manner as it was for the preirrigation and was used to irrigate the entire field 6 times. Twelve hour sets were used for the summer irrigation instead of 24 hour sets. Modifications and changes in the system were made during the first

3 irrigations. The power supply at the transmitters underwent several changes before a suitable design was found. New antenna insulators were put on all receiver antennas, shielded cable was put on two receivers, and the servo modifications were completed.

The water was changed the last 3 irrigations using the radio control system. Water was delivered to one set for 12 hours and then switched to the next set. After each set was irrigated the controller changed to the next station which, with the help of the transmitter, receiver, servos, 3-way valves, and flow control valves, changed the water to the next set. The controllers were connected in series and when one controller had irrigated all of its sets the next controller automatically started on its first set. When the entire field had been irrigated the water automatically went back to the first set to start the next irrigation.

The system changed the water 54 times during the last 3 irrigations and only 9 changes were not made properly. There were minor problems which caused some servos to not activate properly. With the radio control system the water changed sets by itself with no labor required.

An existing gated pipe irrigation system was controlled with radio equipment and the radio control system performed quite well as it irrigated a large field 3 times. Radio control of a gated pipe irrigation system had been accomplished.

The radio control system when perfected can make a large contribution to the irrigation industry by decreasing labor requirements and increasing water use efficiency for furrow irrigation.

SUGGESTIONS FOR FURTHER RESEARCH

The radio control system operated satisfactorily, but additional field testing is needed to further refine the system. As rapid advancements are taking place in the electronics industry, newly developed components should be continually evaluated for their application to automated gated pipe systems. Examples of such components are microprocessors for programming operation of the system, transmitters with many channels, and equipment with low power requirements.

Operation of the radio control equipment in the field with batteries and without solar panels to recharge the batteries in place appears feasible. The batteries, servos, receivers, and receiver antennas can be mounted permanently in the box at the flow control valves. This will make a more compact radio control system which will be easier to set up at the beginning of the irrigation season and to take down and store at the end of the irrigation season. Provisions must be made for easy replacement of batteries during the season and recharge of the discharged batteries. A search should be continued for lower powered electronic parts which can be substituted into the radio control system and reduce the drain on the batteries.

The present controllers and transmitters are run by AC power. In many areas AC power is not readily available. Operation of controllers and transmitters from storage batteries should be investigated. Solar panels are one possible means of recharging the batteries. Battery powered controllers and transmitters would be portable allowing their installation in the field near the gated pipe system.

Automation provides great flexibility in water application rates and times of irrigation. Studies should be conducted to determine the best combination of flow rates, duration of irrigation, and frequency of irrigation for efficient water use. Other water management schemes such as cutback furrow flow should also be investigated.

ACKNOWLEDGEMENTS

I would like to thank my major professor Dr. Harry Manges for his guidance and support throughout the course of this study, and for making the project and my presence in the graduate program at Kansas State, possible.

I also wish to thank Dennis Matteson for his help in setting up the project and his technical assistance.

For the use of his field and irrigation equipment I would like to thank Herschel Webber.

Finally, I would like to thank Dr. Edwin Lindly and Professor Ralph Lipper for being on my advisory committee.

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RADIO CONTROLS FOR GATED PIPE IRRIGATION SYSTEMS

by

HAROLD RICHARD BLUME

B.S., Kansas State University, 1976

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

ABSTRACT

Water in the United States is being used faster and faster by domestic, industrial, recreational and agricultural users. Irrigation is one of the low efficiency users of water, particularly surface irrigation systems which require skilled labor to operate them efficiently. Automation of surface irrigation systems, such as gated pipe systems, can reduce the labor required and still obtain high irrigation efficiencies.

The objectives of this research were to control an existing gated pipe irrigation system using radio controls and to evaluate the performance of the radio control system.

The existing gated pipe irrigation system included a well, underground pipeline, risers, and gated pipe. Radio control equipment used to control the existing system consisted of transmitters, controllers, receivers, servos, batteries and solar panels. Flow control valves, that used water to inflate their diaphragms, and 3-way slide valves connected the gated pipe system with the radio control equipment.

Controllers regulated the transmitters which sent digital signals to the receivers and servos. Digital signals allowed each transmitter to control 6 servos individually. Storage batteries supplied power to the receivers and servos in the field and were recharged with solar panels. The

receivers decoded the digital signals and sent the correct responses to the servos. The servos were mounted on the flow control valves and operated 3-way slide valves which directed water to the diaphragms of the flow control valves. Water was delivered to the field through gated pipe and the flow control valves controlled flow through the gated pipe.

The radio control system was used to preirrigate a 160 acre field in April, 1979. The system controlled the flow of water to the field by directing water to different irrigation sets during the course of the irrigation.

During preirrigation the radio control system changed the water from one set to the next only twice before several of the servos were damaged during a thunderstorm. No damage occurred to any other part of the radio control system. The 3-way slide valves, which had been made for the radio control system, did not function properly during most of the preirrigation.

The radio control system was also used to irrigate in the summer of 1979 where the 3-way slide valves were replaced with 3-way brass gas valves and the servos were modified. The system was set up in the field the same as for the preirrigation and was used to irrigate the field 6 times. Modifications and changes in the system were made during the first 3 irrigations with the radio controls changing the water only a few times. All of the changes for the last 3 irrigations were made automatically with the radio control system. Of the 54 changes made, only 9 changes were not made properly. Failures were due to inoperative servos and receivers, and a poor connection in a controller.