AUTOMATION OF OPEN CHANNEL SURGE FLOW IRRIGATION

By

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The research in this study was concerned with the development and testing of two automated structures for the automation of open channel surge flow irrigation. The major objectives were to construct these gates and test their effectiveness and suitability in field conditions. These gates will be used in future surge flow irrigation studies.

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CHAPTER I

INTRODUCTION

The Problem

Interest in surface irrigation has increased in the past few years, mainly because of rising fossil fuel costs. Surface irrigation requires the least amount of energy when efficiently done (Batty et al., 1975). However, surface irrigation has gained the reputation of being inefficient and wasteful (Stringham and Keller, 1979). These inefficiencies are the result of poor design, poor operator management, and lack of proper equipment. Proper design and management of the system can control runoff and deep percolation losses, thereby improving the irrigation efficiency.

Researchers in the past have tried to increase these efficiencies with the use of automation. Gates, various valves, and several mechanical type structures have been developed. However, few of these structures have intermediate settings between off and on. Without these settings, difficulties arise in trying to reduce the stream size to some desired level.

This inherent problem led to the idea of cyclic or "surge" flow in which water is applied intermittently. Bishop and his co-workers (1981A) at Utah State University developed surge flow irrigation as an attempt to produce automated cutback irrigation. The initial reserch on surge irrigation was followed by the work of others including Podmore and Duke (1982).

The systems currently used for surge flow irrigation can be classified as closed systems; that is, they are constructed of gated pipe with valves to allow for the outflow of water. The costs required to install such a system for large scale surge flow irrigiation would tend to make its application economically infeasible. Since a very large amount of the surface irrigation in the United States is done with open channel conveyance systems, it is important that surge flow irrigation be adapted to make use of these channels.

Objectives

The specific objectives of this research are:

1. To develop two automated gate structures which will allow the automation of open channel surge flow irrigation.

2. To test these gates in actual field studies to determine their performance and suitability.

3. To conduct a hydraulic analysis of the system operation.

CHAPTER II

REVIEW OF LITERATURE

Surge Flow Irrigation

The term "pulse" irrigation has been defined by Karmeli and Peri (1974) as a series of irrigation time cycles, where each cycle includes two phases: (1) the operating phase of the irrigation system, and (2) the phase during which the system is at rest.

The initial work with surge flow irrigation began in 1978 at Utah State University. Bishop et al. (1981A) began their research by designing field experiments to compare continuous flow surface irrigation and surge flow irrigation. Initial studies were done on a silt loam soil. The time required for water advance and the volume of furrow runoff were measured. Several lengths of flow time and several different cycle ratios were used. The cycle ratio is the ratio of on time to total cycle time.

The system used in the experiments consisted of a gated pipe line and automatic air valves. Air was supplied by a commercial air compressor. An electronic controller was developed to open and close the air valves in sequence, and had the capability to produce timing sequences as short as 10 seconds. Stringham and Keller (1979) stated that the cost for the system components and the labor was approximately $10,000. This system is capable of irrigating an 8.1 hectare (20 acre) field with a row length of 402 meters (1320 feet).

Using this system, Bishop et al. (1981B) determined that the surge flow irrigation effects were the most dramatic during the first irrigation; the effects were particularly pronounced in the wheel furrows. The data collected by Poole (1980) indicated that, in wheel furrows, for equal volumes of water, the advance under surge flow conditions was about four times faster than for continuous flow conditions during the first irrigation. Stringham and Keller (1979) found that the advance time for a 16 second on-8 second off furrow was faster than the advance time for the steady flow furrows even though the average stream flow was only about 67 percent as large. These much faster advance rates translate into a higher water application efficiency and better uniformity. Bishop et al. (1981B) also noted that the variation in the volume of water required for surge flow advance during the season and across the field was much less than for continuous flow. This results in a much more uniform soil penetration along the furrow, from furrow to furrow, and from irrigation to irrigation. Again, this will increase the irrigation efficiency. Other cycle-on times (5, 10, 20 min) were studied by Coolidge et al. (1982).

Podmore and Duke (1982) began to investigate the application of surge irrigation to furrow irrigated corn in northeastern Colorado. They used gated pipe in conjunction with pneumatically operated pillow valves. The researchers found that the effects of advance rates were not as encouraging as the results reported in the earlier studies, although a significant advantage to surge irrigation was noted. A tendency for decreased advantage of surge irrigation with increasing length of run was also observed. The surge flow treatments were found to have a significant impact on the infiltration process; they established significantly lower steady state infiltration rates which produced more runoff than the steady flow treatments. This higher volume of runoff gave lower irrigation efficiencies.

These varying results indicate the need for further studies in different locations and on different soil types. Changing soil conditions may influence the effectiveness of surge irrigation, but its use appears to result in better soil moisture uniformity and decreased use of water.

In order to obtain the advantages of surge flow irrigation, automation must be used. Without this automation surge irrigation will not be attractive as a new method to increase water application efficiencies over traditional irrigation practices.

Automation of Surface Irrigation

Attempts to automate surface irrigation have been made by several researchers over the years. Humpherys (1983) used butterfly valves in gravity pipeline irrigation distribution systems. These valves could be operated using springs or pneumatic methods. Air cylinders or rotary actuators were used to operate the butterfly valves. A four-way pilot valve was used to apply air pressure to either one side or the other of the butterfly valve. Humpherys suggested using solenoid pilot valves in conjunction with the double acting air cylinders or rotary actuators.

The battery powered solenoid valves, used to operate the pilot valve, normally require an electrical impulse rather than a continuous supply of electricity. This electrical impulse can be obtained through the discharging of a capacitor. Humpherys (1983) used 12 volt AC solenoids which operated on the DC voltage for the pulsing application. Mechanical and electronic timers were used to control the automated valves.

Fischbach and Gooding (1971) attempted to automate surface irrigation by using irrigation valves on buried pipelines. The automated surface irrigation valve was connected to a riser on the buried pipeline. The valve consisted of a casing and a nylon-reinforced butyl rubber diaphragm. Air pressure was used to inflate the diaphragm, thus stopping the flow of water. The movement of the diaphragm was controlled by a three-way valve.

Haise et al. (1980) have attempted to automate buried pipelines using inflatable pneumatic O-rings. The same authors also developed a pillow-disk valve for pipeline risers. Compressed air was used in both cases to operate the valves.

Humpherys and Stacey (1975) experimented with water inflatable bladders. One such valve consisted of a housing with a modified small tire inner tube bladder. Water in the pipeline filled the bladder, causing it to expand and seal off the flow area. Draining the bladder allowed water to flow out. A pilot valve was responsible for the filling and emptying of the bladder. Different bladders for varying system pressures were developed.

Haise et al. (1980) attempted to apply a modified pneumatic O-ring at a turnout inlet to control furrow discharge. Butterfly valves and modified butterfly valves were tested as well. These authors also tried pneumatic pillows and high pressure convoluted cushions to achieve the desired results.

A more recent attempt to automate surface irrigation with closed pipes is cablegation. A "cablegation" system developed by Kemper et al. (1981) consisted of a concrete standpipe to receive the water supply, and a transmission distribution pipe laid along the desired grade at the head of the furrowed field. Holes were drilled in the distribution pipe at an angle of 30 degrees from the vertical. A plug, slightly smaller in diameter than the pipe, was installed in the pipe. The movement of this plug was restrained by a cable attached to a reel which was driven by a small DC electric motor and a gear reduction assembly. As the plug was pushed through the pipe by the force of the water, pressure was developed which forced water to flow from the orifices near the plug. At a distance away from the plug the hydraulic grade line fell below the orifices. At this point water did not flow out through the orifices or completely fill the pipe. Between this point and the location of the plug, varying flow rates occurred due to the changing hydraulic grade line. Therefore, as the plug slowly moved down the pipe a modified version of cutback irrigation was obtained.

A problem reported in many of these automation studies was the accumulation of trash on the tight fitting valves or similar devices. This trash prevented proper closure and resulted in leaks.

A very large portion of irrigation water distribution systems in the United States are of the open-ditch type. This has resulted in a great deal of effort directed toward developing automated structures for open channels.

One of the first attempts to automate open ditch irrigation was made by Garton (1964). His automatic furrow cutback system consisted of level bays fitted with tubes which extended through the ditch to allow for the discharge of water. An automatic check dam was placed at the end of each bay. Irrigation began in the bay which had the tubes at the highest elevation. When the furrows for that bay had been irrigated, the check dam was removed. The checks were automated by using mechanical timers which released a lever mechanism; this in turn caused the checkdam to collapse, sending the water down the ditch to the next bay.

Humpherys (1967A) worked with the automation of flexible check dams. He considered both portable and semi-permanent structures. A portable model designed for lined ditches consisted of a nylon-reinforced rubber dam supported in a metal frame. This check was made to fit in the cross section of a lined ditch. A drawstring was threaded through the top of the rubber. In its closed position, the drawstring was pulled tight, thus lifting the rubber section and providing an effective check against the flow of water. A timer released the drawstring after the desired irrigation period had elapsed. The timer contained a built-in "trip" for the releasing of the drawstring. The timer could be installed so that it could be engaged with a float-operated mechanism. The model described above was modified to work in an unlined ditch. Here the dam was supported by a bulkhead of metal, wood, or concrete. The ends and bottom of the cutoff wall extended into the bottom and sides of the ditch. This check was semi-permanent and could also be fitted with a float-actuated timer. Further modifications of the above models were made for unlined ditches.

Several investigators attempted to design or modify drop-open and drop-closed gate structures. Haise et al. (1980) stated that semi-automatic structures include a wide variety of simple gates and release mechanisms. The drop-closed structures usually consist of a solid gate made of sheet metal or plywood, hinged at the top, and opening to the upstream side of the check bulkhead. These structures are simpler than the drop-open checks because the force of the water aids in sealing the cracks.

Evans (1977) designed both drop-open and drop-closed gates. The drop-open gate was constructed of three pieces of aluminum attached to an aluminum frame which was made to fit in a gate guide. This guide was was pre-cast into the sides of a trapezoidal concrete ditch. The center panel overlapped the two side panels in the closed position and was held in the upright position by a pivoting angle. This pivoting angle therefore controlled the operation of the gate. The three panels were hinged to the frame with butyl rubber. A timer with a release pin was used in conjunction with a roller bearing and a short length of chain to release the pivoting angle, thus allowing the gate to drop open at the specified time. The drop-closed gate was similar in design to the drop-open structure and closed in the vertical position. The same basic release mechanism was used with a few mounting modifications.

Humpherys (1969) developed a trapezoidal check gate using the principle of hydrostatic pressure distribution and the resultant center-of-pressure force for tripping. The gate could be made fully automatic when used in conjunction with a counterweight. As the water level rose against the gate, the pressure increased. When the water level was high enough, the resultant force caused the gate to pivot open. The gate remained open until the water was turned off; then it automatically returned to its normally closed condition.

A gate similar to that designed by Humpherys was the tip-down check devised by Haise et al. (1980) to seat in a trapezoidal concrete lined ditch. The gate pivoted at the top and was counterweighted to maintain its normally open position. A plastic hydraulic cylinder was used to open the gate.

Automation of surface irrigation using jack-gates was attempted by Payne et al. (1974). Dedrick and Erie (1978) made some modifications to this original jack-gate. The original lifting mechanism on the sliding gate was replaced with an air cylinder. The air was diverted to opposite ends of the cylinder by means of a four-way valve which allowed for either extension or retraction of the cylinder. Springs were installed as a safety measure to ensure a normally open gate. A control system was built with a timer to automatically actuate selector valves. Also included were a sequence selector (to allow the operator to choose the order in which the air pilot lines were actuated) and safety overflow and excess irrigation water disposal features. The irrigator set the timer dials and the sequence in which the gates were to be opened.

Haise and Whitney (1967) constructed and lab tested a hydraulically controlled gate for automated surface irrigation. The system had two separate control functions. One control used stilling wells, bleeder valves, and a four-way hydraulic valve to regulate slide or swing-type gates. The second control was used to override the first hydraulic system, when sufficient water had been applied, in order to close the gates to the lateral distribution ditch.

Kruse, Freeman and Haise (1970) became involved in the automation of surface irrigation with fluidic diverters. Fluidic diverters can be designed to divert a stream of water to different outlets, using no moving parts and no source of external energy. The operation of a fluidic diverter is based on the wall-attachment or Coanda effect where a stream or jet of fluid tends to attach itself to a wall in close proximity to the jet.

CHAPTER III

MATERIALS, EQUIPMENT, AND METHODS

As outlined in the objectives, two gates were designed and built to facilitate the automation of surge irrigation. Both gates were designed to be portable and to fit in an open trapezoidal channel.

Rotating Gate

A manual opening gate of similar design had been in use for several years as a check. The basic characteristics of this gate were retained in the construction of the automated gate.

The framework of the gate consists of 2.54 cm (1 inch) angle iron welded together in a trapezoidal shape to allow it to rest in a ditch with 1 to 1 side slopes (Figure 1). Galvanized sheet metal is attached to the frame with screws. The pivoting or rotating portion of the gate is semi-circular in shape, as is the hole it covers and uncovers (Figure 2). The radius of this rotating section is about 41.9 cm (16.5 inches). The rotation of this metal semi-circle allows water to flow through the gate and down the ditch (Figure 3). Some modifications were made from the original to allow for automation:

1. The top of the gate opening was lowered by 15.2 cm (6 inches) to provide extra room for the mounting of components.

2. An angle iron brace was installed 15.2 cm (6 inches) from the bottom of the gate.

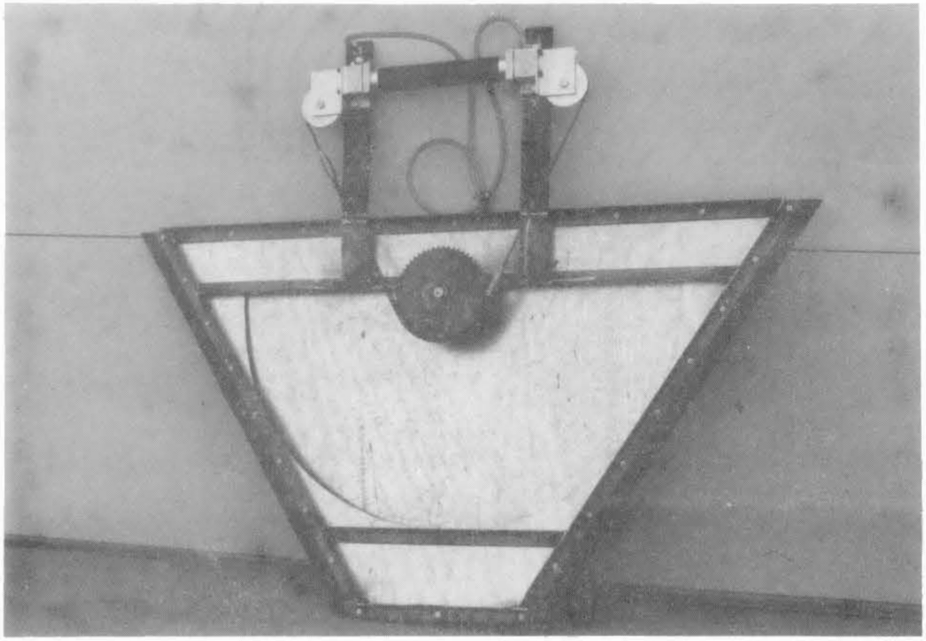

Figure 1. Rear View of Rotating Gate

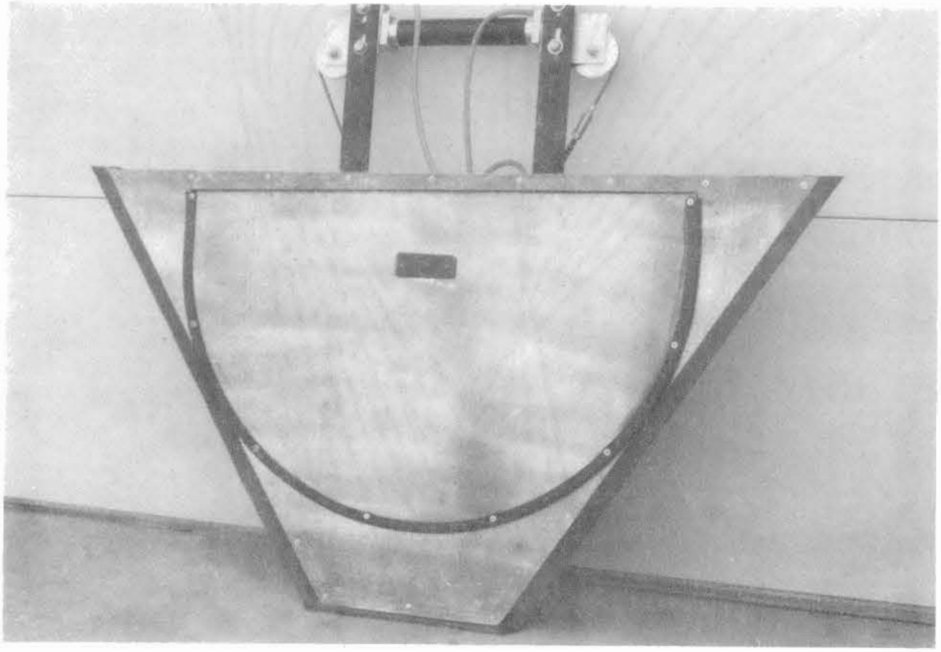

Figure 2. Front View of Rotating Gate

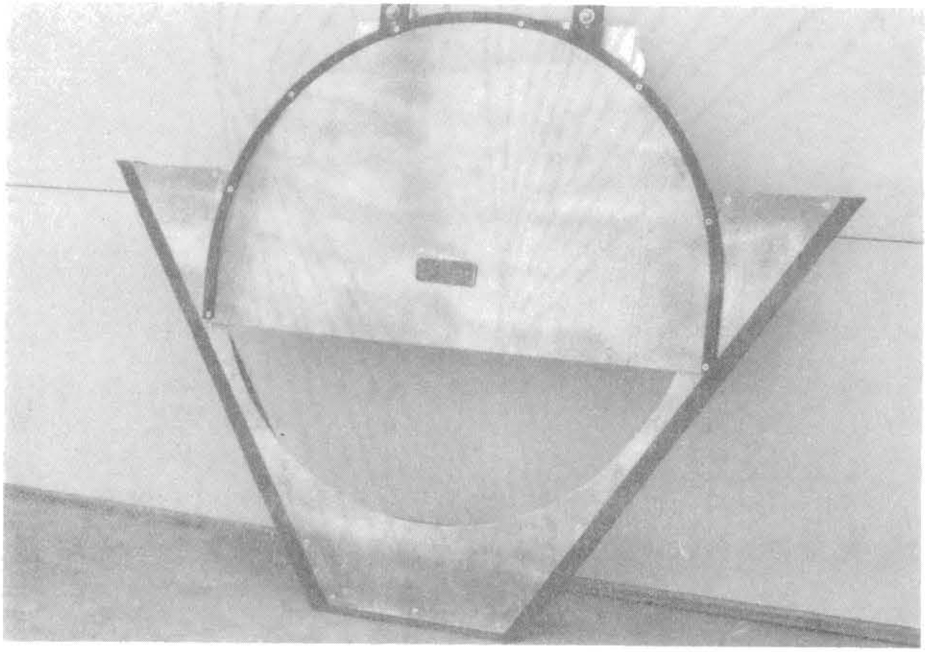

Figure 3. Rotating Gate in the Open Position

3. An angle iron brace was extended across the gate 15.2 cm (6 inches) from the top for strength and to allow mounting of a solid pillow block bearing. A self-aligning pillow block bearing was used initially, but resulted in excessive sideways movement.

4. A 1.91 cm (3/4 inch) diameter shaft was welded to a small plate, which in turn was screwed to the front of the rotating portion of the gate.

5. A 17.8 cm (7 inch) diameter chain sprocket was installed at the rear of the gate on the end of the shaft.

6. Two 44.5 cm (17.5 inch) lengths of 5.1 cm by 6.35 mm (2.0 by 0.25 inch) flat irons were welded to the angle irons on the rear of the gate to form a mounting bracket for the air cylinder.

A 3.81 cm (1.5 inch) bore double acting air cylinder with a 25.4 cm (10 inch) stroke was used. The stroke was determined by considering the length needed to rotate the drive sprocket 180 degrees. The 17.8 cm (7 inch) sprocket was chosen to ensure enough torque. Determining the bore size was mainly an educated guess as accurately measuring the amount of force required to turn the gate against the water pressure was very difficult. A small bore was desired for economic reasons. According to the manufacturer, the air cylinder was capable of developing 222.4 newtons (50 pounds) of force at an air pressure of 600 kPa (87 psi). A 3.18 mm (1/8 inch) cable was provided with the cylinder; a length of bicycle chain was joined to each end of the cable with turnbuckle-type connectors to form a continuous connection. These turnbuckles, as well as the elongated holes in the cylinder mounting brackets, provide separate ways to tighten the sprocket.

Neoprene rubber was riveted around the edge of the rotating section to provide proper sealing. Strips of rubber were also used around the perimeter of the gate to form a sealant against the sides of the ditch.

Rotating Gate Control Unit

A control unit was developed to automatically open and close the gate at specified intervals. This unit consists of (Figure 4):

1. Integrated circuit time clock,
2. Two double pole-double throw 25 amp relays,
3. One four-way double stem, two position, pneumatic control valve,
4. Two 12 volt AC solenoids,
5. One toggle switch to select alternate time intervals,
6. One trigger switch to set and reset the time clock, and
7. One on-off switch with in-line fuse for protection of the time clock.

The solenoids were purchased to screw directly into the four-way control valve, thus eliminating the need for adapters. Fourteen gauge wire was used throughout the unit except for the leads from the battery which were 10 gauge.

A small motorcycle battery was used to provide the power for the timer. As the timer draws only a small amount of current, this size of battery was chosen for portability. Compressed air was provided in a portable tank (Figure 5). Standard 6.35 mm (1/4 inch) air hose was used to deliver air from the tank to the control valve, and from the control valve to the air cylinder.

The timer's schematic diagram is given in Figure 6. The XR2240 is used as a frequency source for the timer. The frequency output at pin 8

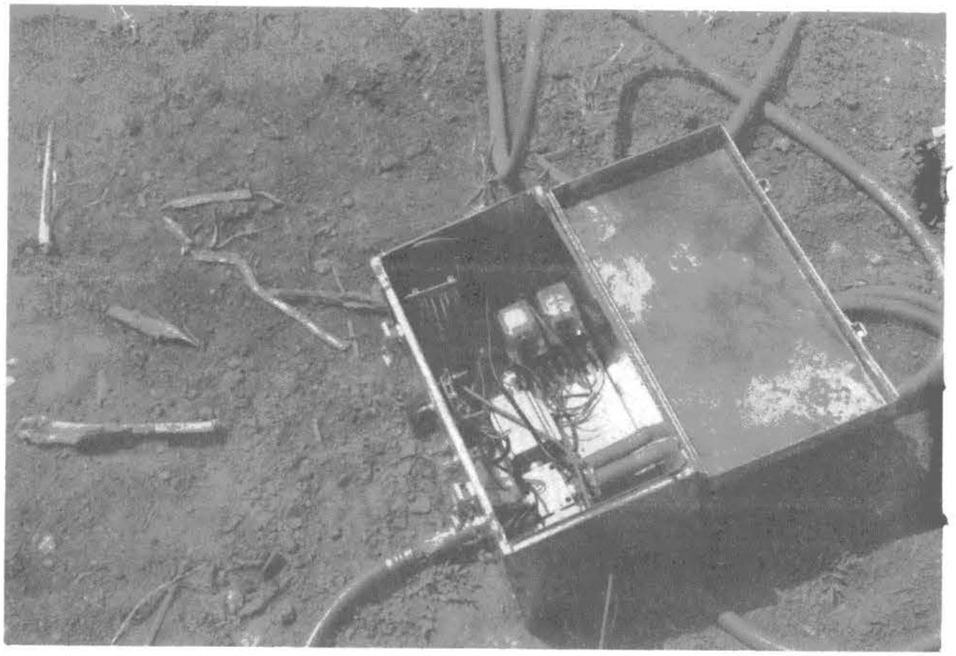

Figure 4. Rotating Gate Control Unit

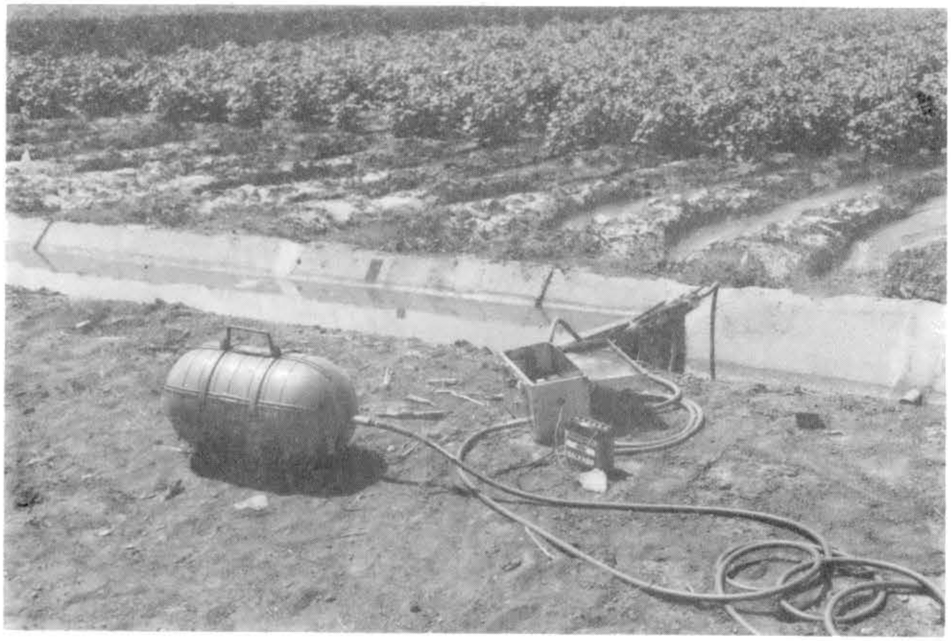

Figure 5. Rotating Gate Control Unit With Air Tank and Battery

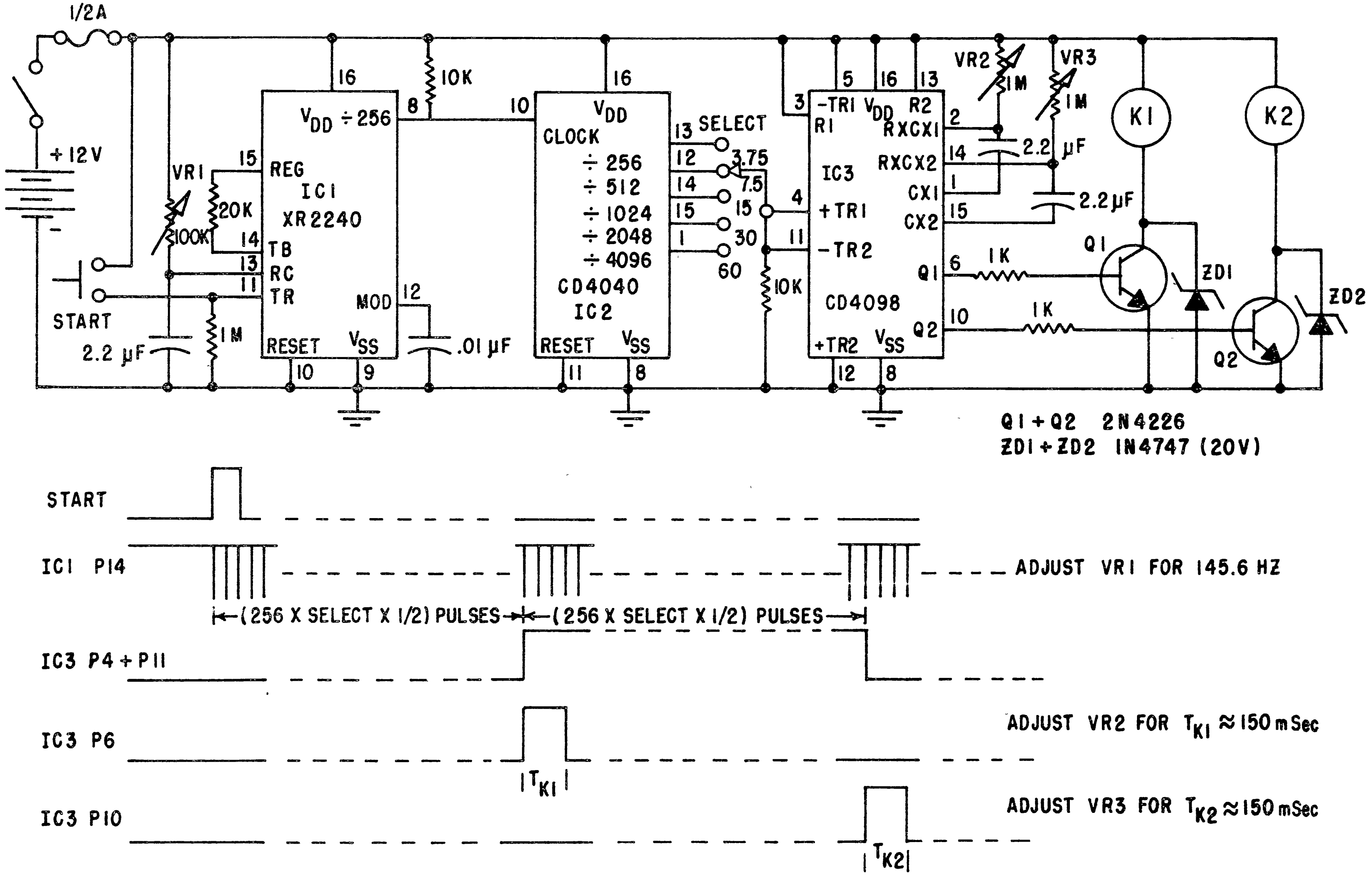

Figure 6. Electronic Timer Schematic Diagram

is the interval frequency divided by 256. The CD4040 is a 12 bit counter used to divide the frequency into intervals; each interval is twice as long as the previous one. The toggle switch is used to connect the proper interval to the input of the CD4098. The CD4098 is an edge sensitive pulse generator used to control the length of time the relay is engaged. The timer was tested at times of 3.75, 7.50, 15, 30, and 60 minutes. These values can be changed to any multiple of two from a desired starting point.

Initially a capacitor was used to store up electricity. This capacitor then provided the pulse of electricity to switch the solenoid. This arrangement was found unsuitable as the capacitor was physically too large and gave problems with portability. Also, the timer uses such a small amount of current that the capacitor did not significantly extend battery life.

A schematic diagram of the basic control unit is shown in Figure 7. The black box controller is the time clock, K1 and K2 are the two relays, and S1 and S2 are the two solenoids. When the time for a cycle has expired, the time clock sends a pulse of electricity to the respective relay, causing the relay to momentarily close. When the relay closes, another pulse of electricity passes through the relay and switches the solenoid. This action moves the stem on the four-way valve, forcing air to either one side of the other of the air cylinder; this results in either an opening or closing of the gate. Pulsing the other relay moves the cylinder in the opposite direction. Thus through a series of alternating pulses the gate can be opened or closed at the desired intervals.

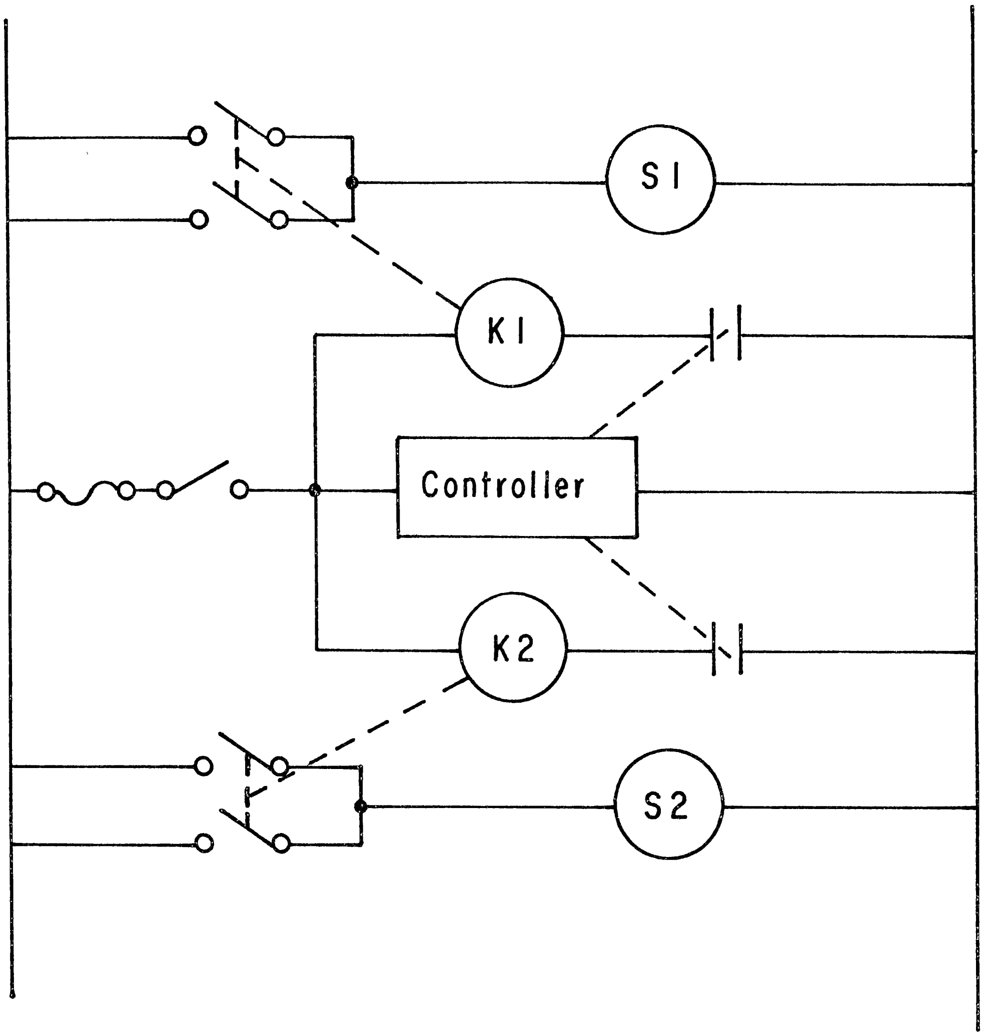

Figure 7. Schematic Diagram of Basic Control Unit for Rotating Gate

Drop Gate

The second gate automated for surge irrigation was a drop-type structure. This gate had previously been used as a semi-automatic check in cutback furrow irrigation.

This unit consists of a nylon-reinforced butyl rubber dam supported in a metal framework. Steel tubing of 12.7 mm (1/2 inch) diameter forms the upper framework and 2.54 cm (1 inch) flatiron is welded to this tubing for the base of the gate. This gate is also designed to fit in a trapezoidal ditch cross section. The rubber membrane is bolted to the base of the gate along three sides. A cable is attached to the center of the remaining side. The gate is placed in the ditch so that its narrow part is facing upstream. The top members of the upper framework are nearly parallel to the bottom of the channel (Figure 8). In its closed position the rubber membrane is lifted up, thus stopping the water (Figure 9). In its open position the membrane falls to the bottom of the channel, allowing water to flow over it and down the ditch (Figure 10).

A first attempt to automate the check was made using a standard 12 volt DC boat winch, two limit switches, and actuators fixed to the moving cable. The limit switches were activated by a lifting motion.

Several problems were encountered with this arrangement:

1. The limit switches were found to be too sensitive--a force of only 0.2 grams was needed to switch them. Often the force of the moving cable was enough to activate them, resulting in premature stopping of the opening or closing action.

2. The winch was capable of developing 6720 newtons (1500 pounds) of pull. This large amount of force was far more than the minimum

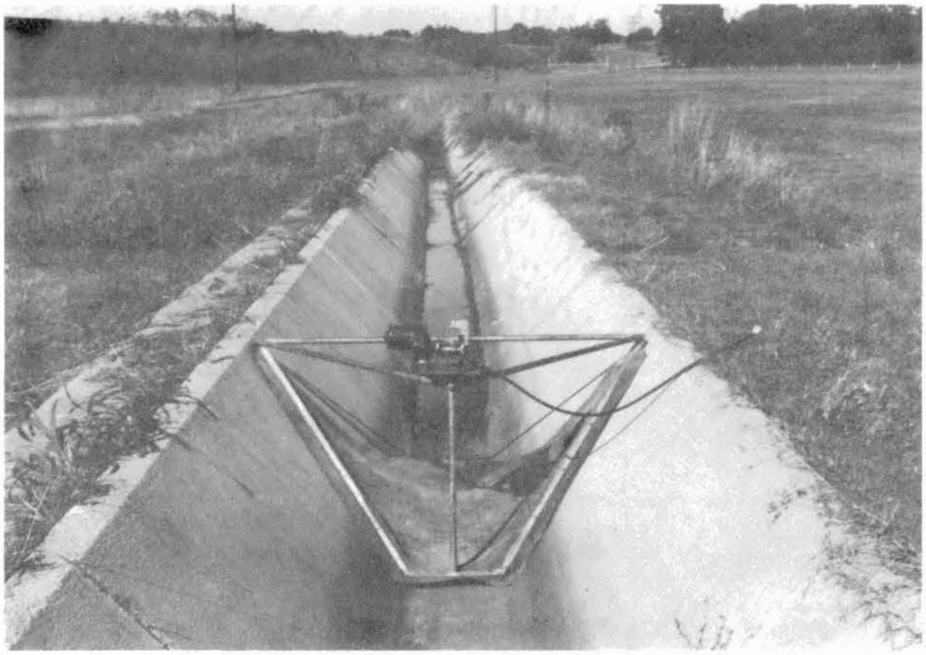

Figure 8. View of the Drop Gate in the Channel

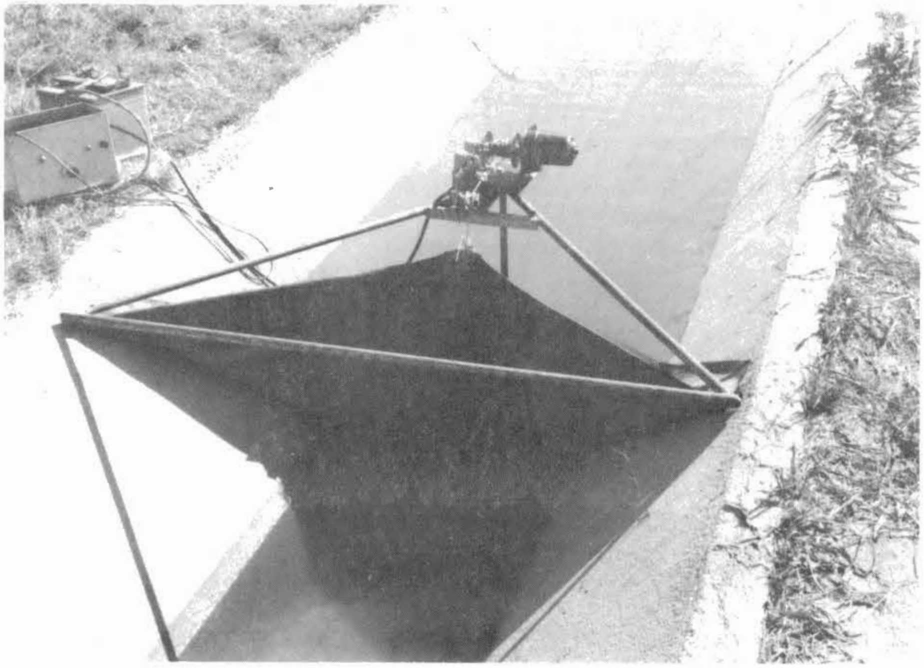

Figure 9. Drop Gate in the Closed Position

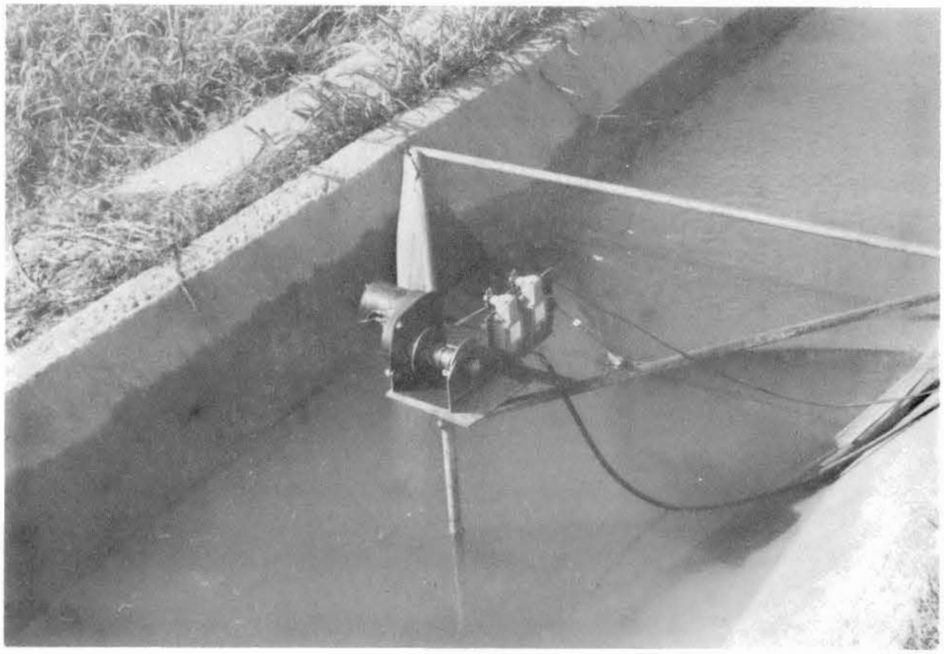

Figure 10. Drop Gate in the Open Position

required to lift the check against a full head of water. This excessive pull was responsible for bending the limit switches and their mounting bracket as well as ripping the rubber membrane when electronic failures occurred.

3. The winch required 35 amps of current under no load conditions. This caused severe problems in the design of a control unit as the components needed were not available in sizes over 25 amps. This restriction applied to both the relays and limit switches desired. In order to achieve the switching action, four single pole, 60 amp relays were used. The full current was then switched to the winch motor with two of these relays at a time. A 25 amp double action relay was also used to switch current to the coils of the 60 amp relays. This double action relay was in turn connected to the same electronic timer used in the control unit of the rotating gate. The limit switches were also connected to the coils of the large relays to avoid the conduction of large amounts of current. This setup became very complicated and difficult to work with as 10 gauge wire had to be used to handle the large power requirements.

4. Difficulties arose in trying to guide the moving cable with its attached actuators and in providing adequate support to prevent damage to the limit switch mounting bracket from the weight of the water. The actuators were larger in size than the cable and tended to catch on any sort of cable guide. The limit switches were not durable enough to handle the loads by themselves.

Several relays were burned up in an attempt to get the unit working properly. Occasionally the circuit would fail to shut off, resulting in the previously described damage to the gate.

After several attempts and failures, the winch and its operating circuit were abandoned. A new winch was constructed from a windshield wiper motor taken from a Dodge passenger car (Figure 11). This winch was much more feasible as it required about 8 amps to operate. The forces developed by it were much less and more in line with the design requirements.

Two new limit switches with lever-type action were ordered (Figure 12). These are not as sensitive and require a larger amount of force to be activated. Stronger springs were installed in the switches to increase the switching force.

A small pulley was bolted to the end of the mounting plate to carry the water load when lifting or closing the gate. This removed any load from the limit switch levers, eliminating the possibilities for damage. A 3.18 mm (1/8 inch) diameter cable was wrapped on the spool of the winch, threaded through the levers on the limit switches, and hung over the pulley.

Drop Gate Control Unit

The control unit which was finally used to operate the check turned out to be quite simple when compared to the original attempts (Figure 13). The unit consists of:

1. Integrated circuit time clock,
2. One double pole--double throw 25 amp relay,
3. A trigger switch to allow for selection of various time intervals,
4. A trigger switch to set and reset the time clock,
5. One 10 amp fuse for the protection of the entire circuit, and
6. One on-off switch to control power to the entire circuit.

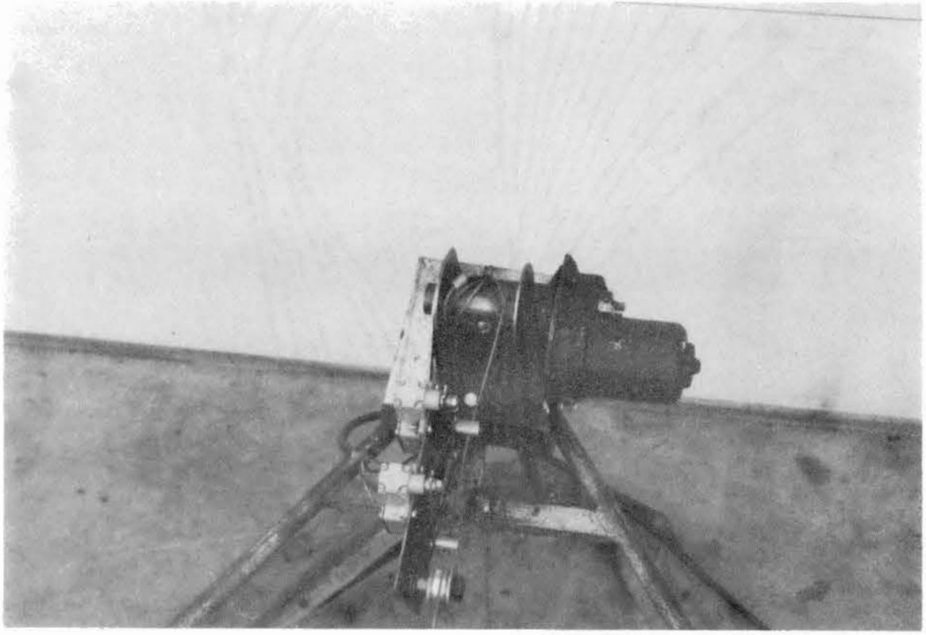

Figure 11. Windshield Wiper Motor Winch

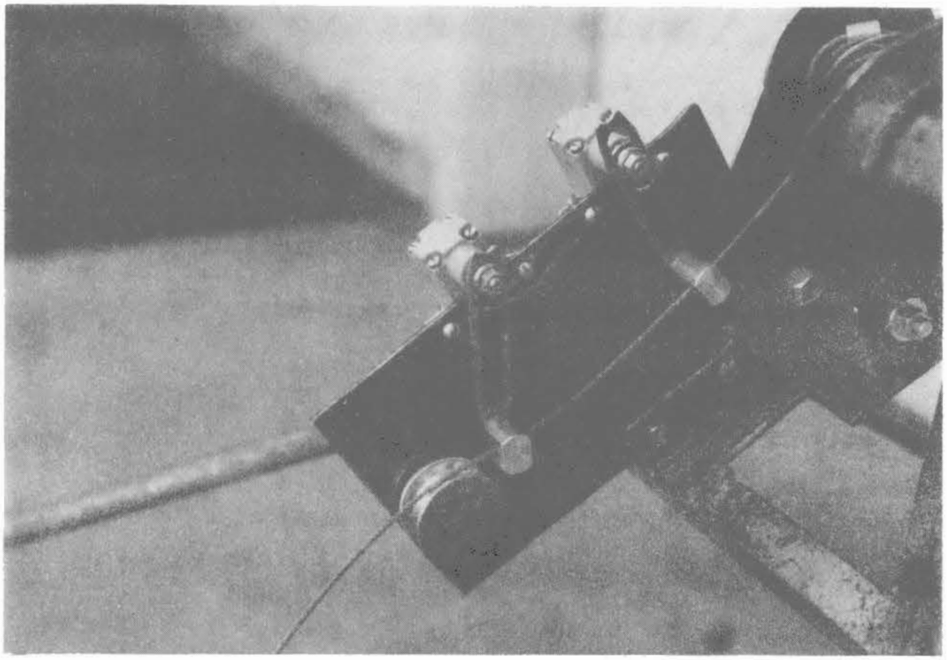

Figure 12. Side View of Limit Switches

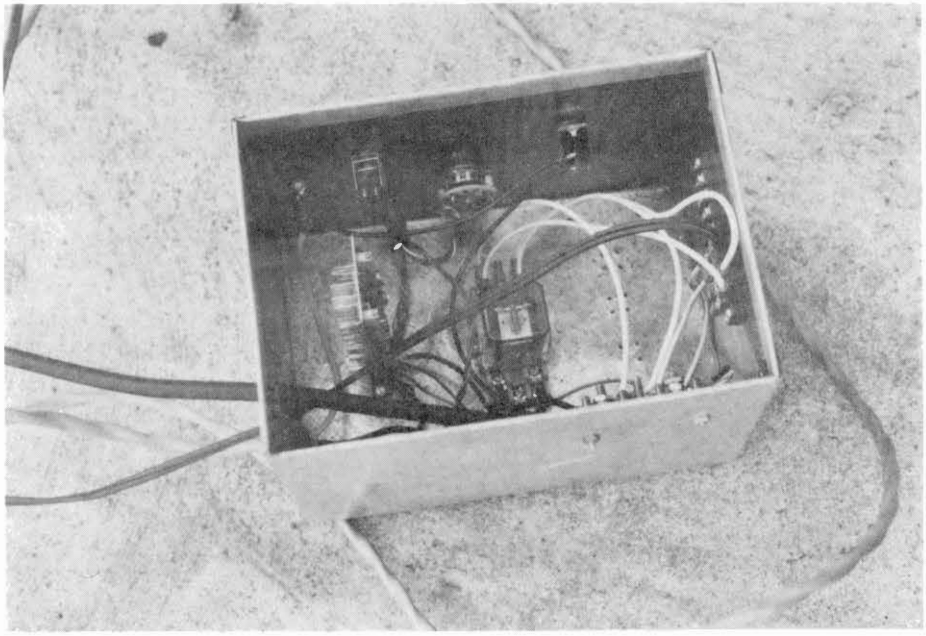

Figure 13. Drop Gate Control Unit

These components, along with the limit switches, allow for an effective way to automate any type of drop structure. Electricity for the circuit can be provided by any size of 12 volt battery depending on the operating interval desired.

The same timer (Figure 6) is used in the control circuit, and this allows for convenient interchanging between the two types of gates. As before, the toggle switch can be positioned to various time intervals.

A schematic diagram of the electric control unit is shown in Figure 14. The electronic time clock is connected to the double action relay, K1. L denotes the two limit switches. When the time for a predetermined cycle has expired, the time clock sends a pulse of electricity to the relay, completing a circuit through the motor in one direction. This operates the winch, either lifting or dropping the rubber dam. A small aluminum cylinder or some other obstruction is drawn up or down until it rotates a lever on one of the limit switches, breaking the circuit and stopping the winch. When the next time interval has elapsed, the relay is changed to its second position. This movement sends electricity the opposite way through the motor and causes an action opposite to that just completed. The first limit switch is released and the winch continues to turn until the second limit switch is contacted which again breaks the circuit. This process is repeated, resulting in alternate opening and closing of the gate.

An advantage of this gate over the rotating gate is its ability to open or close to any desired position, simply by appropriate adjustment of the movable obstructions on the cable.

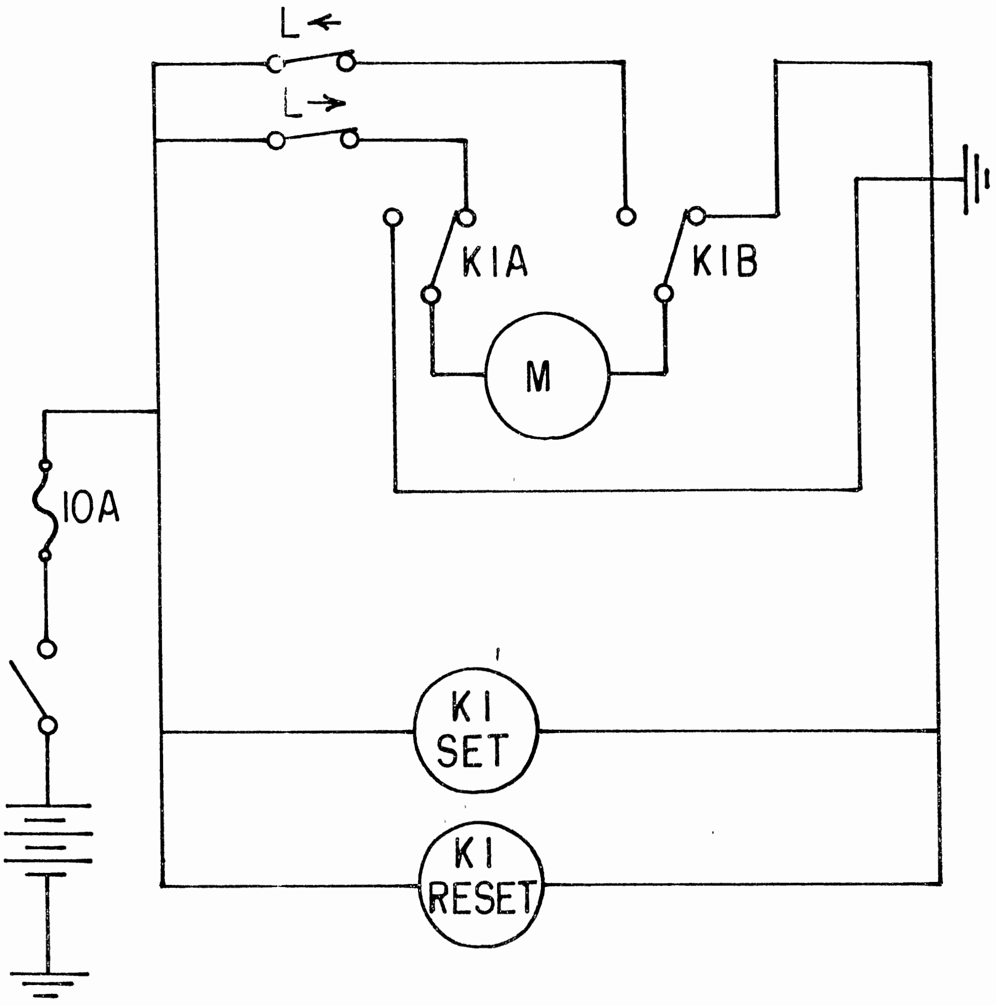

Figure 14. Schematic Diagram of Basic Control Unit for Drop Gate

Material Costs

An approximate breakdown of material costs for the rotating gate and control unit is as follows:

Basic framework and sheetmetal	$150.00
Double acting air cylinder	174.00
Two 12 volt AC solenoids	31.00
One four-way control valve	10.00
Two 25 amp double acting relays	26.00
One rotary switch	5.00
Timer board	25.00
Fittings, hose, wire, and other miscellaneous accessories	20.00
Total	$441.00

The material costs for the drop gate and control unit are as follows:

Basic framework and butyl rubber	$150.00
Two 12 volt DC limit switches	62.00
One 25 amp double acting relay	20.00
Timer board	25.00
Motor and winch	33.00
Rotary switch	5.00
Wire, connectors, and other miscellaneous accessories	20.00
Total	$315.00

Labor costs are not included in the total price of either gate.

CHAPTER IV

RESULTS AND DISCUSSION

Rotating Gate

The rotating gate was initially tested at Altus, Oklahoma, in the modified surge flow irrigation ditch. The gate was placed between the first and second bays where it cycled the water sequentially to each bay (Figure 15). The control unit performed very well, sending alternate pulses of air to each side of the cylinder at the desired time intervals.

Testing the gate without water pressure indicated that very low air pressures, down to 69 kPa (10 psi), were sufficient to operate the gate. However, when water was present, pressures in excess of 690 kPa (100 psi) were needed to open the gate. Considerably lower pressures were needed to close the gate as the weight and the momentum acquired before hitting the water were enough to ensure complete closure.

The high pressures required to open the gate against the water pressure led to an examination of the gate. This revealed that the rotating section was not of constant radius. This resulted in unwanted interference against the gasket at the outer edges of the gate at a point when opening or closing. The drive chain was also found to be out of alignment with the drive sprocket, causing the chain to come off occasionally and increasing the force needed for operation. Field repairs were made for the alignment problem by bending the cylinder mounting brackets. Grease was also applied around the edges of the neoprene rubber sealant

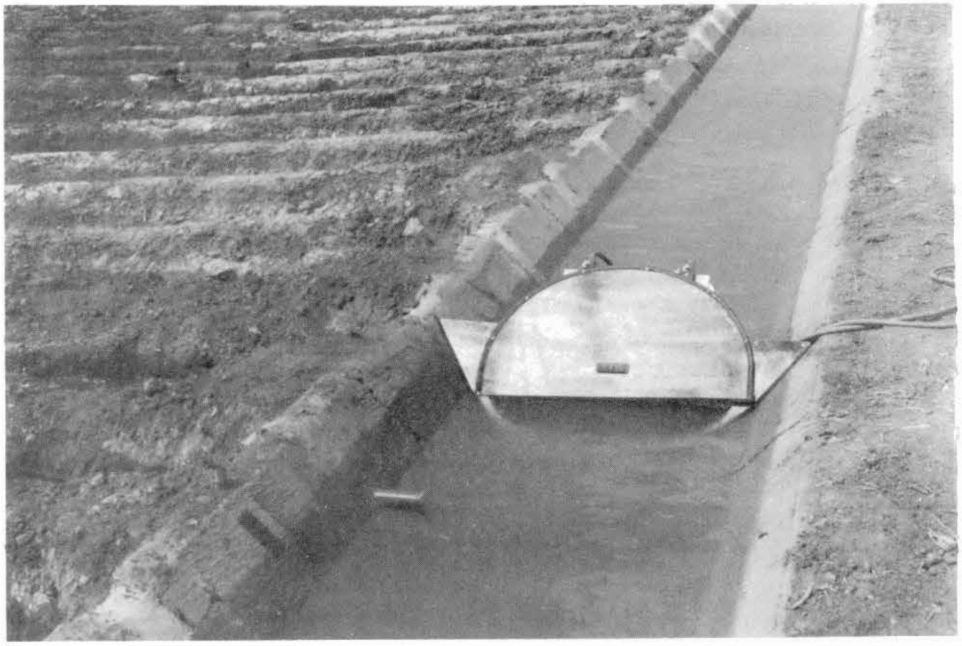

Figure 15. Rotating Gate in Field Operation

to reduce the amount of drag and decrease the opening force. These modifications improved the operation of the gate.

After this initial testing permanent changes were made to the gate. These included trimming the gate so that the rotating section had constant radius and remounting the air cylinder to eliminate any alignment problems. Retesting the gate with a full head of water indicated that the unit would operate at pressures down to about 345 kPa (50 psi) without any form of lubrication on the rubber. The friction problem may be reduced by changing the neoprene rubber to a different material such as teflon to decrease the friction drag on the rotating surface. Consideration could also be given to using an air cylinder with a larger bore. Such a cylinder would require lower air pressures to open the gate and would extend the gate's operating range. Constructing the gate so that it sits in a more vertical position in the ditch would also reduce the operating force needed.

An attempt was made to determine the number of cycles through which the gate would operate using the small air tank as the compressed air source. Crude measurements indicated that 13.8 kPa (2 psi) of air pressure was used during each operation of the air cylinder. Assuming an initial air tank pressure of 827 kPa (120 psi), 30 to 35 complete cycles are possible on one tank before refilling. This number is probably more than the number which would be required in a single irrigation, depending on the frequency of surges desired. Larger air tanks, higher starting pressures, or larger bore air cylinders would extend the length of operation. In a surge irrigation system, underground airlines from a permanent air source might be desirable to provide unlimited operating time.

The electronic timer operated by the motorcycle battery required only very small amounts of current; the battery could sustain sufficient charge to operate the timer and solenoids for several days before charging became necessary.

Reliability is a major consideration in the design of any automated gate. Few problems are anticipated in the continuous operation of the rotating gate because of its ruggedness, its simple design, and its few moving parts.

Drop Gate

The drop gate was tested for performance and suitability at the USDA Outdoor Hydraulics Laboratory. The gate operated for a short while before the timer board ceased to function. The timer from the rotating gate was then used for a few cycles before it quit working as well. The same chip on each board was found to be burned out. There was no obvious reason for these identical malfunctions in the drop gate control unit. The problem was solved by installing a diode in the timer unit to prevent undesirable feedback from the switching relay. The relay used in the drop gate was a different brand than the relays used in the rotating gate and may have generated more "noise" in the circuit, resulting in the burned chips. The diode eliminated any further problems with the control unit.

A minor problem arose with the gate when the winch was required to hold back a large depth of water. When the height of the water reached about 38 cm (15 inches) in the ditch, the force was sufficient to turn the winch and drop the gate. When enough cable had been unrolled the limit switch was released, closing the circuit and causing the winch to operate until the limit switch had been opened again. These actions were repeated as the gate was partially opened and then closed again.

This continuous operation of the winch at high water heads may eventually lead to burnout of the drive motor.

A solution to this problem would be a brake installed on the winch to prevent unwanted feedout of the cable. The brake may consist of a simple friction device which could be adjusted to increase the force required to turn the winch. Other solutions include using a solenoid operated detent in the gear train or gearing down the winch.

The winch had sufficient power to lift the rubber membrane against the depth of water which would normally flow in the ditch, about 27 cm (10.6 inches), when no discharge to the furrows is required.

Storage Analysis

The concrete lined ditch at Altus, Oklahoma, was studied to determine the effects of channel storage. Each bay consists of 29 tubes which extend through one side of the channel. Varying discharges from each bay occurred until the water level in each bay reached its steady state position. The discharges either increased or decreased with time, depending on the bay being used. The first bay of 29 tubes in the ditch experienced increasing discharge with time because storage in the bay had to increase to reach the necessary head. In order for this to occur in the bay, the water level had to rise for a large distance upstream. Consequently, the first bay did not discharge the desired amount of flow until several minutes had elapsed.

The second downstream bay had the advantage of the storage which had built up in the first bay during its irrigation period. The water which had been stored up was released almost instantanesouly, filling the second bay to a depth greater than that needed for the correct discharge. The initial tube discharge was therefore higher than the design level and decreased as the storage was depleted over time. Measurements indicated that the initial discharges were as high as 1.14 L/s (18 gpm). After a few minutes the flow rates decreased to the design level of 0.95 L/s (15 gpm).

These two different storage conditions can produce different outflows, depending on whether the water head is rising or falling. A mathematical analysis of these two different storage conditions was done to obtain the relationship of bay discharge as a function of time. The following symbols are used in the analysis:

A = water cross sectional area
B = bottom width
c = design head on tubes
D = depth of water in channel
D_{max} = maximum depth of water in channel
H = head on outlet tubes
H_{max} = maximum head on outlet tubes
L = channel length
P = wetted perimeter of ditch
t = time
T = top width of water surface
V = water volume
x = difference in elevation between tubes in adjacent bays
y = height of discharge tube inlet above channel bottom
z = ditch side slope.

For calculation purposes, the design conditions and dimensions of the channel at Altus, Oklahoma, are used and are as follows:

1. $y = 30.5$ cm (1 foot)
2. $D_{max} = 54.9$ cm (1.8 feet)
3. Length of bay = 29.5 m (96.67 feet)
4. $z = 1$
5. $B = 30.5$ cm (1 foot)
6. Inflow = 28 l/s (1 cfs)
7. $c = 9.14$ cm (0.3 foot)
8. Outflow = $30.86\ (H)^{0.5}$ l/s
9. $x = 9.14$ cm (0.3 foot)
10. $H_{max} = 24.4$ cm (0.8 foot).

Rising Head Condition

The discharge with rising head was considered first and is the simpler of the two cases. The assumption of constant water depth was made for the entire bay, thus giving the same instantaneous discharge per tube.

Using geometric relationships for the trapezoidal channel:

$$T = B + 2\,zD \tag{1}$$

$$A = (B + zD)D \tag{2}$$

$$V = L(B + zD)D. \tag{3}$$

At this point an initial volume of water is present in the ditch which is at a level just at the tube invert. The head, H, above this depth will cause outflow to take place. Therefore, a new bottom width equal to the top width of the channel at that point must be used. This gives:

$$V = LH(B + 2\,zy + zH). \tag{4}$$

Differentiating:

$$\frac{dV}{dt} = L(B + 2\ zy + 2\ zH)\ \frac{dH}{dt}\ . \tag{5}$$

Also known is the storage equation:

$$\text{Inflow} - \text{Outflow} = \frac{dV}{dt}\ . \tag{6}$$

Substituting:

$$\text{Inflow} - \text{Outflow} = L(B + 2\ zy + 2\ zH)\ \frac{dH}{dt}\ . \tag{7}$$

Therefore:

$$\frac{dH}{dt} = \frac{(\text{Inflow} - \text{Outflow})}{(L(B + 2\ zy + 2\ zH))}\ . \tag{8}$$

This equation must be integrated to explicitly define the times to reach various heads. The integral was evaluated numerically between the limits of 0 and c.

Figure 16 shows the relationship under rising head. Under this condition initial discharge is low and increases to the design level.

The initial discharges in the rising head bays can be better controlled by installing a check structure upstream so that storage will only have to be built up in the desired bay and not in the conveyance section of the ditch.

Falling Head Condition

A slightly different approach was used to analyze the bay discharge under a falling head. The storage and discharge from both the upstream bay and the bay in consideration were used.

From continuity the following equation can be written:

$$\text{Inflow} = \text{Outflow 1} + \text{Outflow 2} + \frac{dS1}{dt} + \frac{dS2}{dt} \tag{9}$$

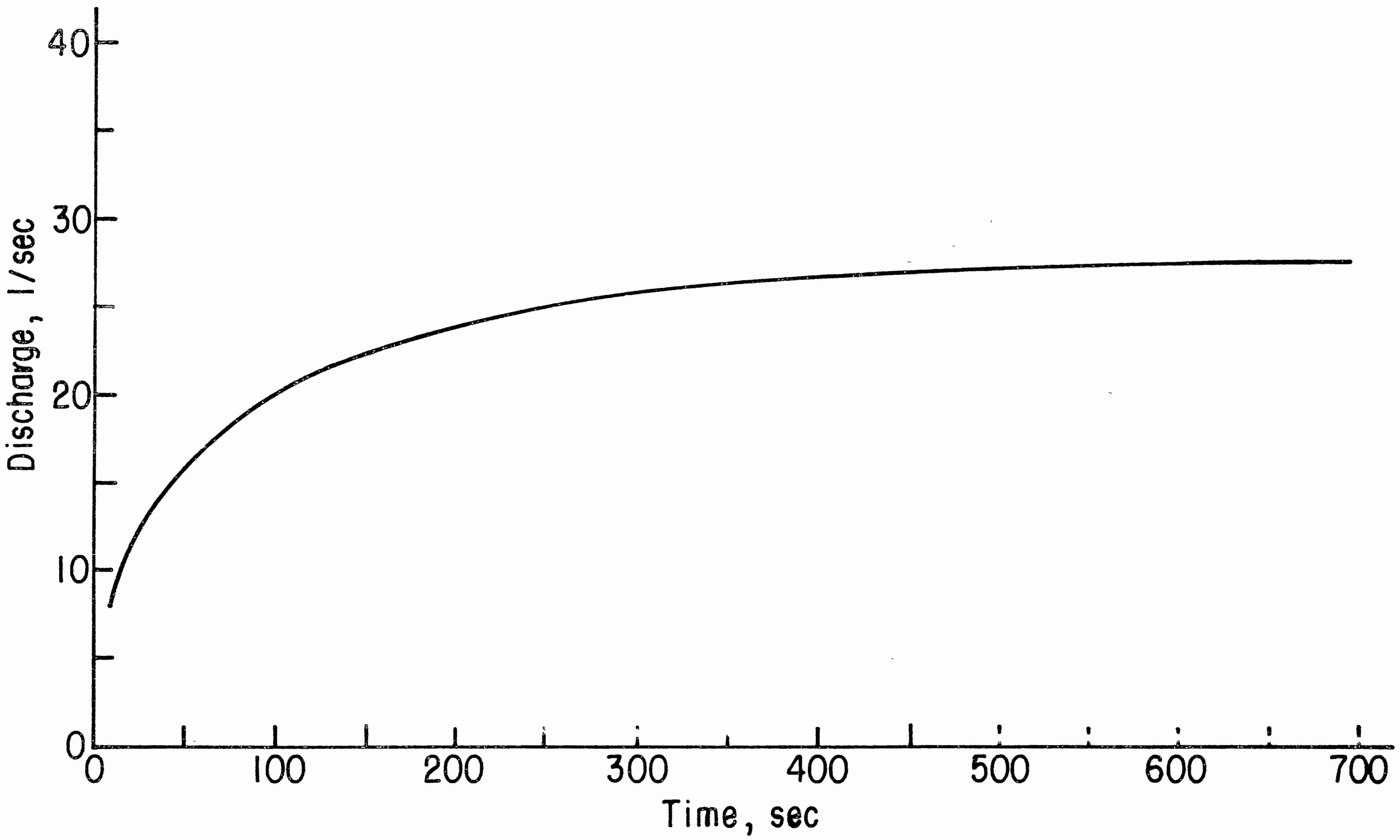

Figure 16. Discharge Under Rising Head Condition

where:

Outflow 1 = outflow from upstream bay

Outflow 2 = outflow from bay in consideration

dS1/dt = change in storage in upstream bay

dS2/dt = change in storage in bay of consideration.

Using the geometric relationships defined previously:

$$dS1 = L(B + 2\ zy + 2\ zH)\,dH \tag{10}$$

$$dS2 = L(B + 2\ zy + z(2H - x))\,dH. \tag{11}$$

Also:

$$\text{Outflow 1} = 50.86\ ((H - 0.3))^{0.5}$$

$$\text{Outflow 2} = 50.86\ (H^{0.5}).$$

Substituting these relationships into Equation (9) and simplifying gives:

$$\text{Inflow} = \text{Outflow 1} + \text{Outflow 2} + L(2B + 4\ zy + 4\ zH - zx)\ \frac{dH}{dt}\ . \tag{12}$$

Therefore:

$$\frac{dH}{dt} = \frac{(\text{Inflow} - \text{Outflow 1} - \text{Outflow 2})}{L(2B + 4\ zy + 4\ zH - zx)}\ . \tag{13}$$

This equation was numerically integrated between H_{max} and c. Figure 17 shows this relationship which indicates that initial discharge is high and decreases to the design level.

Better regulation of outflow is possible in the falling head bay by allowing for flow of excess water over the check dam.

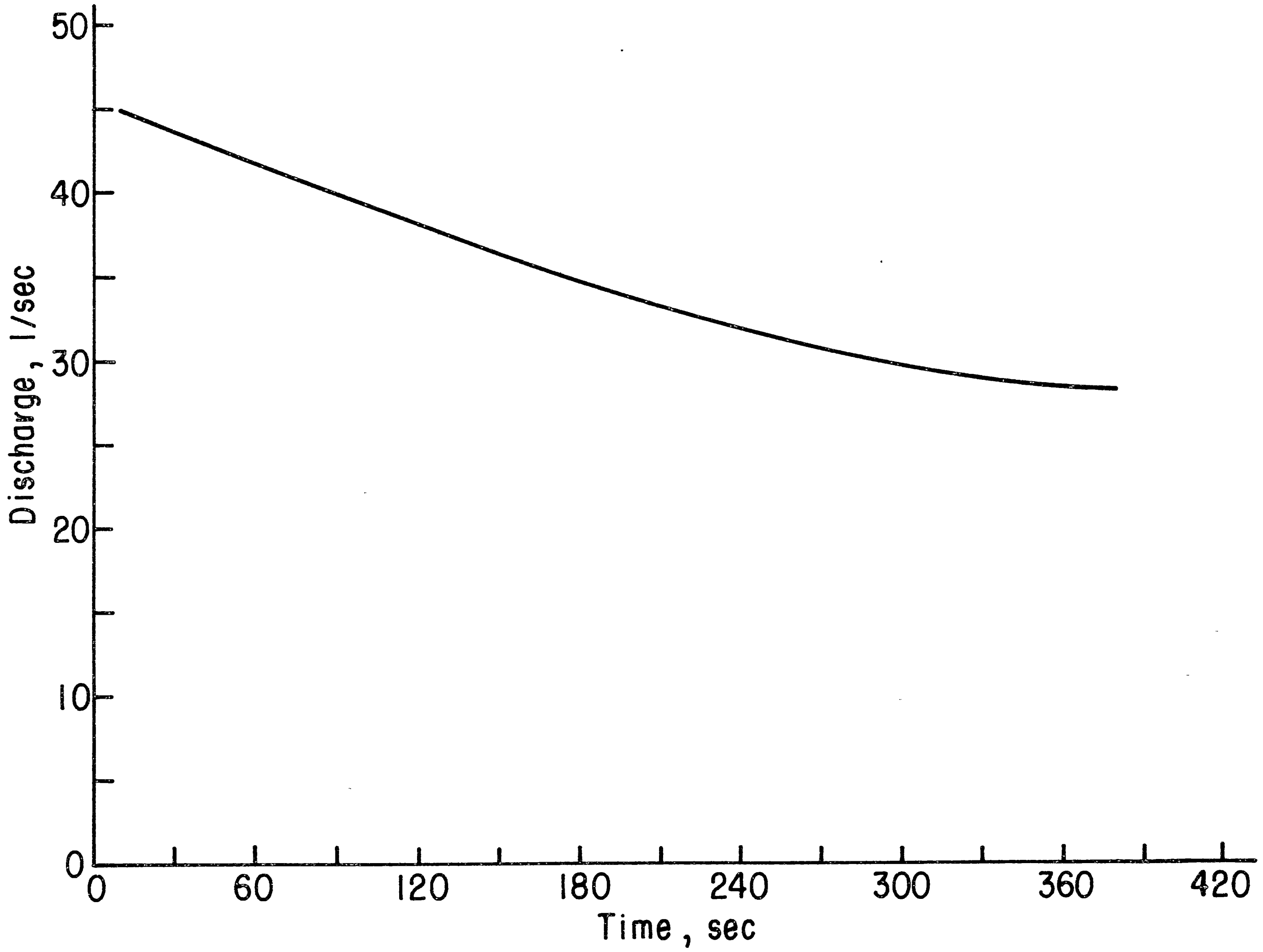

Figure 17. Discharge Under Falling Head Condition

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Two automated gates were built for the open channel application of surge flow irrigation. Both gates were designed for use in trapezoidal channels with bays of tubes or spiles. The presence of such channels is essential for the application of surge flow irrigation with these gates.

The first structure built was of a rotating design and utilized a double acting air cylinder to open and close the gate at specified intervals. An electronic timer was used in conjunction with solenoids and a four-way control valve to operate the gate. This gate performed very well and few problems are anticipated with its future operation. A larger air cylinder may be needed if the gate is to be used with large heads of water or if lower operating air pressures are desired. The air cylinder and control unit can be easily adapted to other basic gate designs.

The second structure was a modified drop check. In its final form the gate has a small electric winch to lift or drop a butyl rubber membrane. The control unit utilized the same electronic timer as used in the rotating gate as well as a double acting relay to switch the current through the motor. Limit switches were mounted to stop the raising and lowering of the gate. Performance of this gate was adequate, but its larger number of moving parts is a disadvantage when compared to the rotating gate. A big advantage of this gate is the capability of intermediate settings. By appropriate use of the limit switches infinite discharge rates are possible.

Both gates are portable which allows their use at more than one irrigation site. This portability will dramatically decrease the capital costs over permanent gated pipe systems. Material costs for the rotating gate were approximately $441.00. A larger bore air cylinder will increase this total by at least $100.00. For the drop gate material costs were about $315.00. This slight price advantage may be offset by decreased reliability.

Conclusions

1. The rotating gate is a very effective structure for the application of open channel surge flow irrigation.

2. The drop gate, though not as effective as the rotating gate, will provide surge irrigation at a lower cost.

3. The timer and control unit for both gates performed very well. These components can be easily adapted for other automatic structures.

Suggestions for Further Study

1. The use of a microprocessor to allow for easy, infinite control is desirable. Such a unit will allow the operator to set other than 50 percent cycles and will give the operator the option of using different time intervals for the initial stages of irrigation and the final stages when the wetting front has reached the end of the furrows. This will reduce runoff and further enhance the advantages of surge irrigation.

2. Studies should be done on the operation of the two gates to determine their long term performance and dependability.

3. Research on the design of other automated checks should continue to achieve increased reliability and decreased costs.

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