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**A device for controlling the installation rate of subsurface trickle
irrigation laterals**

Wodrich, Timothy Dirk, M.S.

The University of Arizona, 1990

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A DEVICE FOR CONTROLLING THE
INSTALLATION RATE OF SUBSURFACE
TRICKLE IRRIGATION LATERALS

by

Timothy Dirk Wodrich

A Thesis Submitted to the Faculty of the
DEPARTMENT OF AGRICULTURE & BIOSYSTEMS ENGINEERING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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STATEMENT BY AUTHOR

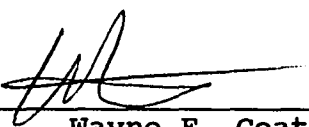
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APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:



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Associate Professor of
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11/29/90

Date

DEDICATION

This thesis is dedicated to my father and mother, Noel and Donna.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. K.A. Jordan for his advice and help in the development of the electronics involved in the project. Thanks are also greatly extended to his thesis advisor, Dr. W.E. Coates, whose guidance and assistance assured that this project would be completed.

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ABSTRACT

A three-point hitch, mounted implement was developed to control the injection rate of trickle irrigation tubing. Power to the implement was supplied by the tractor's electric and hydraulic systems.

A doppler radar velocity sensor measured ground speed and provided a signal to a single board computer. The computer generated an output signal which operated a throttling valve that controlled the hydraulic flow to the motor coupled to one of two pulling wheels. The wheels, mounted on parallel shafts with their faces in contact, utilized friction to feed the tubing. An error feedback loop controlled the pulling wheels speed with satisfactory operation being obtained over a range of travel speeds of 3.7 km/h to 5.6 km/h.

Extra tube dispensing and cutting systems were incorporated in the design. These were manually activated by the operator when required.

INTRODUCTION

Background

In the last 15 years, trickle irrigation has experienced a tremendous increase in commercial use. Hall (1985) stated that over one-half million acres were being irrigated by this technique. Not only in arid areas is trickle irrigation being used, but it is also used in humid areas to provide supplemental water during dry periods to meet evapotranspiration; that is evaporation plus water loss from plants (Arnon, 1972).

One method of trickle irrigation uses tubing installed below the soil surface. Equipment used to install subsurface trickle irrigation tubing consists of a vertical tillage tool, such as a subsoiler, which has a channel or duct mounted behind the subsoiler that guides the tubing into the soil. Tubing is supplied from a roll mounted above the duct. To start the process of installing the tubing, a person either stands on the end of the tubing or attaches the end to the ground with a large staple to hold it in place. The implement then moves through the field inserting the tubing into the ground. The force required to pull the tubing from the reel is supplied by the frictional force of the soil acting against

the tubing. At the end of the field, sufficient tubing is manually pulled off the reel to permit connection to the submain. The tubing is then cut, and sometimes sealed by tying a knot in the line, then the process is repeated. Sealing prevents foreign material from entering the tubing and clogging the emitters which would reduce water flow.

Pierre deWet (1987), manager of rose production at Red Mountain Farms, has expressed concerns that installing the tubing into the ground, using only frictional forces to pull tubing off the reel, could cause stretching (elongation) of the tubing. Geohring, Swader, and Thomas (1982) stated that stretching could affect the strength characteristics of corrugated plastic drain tubing and its life. Also stretching and/or pulling the tubing through the soil could allow soil particles to enter the emitters. This could reduce, or stop, the water flow resulting in an uneven wetting pattern.

Controlling the feed rate of the tubing to match ground speed of the implement would enable the tubing to be placed into the soil in a relaxed state, meaning without tension. This would eliminate tubing strain, and prevent stretching or dragging of the tubing through the soil. Reduced strain would also allow the use of lighter weight or thinner walled tubing. This would be an economical benefit for the producer since thinner walled tubing costs less.

Addition of a semi-automatic tube cutting and feed out system would permit a single person to install laterals without having to leave the tractor seat except to change rolls of tubing, or for correction of malfunctions. If such an injector was constructed as a module, multiple row implements could be assembled which would require only a single operator. For a four row implement this would reduce the number of people required from three or more to one, thereby greatly increasing labor capacity.

Literature Review

No articles were found during an exhaustive literature review of the effects of stretch on trickle irrigation tubing. Geohring, Swader, and Thomas (1982) studied corrugated plastic drain tubing stretch during drain plow installation. Tubing was installed both with and without the assistance of a power feed device. Stretch was observed to range from zero to 9.5 percent without the power feed. Stretch was reduced to between -3.2 and +2.6 percent with the power feed device. This indicates that a power feed device can significantly reduce tubing stretch. According to Drablos et al. (1973), stretch affects the relative strength of corrugated plastic tubing. The relative strength of tubing stretched 5 percent is 11 percent less than unstretched tubing for a given

temperature. Ten percent stretch relates to a 24 percent decrease in relative strength.

Haffar, Baasiri, and Marrush (1986) developed a prototype plastic-mulch, trickle irrigation tubing installation machine which was powered by two ground driven wheels. Power was delivered, through a transmission, to a feeding unit which was geared to provide the length of tubing unrolled approximately equal to the ground distance traveled. The feeding unit consisted of two rubber wheels which rotated against each other and pulled the tubing from a reel. Tubing was then guided to the soil surface by means of a metal tube attached to the frame.

A device for installing subsurface trickle irrigation tubing was developed by Coates and Lorenzen (1987). The single row implement unwound tubing at a rate equal to the installation ground speed. A pair of pneumatic tires, mounted on parallel shafts so that the faces were in contact, utilized friction to feed the tubing at the desired rate. The tires were powered through chains and a belt drive from a ground-driven wheel. Adjustment of a variable pitch diameter sheave permitted the rate of tubing feed out to be set equal to the ground speed. During operation, the driver had to continuously monitor the tubing to ensure that the proper feeding rate was maintained. In addition to monitoring the

feed rate two manual tasks were required: cutting the tubing, and feeding out sufficient tubing at the end of each lateral.

OBJECTIVES

The objective of this project was to design a subsurface trickle irrigation installation device that would control the rate at which trickle irrigation tubing was metered into the soil. The implement would be required to:

- 1) Control dispensing of tubing at a rate equal to ground speed.
- 2) Cut the tubing.
- 3) Feed out extra tubing at the start of, and upon reaching the end of, a lateral.

IMPLEMENT DEVELOPMENT

In order to obtain higher accuracy and have adaptive control of a system, a link or feedback is needed from the output to the input of the system. In a closed-loop control system, or feedback control system, a controlled signal is fed back and compared with a reference input. An actuating signal, proportional to the difference of the input and the output, is then sent through the system to correct the error (Kuo, 1987).

In the design reported on in this thesis, micro-processors were used to monitor both travel speed and feed rate of the tubing in order to control the rate at which the Bi-wall tubing, a thin walled trickle irrigation tubing that does not hold a round shape, was metered into the soil (Trade names are given for clarity and do not constitute an endorsement of the product by the author or the University of Arizona). Through the use of a closed-loop control system, an output signal was sent to a mechanism which unwound the tubing at a rate equal to the travel speed of the implement.

Ground Speed Measurement Techniques

Ground speed measurement techniques have been investigated by Richardson et al.(1982), Smith (1985), and

Tompkins et al.(1985). Free-rolling fifth wheels have been widely used in agriculture to sense ground speed for monitoring and control. A straight forward approach to measuring ground speed is to assume that it equals the circumferential speed of an undriven wheel. Implicit in the assumption is that the wheel is operating at zero wheel slip, and that its rolling radius is known. Smith (1985) showed that average rolling circumference changed with soil type and velocity. Soft soils allowed the wheel to sink, which increased rolling resistance and caused variations in wheel slip (sliding) depending on wheel type and vertical load. As slip increased, accuracy of speed measurement decreased. A speed sensor utilizing a ground contacting wheel should be calibrated for the specific soil conditions on which implement speed measurement is to be obtained. Since subsurface trickle irrigation installation implements are operated over a wide variety of soil conditions, fifth wheel methods of measuring ground speed appear unsuitable. Additionally, inaccuracies introduced by this type of sensor prevent them from being effectively used as an input parameter for a closed loop control system (Tsuha, McConnell and Witt, 1982).

A report by Stone, Kransler, and Appleman (1985) stated that image based speed measurement had the potential to overcome the limitations of free rolling fifth wheels. While

it has that advantage, it also has several disadvantages.

An image based system uses successively acquired images to obtain displacement. Displacement of objects in consecutive images is proportional to displacement of the implement. The amount of time between consecutive images and the displacement are then used to calculate speed. To obtain the greatest input signal into a computer imaging chip, the surface image must be in focus. Operating on a rough surface could cause the image to come in and out of focus resulting in a poor input signal. Other problems associated with image based speed measurement systems are: side-slip mis-alignment (perpendicular to displacement) is limited to 6% of the displacement, extra illumination is required for low light conditions, angular mis-alignment is limited to 0.9 degrees, and images can be obscured by dust. Because of these limitations, an image based speed measurement system was not investigated for this project.

A doppler radar speed sensor is the most reliable sensor for control applications as reported by Richardson et al.(1982), Tompkins et al.(1985), and Tsuha, McConnell and Witt (1982). The typical accuracy of a single-beam radar sensor is plus or minus 2% (Sokol, 1985). An added advantage is that these devices provide a conditioned output signal whose frequency is directly proportional to true ground speed.

A radar sensor transmits and receives a radio frequency at 24.125 GHz. Frequency difference between the signals sent to, and those received from, the ground are proportional to the implement's ground speed and are technically known as the Doppler frequency shift. This frequency difference is converted to a TTL level output signal, of approximately 27.5 Hz per km/h, and is a time varying square wave. With output being in a TTL format, it can be easily accepted by a microprocessor and is compatible with standard digital devices. Other advantages of radar sensors are: compatibility with the overall electrical performance and capability of most vehicle electrical systems, and minimal electrical power requirements.

Description of Implement

Controller and Microprocessor

The microprocessor used in the design was a Micromint BCC52 BASIC computer/controller board, hereafter referred to as BCC52. The BCC52 used an Intel 8052AH-BASIC processor. The processor was an 8 bit micro-controller chip which contained a ROM resident 8K byte BASIC interpreter. In addition to the processor, the BCC52 contained space for 48K bytes of memory, a 2764/27128 EPROM programmer, three parallel

ports and a serial terminal port with automatic restart and baud rate selection.

The three parallel ports of the BCC52 were configured to have port A as input, and both ports B and C as outputs. Port C was dedicated to sending logic control signals. Those logic signals were used to control various logic devices, or initiated the operation of electronic components in their proper sequence. Ports A, B and C were connected to a data bus which passed information between the BCC52, the main controller unit and the peripherals.

The main controller unit developed during the project consisted of integrated circuit chips and various other electronic components. The main controller schematic is shown in Figure 1. Its function was to take signals from the various sensors and either convert analog signals to digital signals, convert digital signals to analog signals, control the direction of signals, or control the timing and sequence of events. The wiring schematics of the main controller unit are provided in Appendix A.

The timing and sequence of events were controlled by the computer. To eliminate bus contention three-state latches were used. These logic devices were octal D-type latches, 74LS373. These latches operated bi-directionally which allowed information to be stored and then either passed

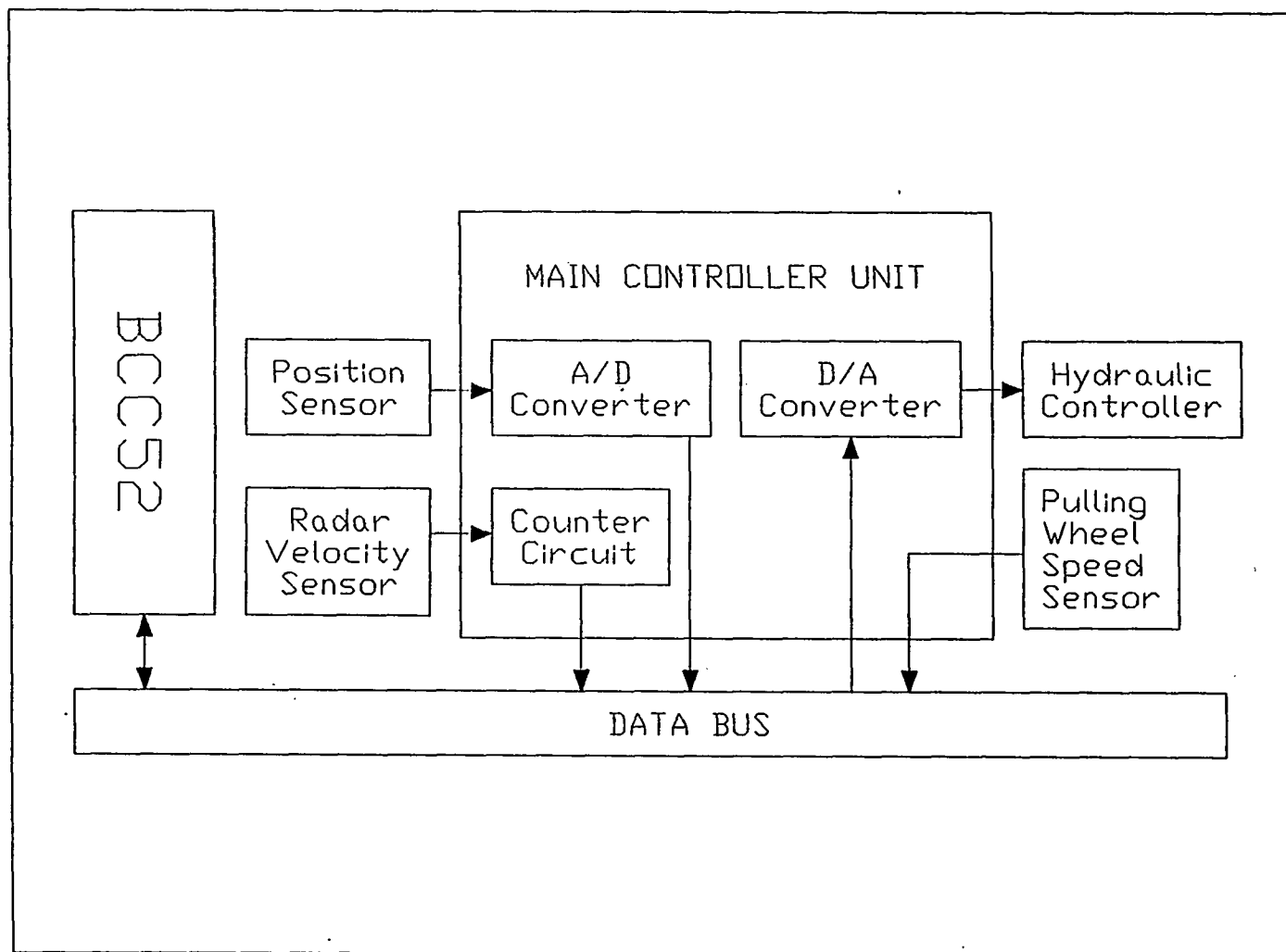


Figure 1. Main Controller Schematic

through to the data bus, or received from the data bus when activated. They are isolated from the data bus when in the tri-stated condition.

Ground speed and feedback signal information entered the BCC52 through port A as binary code. The BCC52 was programmed to control the timing and proper sequence at which the signals entered the 74LS373 D-type latches.

In order to control the rate at which the tubing was dispensed, a feedback control system was developed. In this system, a signal from the pulling wheels speed sensor (described later) was compared with a reference input, in this case the ground speed of the implement. The difference between the input and the output was then calculated in the BCC52's program, which then provided the signal to enable control action. The calculated difference was multiplied by a dampening ratio and added to the output signal. The proportional gain or dampening ratio was set as a percentage of the error and limited the magnitude of the reaction to a step response change of the reference input, in this case, the travel speed of the implement. The output signal was sent through port B to the main controller unit. In the main controller unit, a voltage output 8-bit digital-to-analog convertor changed the digital output signal to a corresponding voltage level which was used to control a hydraulic motor

described later in the text.

Ground Speed Measurement

A method of frequency counting described by Cooper and Helfrich (1985) operated on the principle of gating a known input frequency into a counter circuit for a specified amount of time. A similar technique was used in this study. To determine the frequency of the ground speed sensor, the signal was gated together with a known clock frequency by using an AND logic gate.

Ground speed information for the test implement was supplied by a microwave transceiver, a DICKEY-john Radar II Velocity Sensor. It produced a square wave signal whose frequency was proportional to the ground speed of the vehicle, 27.5 Hz per km/h. Gating was accomplished by using an AND gate and a known input clock frequency of 125 KHz. At this clock frequency, a resolution of 0.0002 km/h was possible in the velocity reading.

The frequency counter was started by a signal sent from the BCC52, through port C, to a logic AND gate which directed the 125 KHz clock signal to the counter circuit. The counter circuit counted the number of cycles of the 125 KHz clock for one complete cycle of the radar signal. A more detailed analysis of the control logic of the counter circuit is listed

in Appendix B.

The synchronous binary counters were decoded to determine the number of clock pulses, from the 125 KHz clock frequency, that occurred during one complete cycle of the radar signal. The binary count was transferred sequentially in two bytes on the data bus to port A of the BCC52. The BCC52 then combined the two bytes and calculated the speed of the implement.

The counters were constructed of four synchronous 4-bit binary counters, 74HC161. The 4-bit binary counters were connected as a synchronous counter to provide a 16 bit count or a maximum count of 64K. The outputs of the first two counters, the low byte, were connected to a 74LS373 octal D-type latch, A, shown in figure A3 of Appendix A. The second two counters, the high byte, were connected to a second 74LS373 octal D-type latch, B, shown in figure A3. The latches, A or B, were selectively connected to the 8-bit data bus. Selection was necessary to eliminate data bus contention, having two signals on the data bus at the same time. The BCC52 program selected the low byte counter by sending a logic signal to A that brought the D-type latch out of the tri-stated condition. The low byte counter then passed its information onto the data bus. The high byte passed its information onto the data bus when the BCC52 program brought the high byte D-type latch out of the tri-state condition.

The information passed on the data bus was received by the BCC52. The proper sequence of events were controlled by the BCC52's program through port C, PC0 - PC2, using a 3 to 8 decoder, 74LS138.

The accuracy of the DICKEY-john Radar II Velocity Sensor was stated, by the manufacturer, to be within plus or minus 3% of actual velocity over the speed range of 0.4 to 3.2 km/h and plus or minus 1% of actual velocity over the speed range of 3.2 to 70.8 km/h. To correct for inaccuracies in speed measurement, a position sensor monitored the position of the tubing as it followed a pre-determined path through the implement. The tubing looped underneath a wheel, which was free to move vertically, and then travelled up over a fixed axis wheel and down toward the soil as shown in Figure 2. Both idler wheels were 152 mm in diameter and 50 mm wide. When the tubing deviated from the set path, it caused the movable wheel to change position. The position sensor detected the change in the wheel's position, which corresponded to a change in the tubing position.

The position sensor was a Celesco position/displacement transducer, model PT-101-30A. It had an input impedance of 500 ohms and an output impedance of 0 to 500 ohms. The transducer provided a variable output voltage signal of 0 to 5.12 volts DC. It was mounted on the frame near the movable

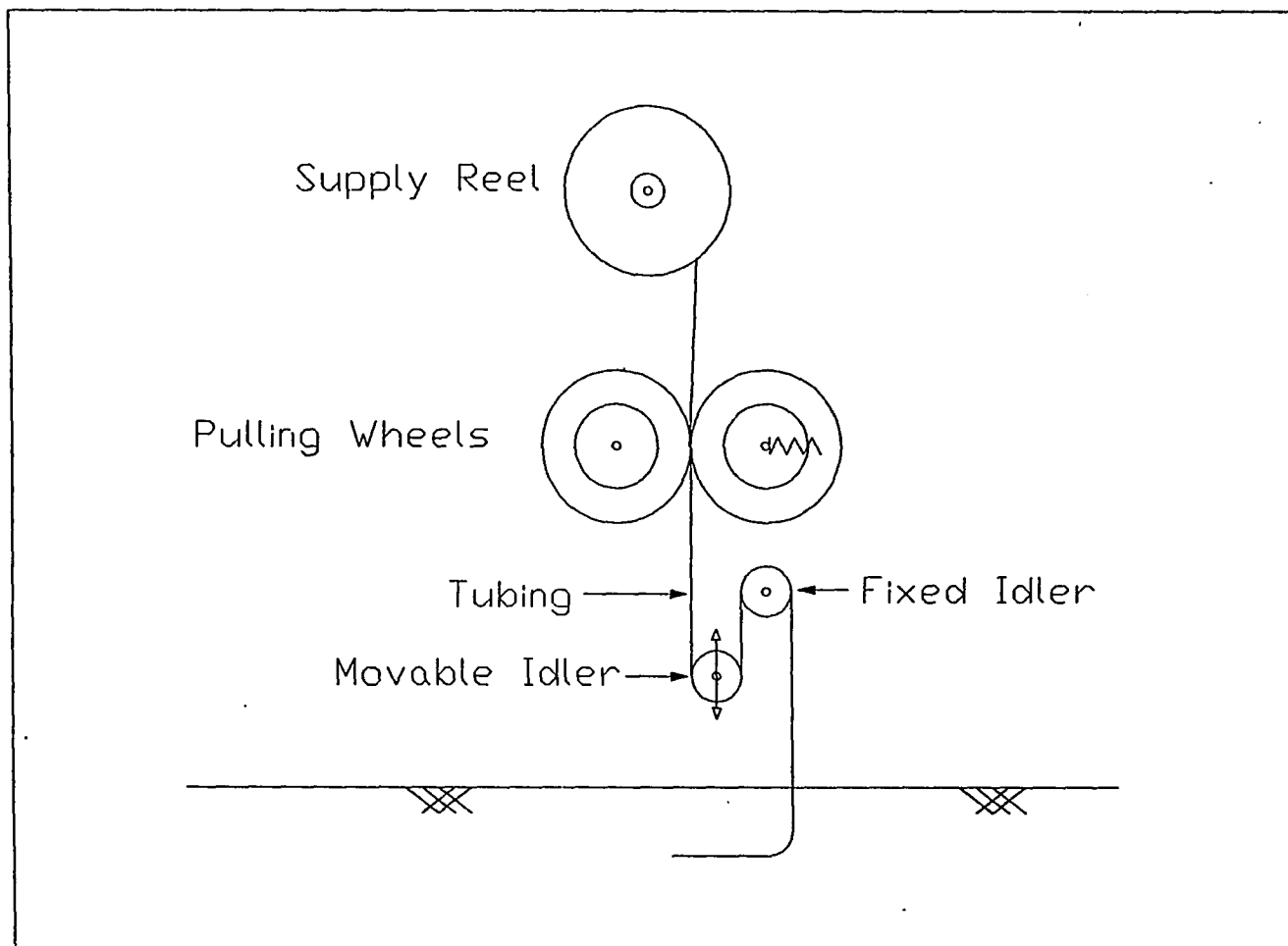


Figure 2. Position Sensor Schematic

idler wheel with its sliding cable connected to the axle of the wheel. As the idler wheel rose or fell, the transducer sent a variable voltage signal to the main controller unit.

Underestimated ground speed caused tubing feed rate to be insufficient as compared to the rate of travel of the implement. This caused the movable idler wheel to move up, and this motion was sensed by the position sensor. The converse occurred when the radar velocity sensor overestimated true ground speed.

The variable voltage signal from the position sensor was sent to a 8-bit analog-to-digital converter in the main controller unit. The converter changed the voltage signal to a digital signal which was sent to the BCC52. The BCC52 then added the error to the signal received from the radar velocity sensor to make appropriate adjustments to the tubing feed rate.

To provide the operator with knowledge of the tubing's position, status lights mounted on the control box indicated the tubing's position. When the position sensor deviated excessively from the normal, a warning light alerted the operator of a possible malfunction. Otherwise, the other status light indicated that the system was operating normally.

Tube Feeding System

A tube feeding system was constructed similar to the one developed by Coates and Lorenzen (1987). The device consisted of a pair of

0.514 m diameter pneumatic tires, 0.114 m wide, mounted on parallel shafts so that the faces were in contact. They utilized friction to pull the tubing from the supply reel at the desired rate. One wheel, mounted on a fixed axle, was powered by a hydraulic motor. The other wheel moved horizontally, against spring tension, thereby permitting the tires to separate slightly and allow tubing connectors to pass between the pulling wheels without being damaged.

Pulling Wheel Speed Sensor

The sensor was a Hewlett Packard HEDS-9100 series optical incremental encoder module and code wheel. The module consisted of a lensed LED source and a detector integrated circuit enclosed in a small C-shaped plastic package. Due to a highly collimated light source and a unique photo-detector array, the module was extremely tolerant to mounting misalignment. The module was mounted on the frame near the axle. The code wheel, attached by adhesive directly to the end of the pulling wheel's axle, rotated between the module's

emitter and detector. This positioning caused the light beam to be interrupted by the code wheel's pattern of spaces and bars as the wheel rotated. Photodiodes detected those interruptions, and signal processing circuitry produced digital waveforms. One revolution of the code wheel produced 512 cycles of the digital waveform.

A quadrature decoder/counter interface integrated chip processed the digital waveforms from the HEDS-9100. A Hewlett Packard HCTL-2000 performed the quadrature decoding, counting, and 8-bit data bus functions. The HCTL-2000 consisted of a 4 times quadrature decoder, a 12 bit binary up/down state counter and an 8-bit data bus interface.

A second Micromint BCC52 BASIC computer/controller board was dedicated solely to calculating the pulling wheels peripheral speed. This BCC52 continuously calculated the pulling wheels peripheral speed. The system was designed to provide the quickest possible response time. This BCC52 received the number of pulses that were counted by the HCTL-2000 12 bit binary up/down state counter in a 400 ms time span. This number was converted to the pulling wheels peripheral speed and then sent, as a digital output, to the main controller unit on the data bus. The system had a resolution of plus or minus 0.0045 km/h.

Hydraulic System

The hydraulic system is shown in Figure 3. One pair of remote tractor hydraulic outlets provided the source of hydraulic power. The hydraulic system was divided into two circuits. Circuit (A) powered the pulling wheels, and circuit (B) powered the cutting device.

In circuit (A), a Vickers solenoid activated proportional throttle valve, model KTG4V-3-2B19S-MPB-W-G-40, controlled the flow to a Char-Lynn hydraulic motor, model 101-1002-009. The hydraulic motor was coupled directly to the axle of the fixed axis pulling wheel. The throttle valve was activated by a Vickers electronic proportional valve controller, model EM-VP-12-10. This hydraulic controller consisted of a pulse width modulated output stage with current sensing which provided an output current proportional to an input voltage. The input voltage was generated by the main controller unit described earlier.

In circuit (B), a Vickers solenoid activated four-way directional control valve, model DG4S4-018C-50, controlled the fluid flow to the hydraulic cylinder which actuated the tubing cutter. The 12 vdc solenoid was activated, by the operator, with a three position switch. The momentary on, off, momentary on switch was held in one position to extend

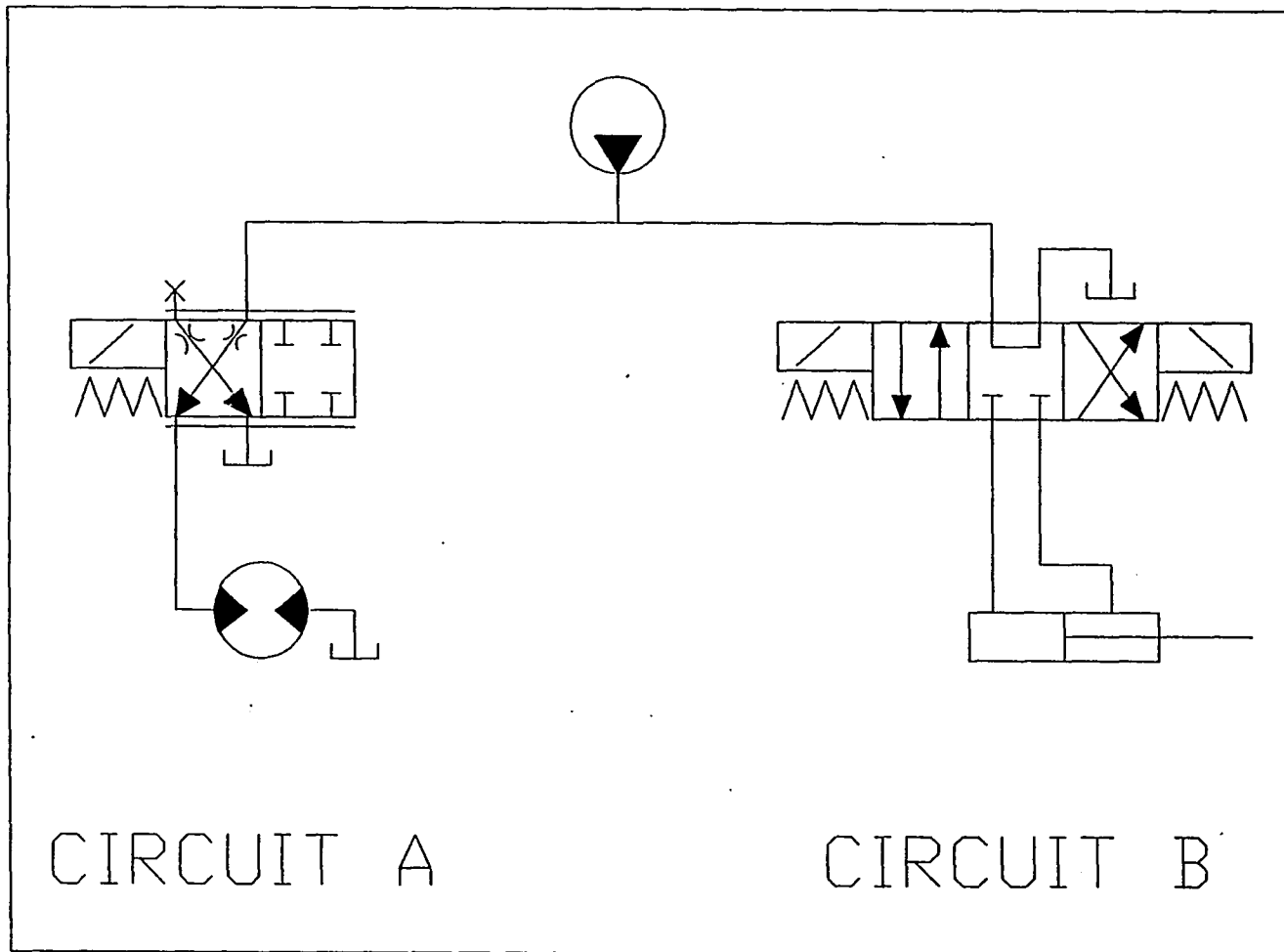


Figure 3. Hydraulic System

the cylinder, and then held in its opposite position to retract the cylinder. The spring loaded switch returned to its center, or off, position after cutting the tubing.

Dispensing Extra Tubing

A manually operated switch was used to dispense extra tubing at either end of a lateral. When activated, the switch sent a signal, to the main controller unit, bypassing the ground speed sensor. The controller then sent a constant binary code to the voltage output 8-bit digital-to-analog convertor, which provided a constant output voltage to the hydraulic controller. The switch was turned on until the desired length of extra tubing was dispensed, and then was returned to the neutral or off position.

Tube Cutting System

The tube cutter was a hydraulically powered, two-element shearing device. The tubing was cut by activating a control valve which extended a double acting hydraulic cylinder. A sickle section attached to the cylinder ram passed a stationary knife edge and provided effective two element shear. After cutting, the operator reversed the hydraulic flow in the control valve, which retracted the cylinder's ram, and moved the sickle section from the tubing path.

Functional Evaluation of The Implement

Ground Speed vs. Pulling Wheel Speed

Tests were run to observe the behavior and functionality of the main controller unit. Drip irrigation tubing was metered out onto the ground surface to visually observe the behavior of the tubing as the implement travelled. The free end of the tubing was tied to a weight to provide tension in the tubing. This was intended to simulate the frictional forces of the soil acting against the tubing which exist if tubing is inserted into the soil.

During these tests the ground speed of the tractor, and the pulling wheels peripheral speed were recorded every 500 ms. Tractor speed was sensed by the radar velocity sensor, while the pulling wheel peripheral speed was sensed by the optical encoder. The data points, taken during the time required to traverse a 25 meter test length, were stored in the BCC52's internal memory. At the end of each test, the data was transferred to a magnetic disk for storage.

At the start of the series of tests, the proper gain of the variable voltage signal sent from the position transducer was unknown. Tests were conducted to determine the level of gain which would provide the desired reaction behavior to the

inaccuracies in the detection of ground speed.

For the first trial the gain was arbitrarily set at 15. The most undesirable results of two runs conducted with this gain are shown in Figure 4. During these runs the pulling wheels peripheral speed did not settle down and match that of ground speed, rather it changed radically and had a large coefficient of variation. The sensed tractor ground speed averaged 3.61 km/h, and had a coefficient of variation of 8.03%. The pulling wheels peripheral speed averaged 3.40 km/h, with a coefficient of variation of 43.53% being recorded.

The movable idler wheel, which monitored the tubing's position, rapidly travelled from its minimum to maximum positions during both tests. Study of the data showed that the magnitude of the gain was too great, causing the controller to over-react to the variable voltage signal received from the position sensor.

Based on those observations, the gain of the position sensor was reduced to 6. A new set of tests were run while recording both tractor ground speed and pulling wheel peripheral speed. The most undesirable test results are shown in Figure 5. Again the pulling wheel speed did not settle down and match that of ground speed. The tractor speed averaged 3.95 km/h, with a coefficient of variation of 9.87%.

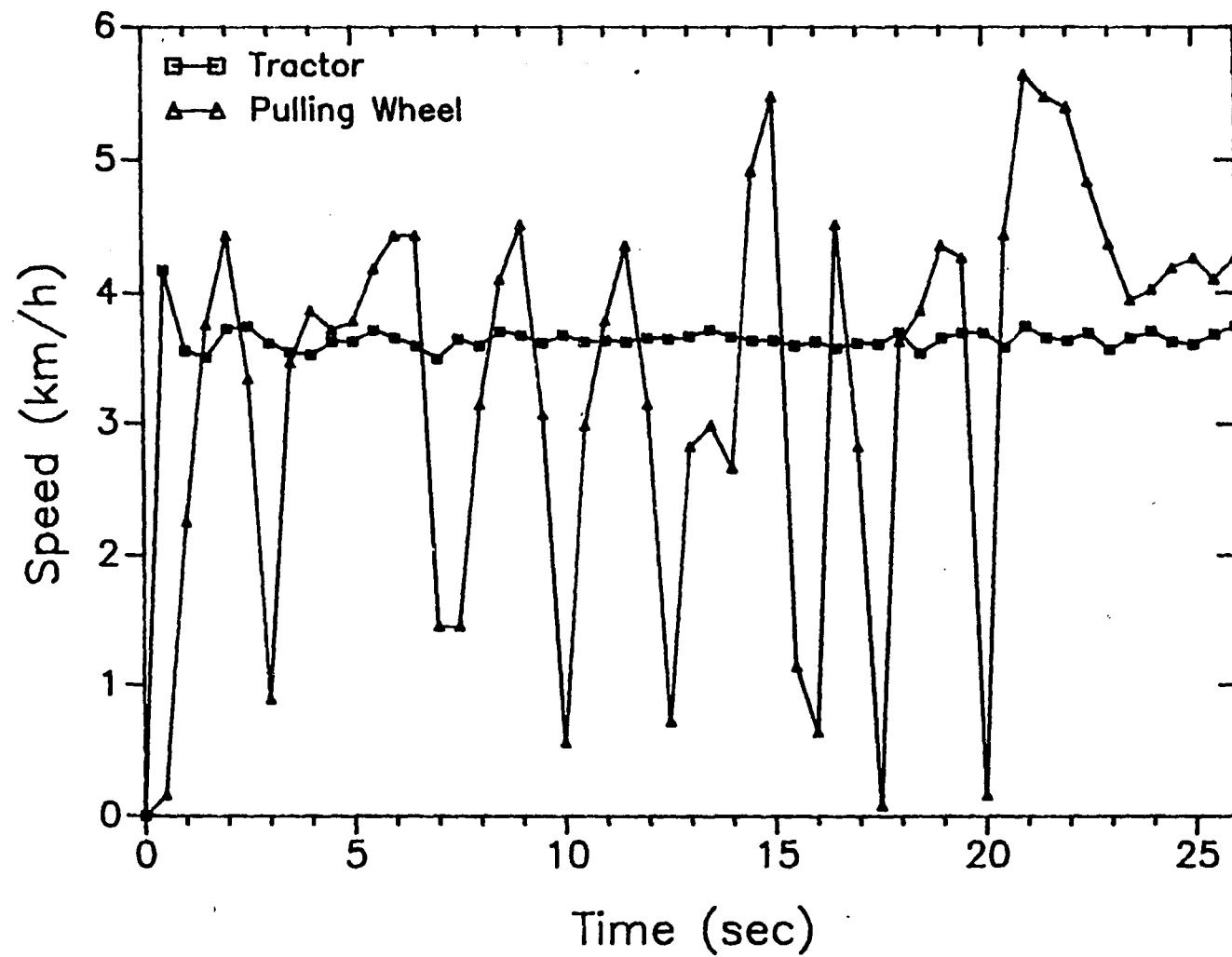


Figure 4. Tractor and Pulling Wheel Speed vs. Time: Gain 15

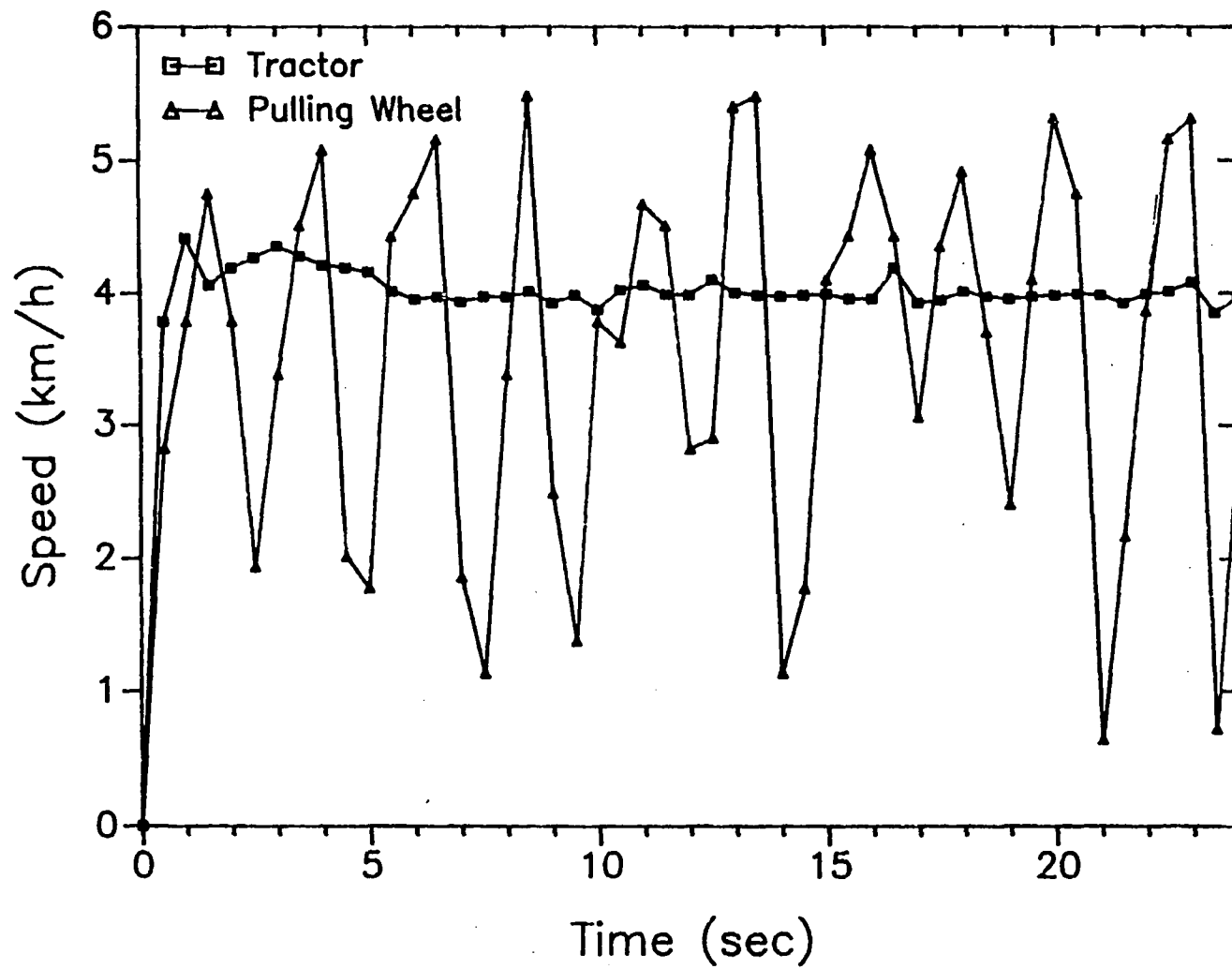


Figure 5. Tractor and Pulling Wheel Speed vs. Time: Gain 6

The pulling wheels peripheral speed averaged 3.67 km/h, with a coefficient of variation of 37.33%. Again the movable idler wheel rapidly travelled from its minimum to maximum positions during these tests and the drip irrigation tubing was observed to be dispensed in a very erratic manner. At times extreme tension was placed on the tubing indicating very undesirable results.

In an attempt to eliminate the occurrence of periodic tension, the variable voltage gain was reduced to 3. Similar results occurred as are shown in Figure 6. Further gain reduction caused the signal from the position sensor to be negligible when compared to the overall output signal magnitude. As a result no further tests were conducted.

It was concluded from this series of tests, that the position sensor did not operate as intended. It was unable to correct the inaccuracies in the ground speed measurement as sensed by the radar velocity sensor. As a consequence this method of using a movable idler wheel to monitor the tubing's position was abandoned.

Dispensing of Extra Tubing

Throughout the tests which were conducted to observe the behavior of the main controller unit, the system intended to dispense extra tubing at the ends of a lateral did not operate

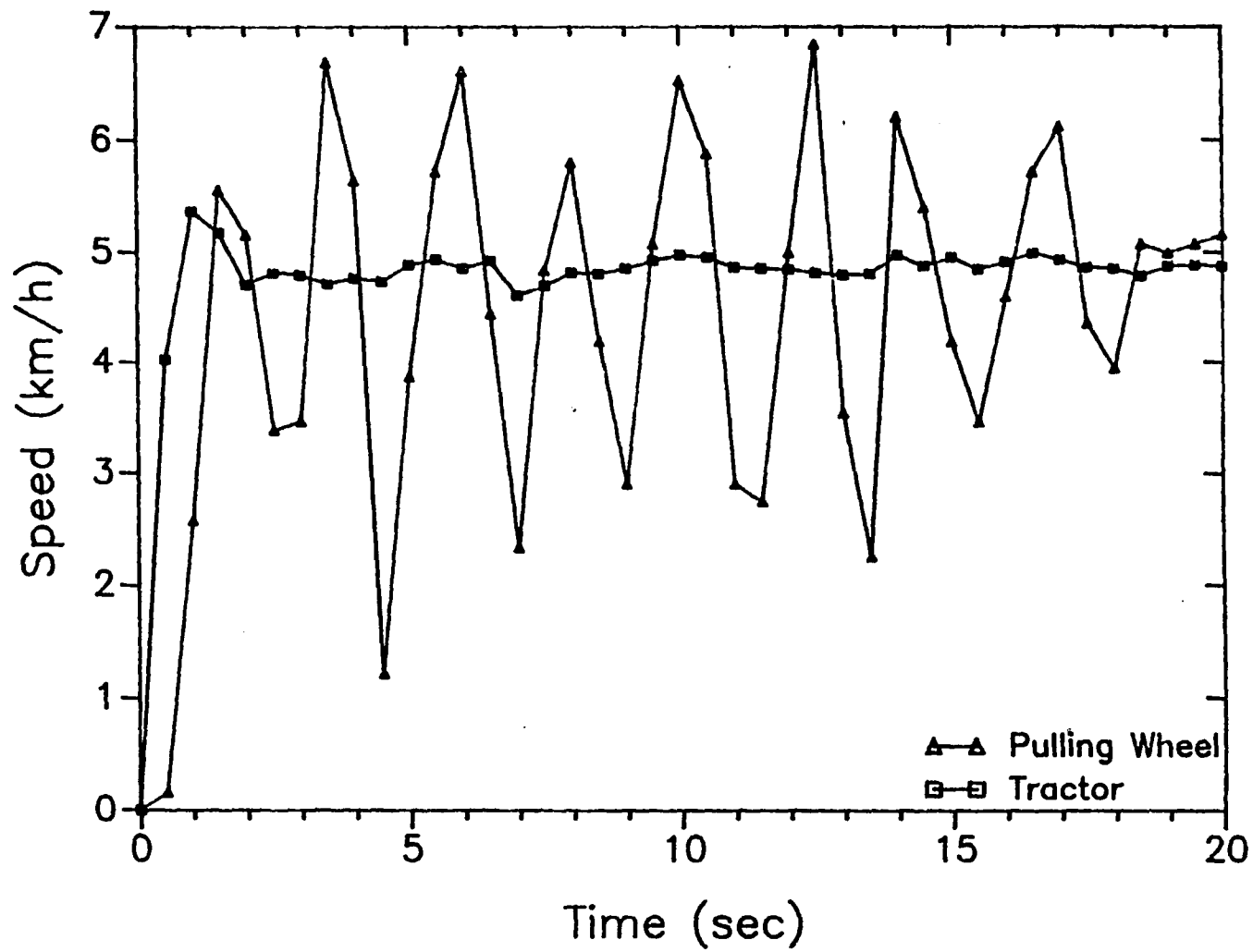


Figure 6. Tractor and Pulling Wheel Speed vs. Time: Gain 3

successfully. When extra tubing was dispensed, it became jammed within the implement.

A pair of side shields, set 50 mm apart, was intended to guide the tubing and keep it from slipping off the idler wheels. When extra tubing was dispensed, it became jammed in the space around the wheels and between the shields. With no force, or tension, created by the soil to pull the tubing around the idler wheels, the tubing did not exit the system. This situation is similar to trying to push a rope through a curved path. Considering both the erratic behavior of the movable idler wheel described earlier, and the problem of the tubing jamming between the shields when extra tubing was dispensed, it was decided to remove the two idler wheels.

This significantly simplified the design of the implement. After leaving the pulling wheels, the tubing travelled in a duct to the tube cutting device, and then down to the soil as shown in Figure 7. This eliminated the position sensor, which was shown to be ineffective in earlier tests, and reduced the problem of pushing the tubing around the two idler wheels when dispensing extra tubing. Tests showed that the removal of the idler wheels allowed extra tubing to be dispensed without lodging between the shields.

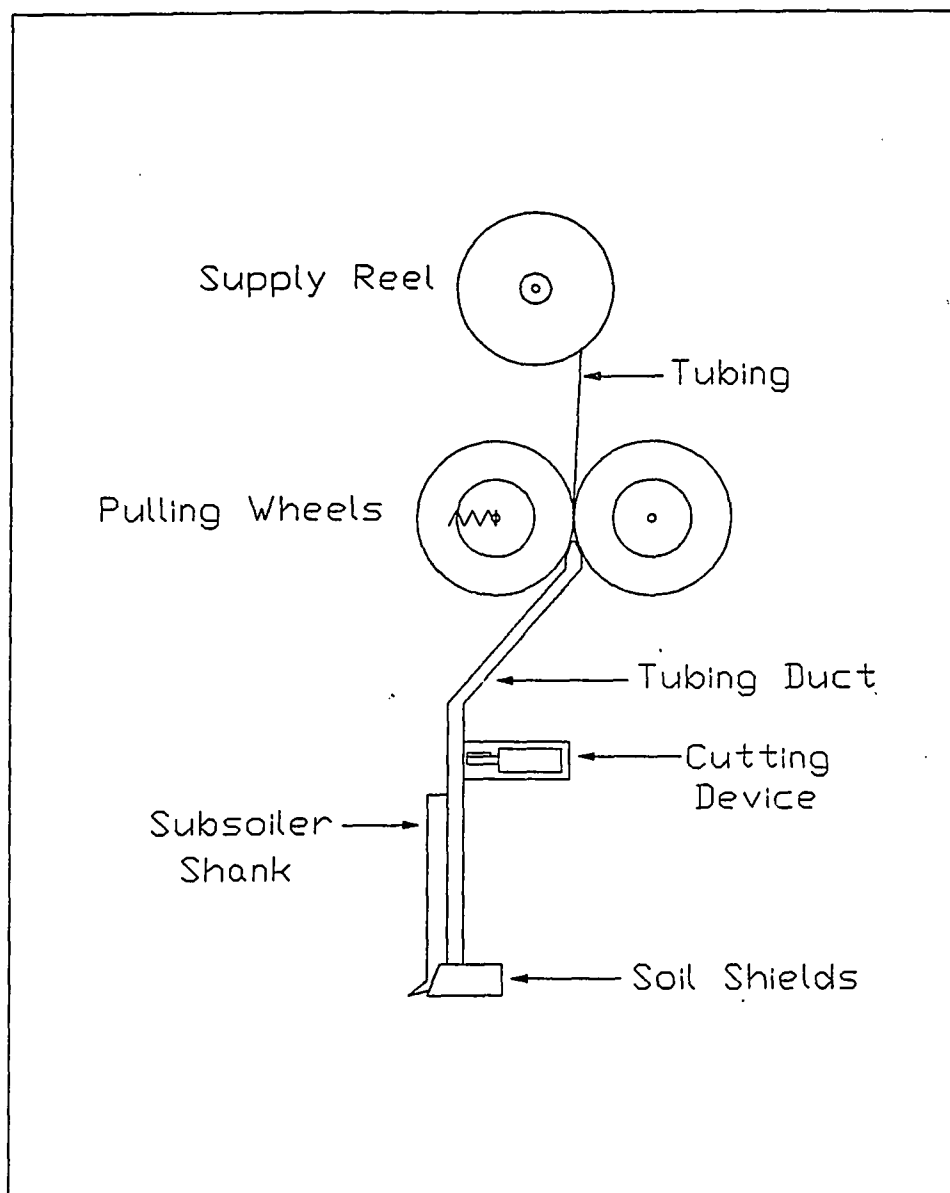


Figure 7. Tubing Injector Schematic

Insertion of Tubing

Tests were run to observe the implement while installing tubing under field conditions. At the start of a lateral, the procedure began by dispensing approximately 2 m of extra tubing. This was done to simulate the extra tubing needed to permit connection to a submain. As the tractor started to move forward the implement was gradually lowered, by the operator, approximately 100 mm into the ground.

The hydraulic throttling valve had a delay time of approximately 90 ms. The reaction time of the controller and the delay time of the throttling valve combined to give an overall delay time for the implement of approximately 1.5 seconds. Due to this overall delay time, the time from the start of the implement's movement to the start of the pulling wheels rotation, the tubing was dragged through the soil for a short distance. This dragging was concluded to be permissible since the frictional forces of the soil acting against the tubing at the start of a lateral were thought to be insufficient to cause stretching of the tubing. For this reason no attempt was made to correct the problem.

When malfunctions occurred during tube insertion, the implement was stopped to correct them. The implement was not raised since it was in the process of inserting a lateral.

Upon resuming operation, the delay time caused the implement to drag the tubing for a short distance before the pulling wheels started to rotate again. Since a length of tubing was already in the soil, the distance the implement moved without dispensing any additional tubing caused the tubing to be stretched excessively.

One aspect thought to aggravate the problem was that the length of time which the main controller unit's program took to cycle was excessive. This caused an overly long reaction time. Revision of the program by eliminating the steps which stored data in the memory decreased the cycle time to 95 ms from the original 500 ms. The feedback control system's program was also rewritten which reduced its cycle time to 100 ms from the original 400 ms.

Even with these changes the problem of an overly long reaction time persisted. Study showed that each time the program cycled, the output signal was adjusted by the error, as calculated by the BCC52. At the start of a new lateral, the pulling wheels did not rotate for the first several cycles of the program. In each cycle, the output was increased by the adjusted error. Several cycles were needed in order to reach the threshold at which the hydraulic valve controller reacted. Meanwhile the tractor had reached its field speed. When the hydraulic controller finally reacted to the

increasing output signal, the pulling wheel peripheral speed was greater than the ground speed. This reaction caused the pulling wheel speed to overshoot the ground speed by 10% to 60%. The main controller unit subsequently reacted to reduce the pulling wheels speed to match the ground speed. The output signal was reduced and caused the pulling wheels peripheral speed to undershoot the ground speed. The system then oscillated until it settled down to a steady state condition, that being ground speed as detected by the radar velocity sensor.

From field tests, it was deduced that during the period of overshoot, the rate of tubing entering the system was greater than the rate of tubing leaving the system. This caused the total length of tubing between the pulling wheels and the entry point into the soil to be larger than required. The increased length caused the tubing to go into compression. Excessive compression caused the tubing to buckle and become lodged between the guides leading from the pulling wheels down to the entry point into the soil. This was followed by severe stretching of the tubing which had been inserted into the soil since the tubing was unable to be dragged through the soil. The frictional forces of the soil acting against the tubing prevented movement. When the earlier tests of laying tubing onto the ground surface were conducted, this problem was not

detected. This indicated that the observation techniques used in the previous tests were not adequate. When the tubing was laid on the ground surface, the excess tubing fed out during periods of overshoot, was able to leave the implement and consequently did not become wedged in the tubing guides.

To reduce the amount of overshoot, the dampening ratio was reduced. This slowed the overall reaction time of the system. This caused an even greater delay time, and further increased the distance that the tubing was pulled through the soil at the start of each lateral.

Another aspect thought to aggravate the delay problem was the torque required to accelerate the pulling wheels from rest to field speed. Calculations, shown in Appendix C, indicated that 1.26 N-m of torque was required to accelerate the pulling wheels from rest to 4.8 km/h in 1.5 seconds. At system operating pressures the hydraulic motor was capable of developing approximately 24.9 N-m; this represented 19.8 times the torque required. To accelerate the pulling wheels, roughly 5% of the hydraulic motor's capacity was required and consequently this was not considered to be the source of the problem.

Another concern related to acceleration and time delay was when a full supply reel of tubing was mounted on the implement. Considering the same field speed previously

described, the torque required to accelerate a full reel of tubing was 2.64 N-m. The combined total torque required to accelerate the pulling wheels and the full supply reel of tubing was approximately 3.90 N-m. This was only 16% of what the hydraulic motor was capable of producing. From these calculations it was concluded that the moment of inertia to start the pulling wheels and the roll of tubing did not significantly affect the system.

Further analysis of the buckling problem showed that this only occurred during periods of overshoot when the main controller unit reacted to a large step response in the ground speed. To prevent this from occurring, the main BCC52 program was rewritten such that the pulling wheels peripheral speed was compared to the ground speed and the BCC52 reacted accordingly. If a difference of ten percent or more existed between the two speeds, the BCC52 sent a step response output to the hydraulic controller. When the difference was less than ten percent, the BCC52 sent a response output which utilized feedback control. A listing of the program is provided in Appendix D. The decision making section of the program is lines 22 to 70. Field tests using the modified program showed that the large overshoot produced by the earlier program had been eliminated and the implement inserted the tubing satisfactorily between travel speeds of 3.7 km/h

and 5.6 km/h. As shown in Figure 8, the pulling wheel peripheral speed followed the ground speed satisfactorily. The average pulling wheel peripheral speed deviated 1.46% from the average ground speed. This error was within the design objective of 2% of the average ground speed.

Tube Cutting System

The tube cutter performed satisfactorily. The sickle section made a clean shear of the tubing. The four-way directional valve had some internal leakage which caused the cylinder ram to extend slowly when the valve was in its neutral position. This caused the sickle section to move into the path of the tubing. This problem did not affect the overall performance of the implement, however.

Distance Travelled vs. Tubing Length Dispensed

Tests were conducted to compare actual implement travel distance to the length of tubing metered out. During these tests the tubing was dispensed on top of the ground surface. The controller program utilized during the trials, was the final version which had a cycle length of 95 ms and which utilized the initial step response followed by feedback control.

Prior to each run the tubing was unwound and was marked

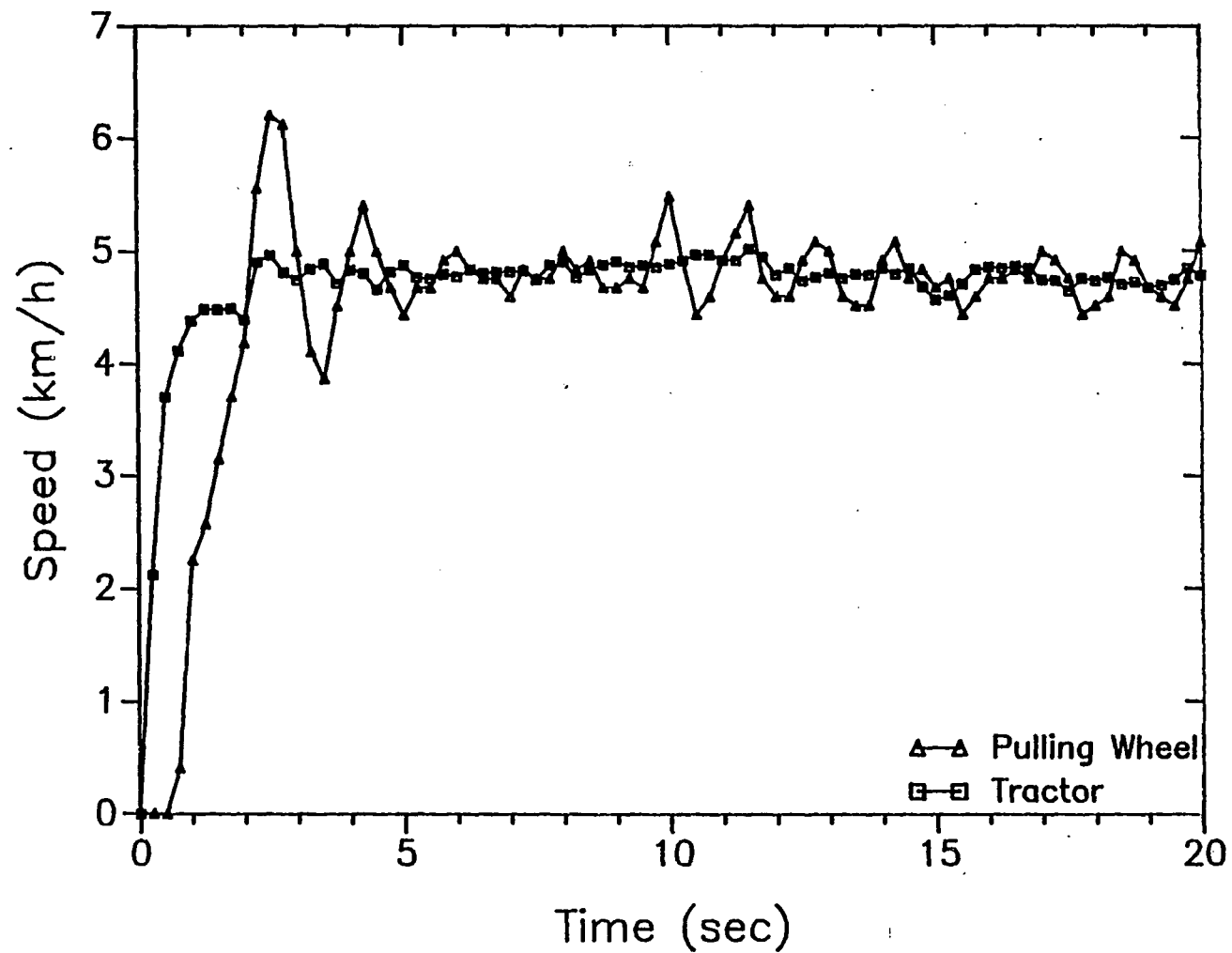


Figure 8. Tractor and Pulling Wheel Speed vs. Time

with red tape wrapped around it, approximately 7 m from the free end. The tubing was then rewound back onto the supply reel. When the red mark on the tubing left the implement, a person marked the spot on the ground with a stake where the red mark was dispensed. This delay from the start of dispensing was done to ensure that data would not be taken until the implement dispensing rate had settled to the ground speed rate following the initiation of motion. After the implement travelled approximately 33 m, the person walking behind the implement drove another stake through the tubing, anchoring it to the ground. The length of marked tubing, from where the stake was driven through it to where the red mark was, was measured with a steel tape measure. The marked distance covered by the implement between the stakes was also measured with the steel tape measure.

The test results are shown in Table 1. The accuracy of the tubing measurement was determined to be plus or minus 5 cm. This error was determined since direct sunlight striking the tubing caused the plastic to become more pliable, hence it could be stretched, by hand, 5 cm with little effort during the measuring process. The percent difference in length between the distance travelled and the length of tubing dispensed ranged from 0.0 to -5.73 percent. Only one measurement showed no difference, while the others indicated

that the length of tubing dispensed was less than the distance travelled by the implement. The design difference was intended to be plus or minus 1 percent, while the actual average difference was -2.76 percent. The coefficient of variation of the difference was 60 percent and the standard deviation was 1.66. The results show that there was a large variance in the percent difference between the tubing dispensed and in the distance travelled. The data shows that under field conditions the majority of the time the tubing would be inserted into the soil under a small tension force.

Table 1. Comparison of Actual Distance Travelled by the Implement to The Length of Tubing Dispensed.

Distance travelled between stakes, (m)	Length of Tubing dispensed, (m)	Net change, (m)	Percent difference from distance travelled, (m)
27.36	26.01	-1.35	-4.93
24.36	23.87	-0.49	-2.01
23.65	22.99	-0.66	-2.79
26.69	25.60	-1.09	-4.08
26.34	26.01	-0.33	-1.25
24.51	24.00	-0.51	-2.08
26.14	25.25	-0.89	-3.40
19.94	19.94	0.00	0.00
25.40	24.82	-0.58	-2.28
26.26	25.78	-0.48	-1.83
25.30	23.85	-1.45	-5.73

Reconfiguration of Implement

Although performance of the implement was generally considered adequate while inserting tubing, the field tests also showed that frequently when extra tubing was dispensed, it became jammed inside the implement. When this situation occurred, the operator had to dismount the tractor, and manually pull the tubing from the implement in order to rectify the problem. This greatly reduced the field capacity of the implement.

As shown in Figure 7, after the tubing passed between the pulling wheels it travelled diagonally, in the tubing duct, to the cutting device. At the locations where the tubing duct deviated from a straight line, the tubing buckled during the dispensing of extra tubing. Sufficient resistance, at the point of deviation, restricted the movement of the tubing causing it to become lodged.

To eliminate the two bends in the tubing duct, the implement was reconfigured. In the new design, shown in Figure 9, once the tubing left the contact point of the pulling wheels it travelled along a straight path to the entry point into the soil. This was accomplished by relocating the pulling wheels to just above the cutting device. From there, the tubing duct led down behind the subsoiler shank and into

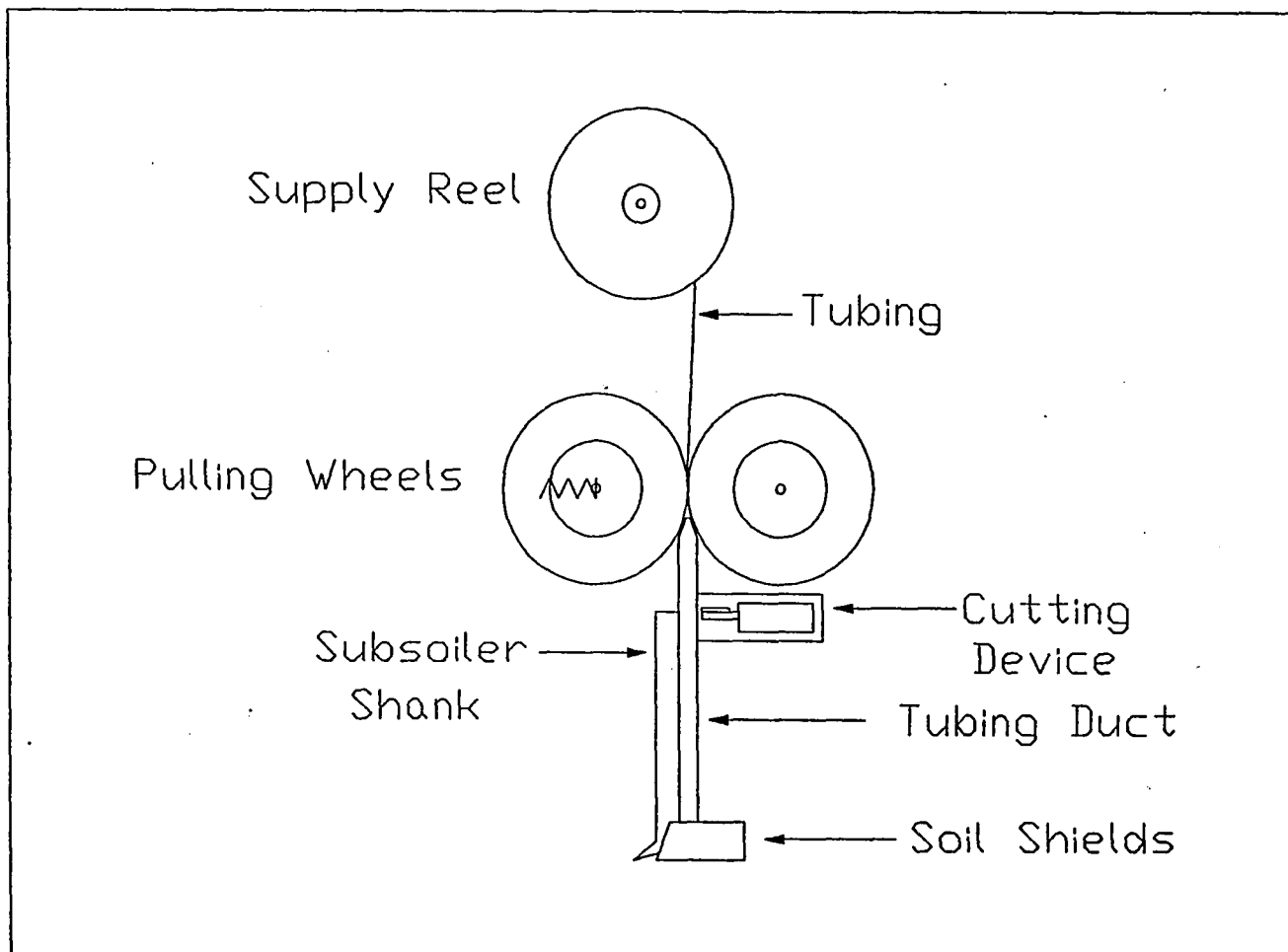


Figure 9. Reconfigured Injector Schematic

to the soil.

Functional Evaluation of Reconfigured Implement

Field tests of the reconfigured implement, shown in Figure 10, proved it to be superior to the previous version. Dispensing of extra tubing proceeded without problems, with the implement successfully operating between travel speeds of 3.7 km/h and 5.6 km/h. Outside that range, the main controller unit was unable to control the dispensing of the tubing sufficiently. This was due to the magnitude of the initial step response in the program. This limitation could be overcome by the revision of the main controller unit's program.

The tube feeding device functioned satisfactorily. The implement dispensed tubing into the soil with little movement of the free end observed. This indicated that the pulling wheels supplied the total force required to unwind the tubing from the supply reel. This eliminated the need for an extra person to secure the tubing to the soil surface before the start of each lateral, thereby greatly increasing labor capacity.



Figure 10. Reconfigured Implement

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

During the initial field tests, a major problem was encountered. The pulling wheel peripheral speed overshot the ground speed causing the tubing between the pulling wheels and the entry point into the soil to be compressed. This caused the tubing to buckle and then become lodged between the tubing shields.

Revision of the main controller's program resulted in the elimination of the overshoot, but limited the functional speed range of the implement. The new program compared the pulling wheels speed to the ground speed, and if a difference of ten percent or more occurred, a step response rather than a controlled response was sent from the BCC52. Alternate speed ranges could be accommodated by adjusting the step response in the program.

Redesign of the implement enabled it to meter tubing into the soil with very little movement of the free end. This indicated that the pulling wheels were supplying the total force required to unwind the tubing from the supply reel. This eliminated the need for having a person secure the tubing to the soil surface prior to the start of each lateral.

The design difference between the length of tubing dispensed and the distance travelled by the implement was plus or minus one percent. The actual average difference was measured to be -2.76 percent.

The implement dispensed tubing satisfactorily at the beginning of, and at the end of, a lateral. The operator controlled the amount of the tubing dispensed by activating a switch until the desired length of tubing was metered out. The tube cutting device performed satisfactorily. The sickle section made a clean cut when engaged by the operator.

Recommendations

The implement was intended to be a one row prototype. The unitized, toolbar mounted design would permit more than one row of irrigation tubing to be inserted at a time by mounting additional units on a toolbar.

A program with twice the cycling time as the response time of the hydraulic valve is recommended. This would provide the quickest overall response time for the implement. Applying the Nyquist stability criteria, sampling rate should be twice that of which is to be measured as controlled. Also a program that allows the implement to operate over a wider range of operating speeds should be developed by careful attention to matching the control algorithm and the system

control-ability. This would make the implement commercially acceptable.

Only minor modifications to the main controller unit are recommended. The greater use of CMOS type components would decrease the power load. A computer/controller that is capable of multi-tasking would eliminate one of the two BCC52 computer/controllers.

The use of smaller diameter pulling wheels would decrease the physical size of the implement.

A single signal that would both engage and then disengage the cutting device is recommended to be incorporated into the design. This would eliminate the possibility of an operator neglecting to retract the cutting device.

APPENDIX A
WIRING SCHEMATICS

Connections Between Components

In the following figures, PAX are input lines, PBx are output lines, and PCx are command lines. The symbol x stands for lines 0 to 7. All lines designated by either PAX, PBx, or PCx, in Figures A1, A2 and A3, are connections to the data bus.

The data bus is connected to the BCC52 that controls the main controller unit.

In Figure A4, the lines PA0 to PA7 from the HCLT-2000, PB0 to PB7 from the 74LS373, and PC0 to PC2 are connected to the Pulling Wheel Speed Sensor Dedicated BCC52. The lines PA0 to PA7, from the 74LS373, are connected to the Data Bus which is connected to the main computer.

Line A is connected between Figure A1 and both Figure A2 and Figure A3.

Line B is connected between Figure A1 and both Figure A2 and Figure A3.

Line C is connected between Figure A1 and Figure A4.

Line F is connected between Figure A1 and Figure A2.

Line G is connected between Figure A1 and Figure A2.

Line AA, Figure A2, is connected to a switch on the main controller unit front panel that controls the signal from the

radar velocity signal into the main controller unit's circuit.

Line BB, Figure A2, is connected to the output signal line of the DICKEY-john Radar II Velocity Sensor.

Line CC, Figure A2, is connected to a switch on the main controller unit front panel that controls the dispensing of the extra tubing.

Line DD is connected between Figure A2 and Figure A3.

Line EE is connected between Figure A2 and Figure A3.

Line FF is connected between Figure A2 and Figure A3.

Line GG is connected between Figure A2 and Figure A4.

The input to the hydraulic controller, Figure A1, is connected to the input of the Vickers electronic proportional valve controller.

Wiring connections between both the main controller unit and the control box from the peripherals

The 8 pin screw connector on the power supply card.

- 1 : 12v-unreg.
- 2 : Ground (12v)
- 3 : 6vdc battery
- 4 : Ground (6v)
- 5 : NC
- 6 : NC
- 7 : NC
- 8 : 5v

The 16 pin screw connector inside the main controller unit is mounted on a separate card.

- 1 : NC
- 2 : NC
- 3 : NC
- 4 : 5v
- 5 : Ground
- 6 : Channel A
- 7 : Channel B
- 8 : Ground
- 9 : Output signal
- 10: NC
- 11: NC
- 12: NC
- 13: Activate Radar
- 14: Dispense Extra Tubing
- 15: NC
- 16: Radar Sensor Signal

Pin 8 of the 8 pin screw connector is the supply voltage for the front panel. The voltage is to activate the switches which control the dispensing of the extra tubing and allow the radar signal to enter the main controller unit circuitry, the radar signal on/off switch.)

Pins 4-7 of the 16 pin screw connector are connected to the optical encoder.

Pins 8 and 9 of the 16 pin screw connector are connected to the Vickers electronic proportional valve controller.

Pins 13 and 14 of the 16 pin screw connector are connected to the front panel of the control box.

Activate Radar and Dispense Extra Tubing switches are mounted on the front panel of the control box.

Pin 16 of the 16 pin screw connector is connected to the output from the DICKEY-john Radar Velocity Sensor.

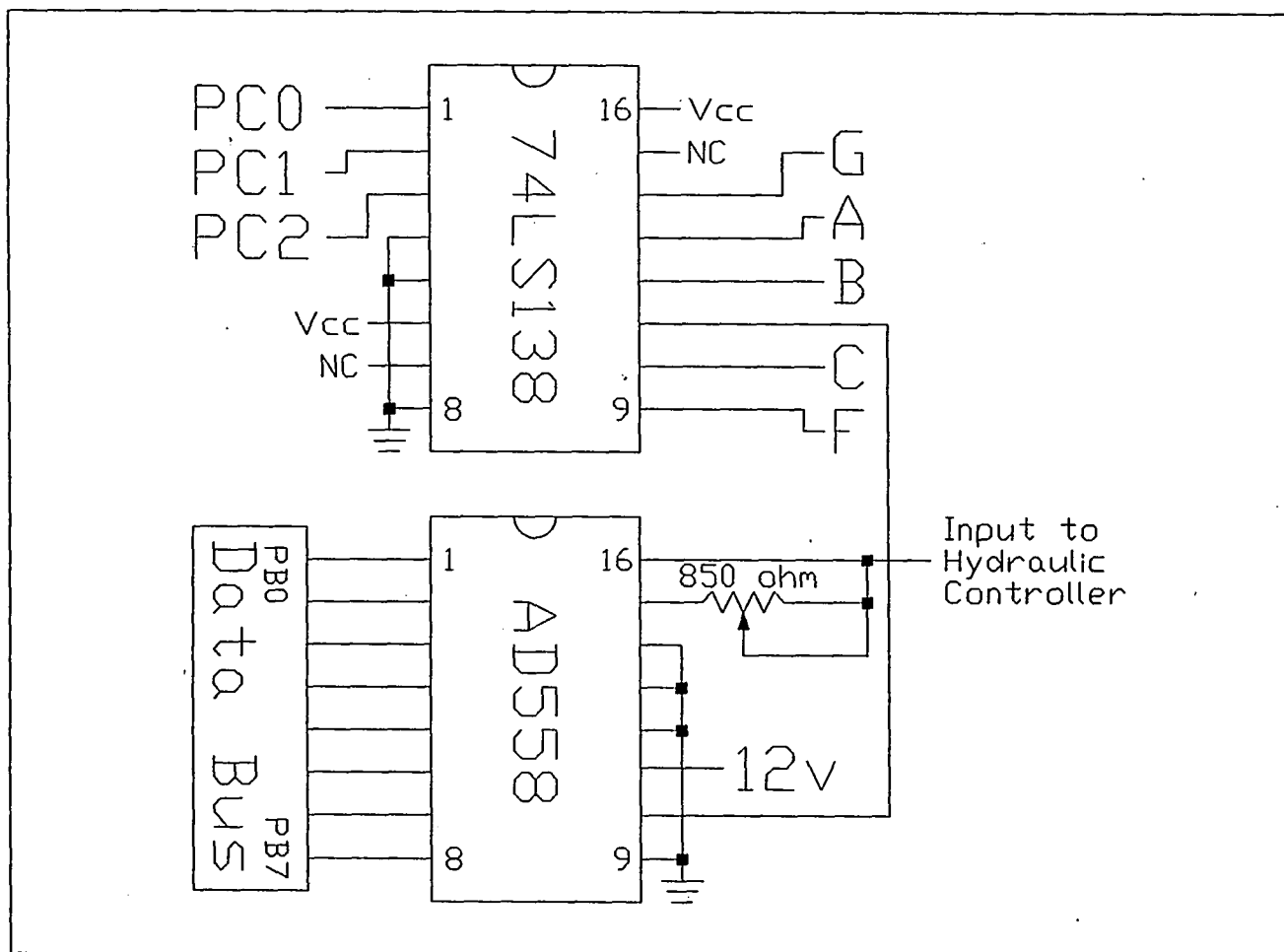


Figure A1. Wiring Schematic

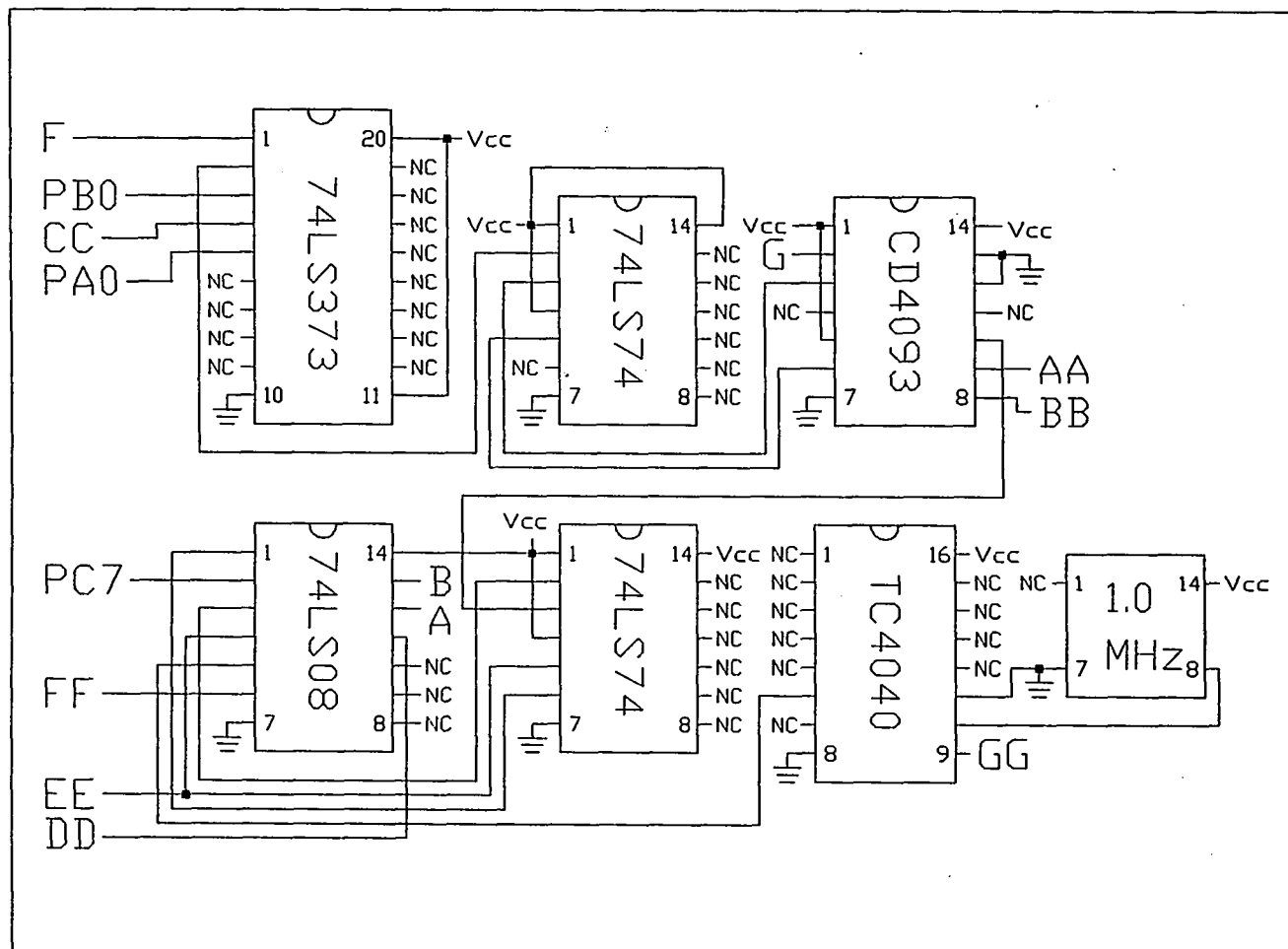


Figure A2. Wiring Schematic

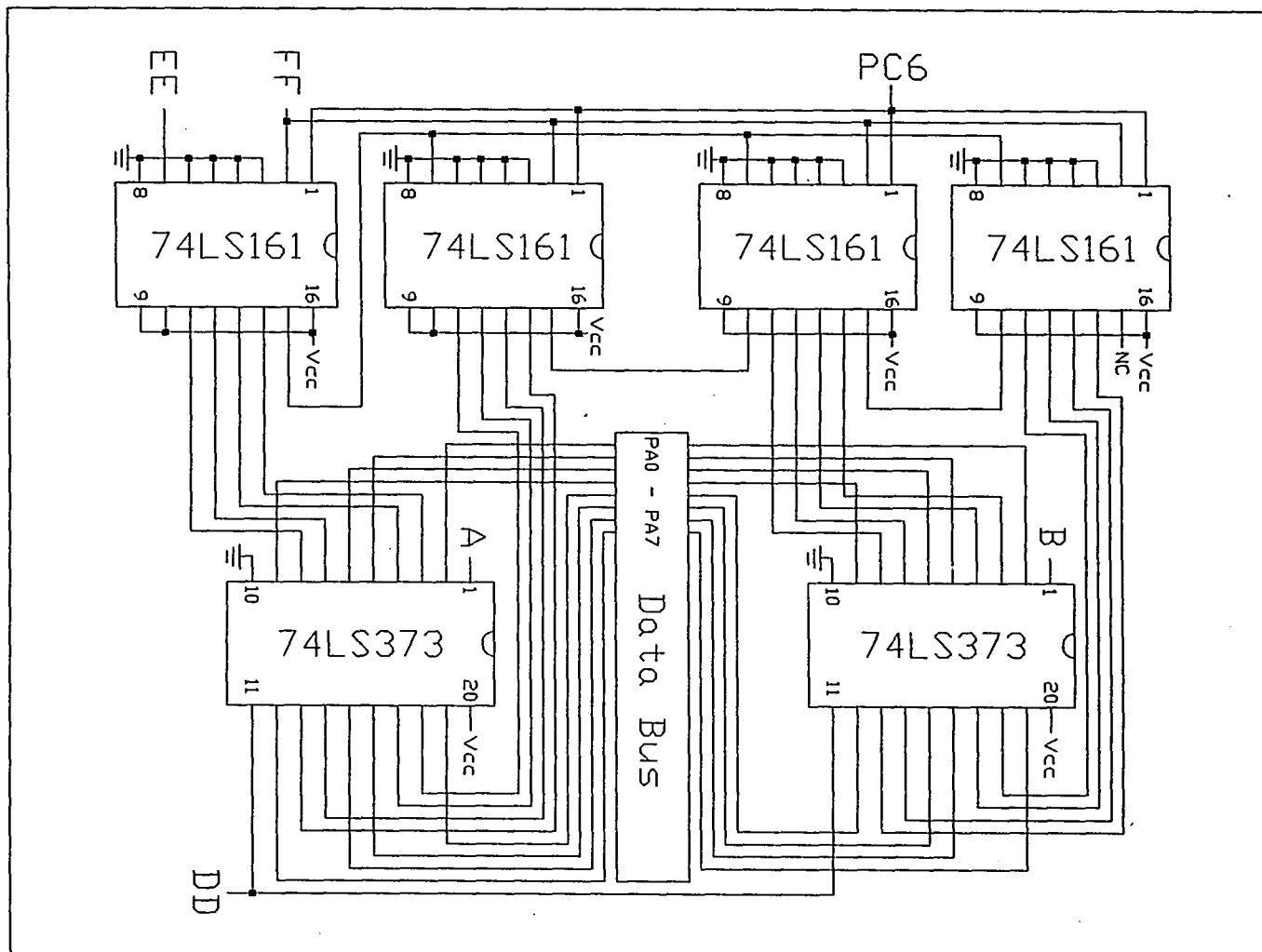


Figure A3. Wiring Schematic

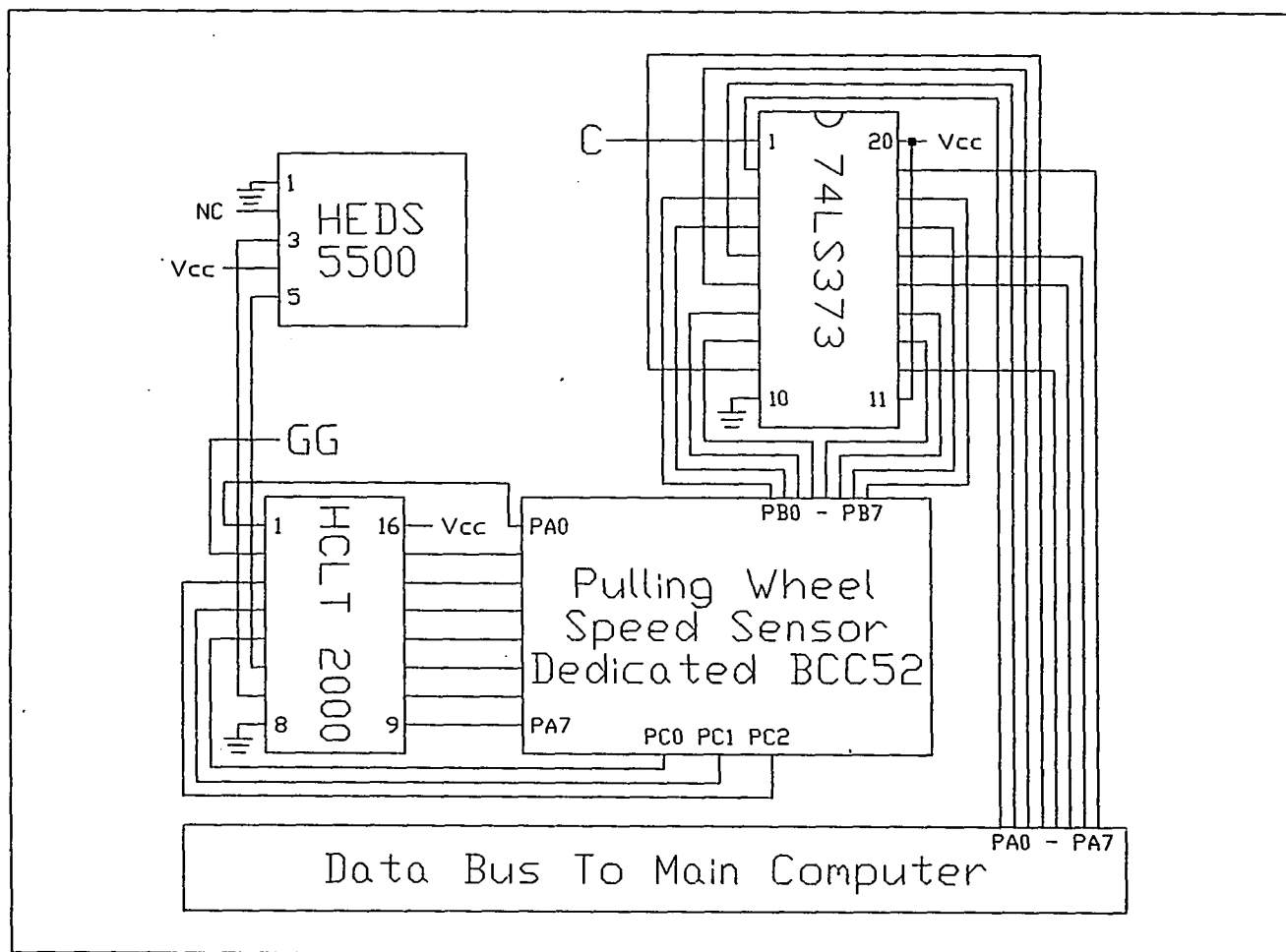


Figure A4. Wiring Schematic

APPENDIX B
COUNTER CIRCUIT
CONTROL LOGIC

A pulse to start the frequency counter was obtained by a signal on PC7, Figure A2, sent from the BCC52. The radar sensor signal was sent to the clock pulse input of a D type flip-flop, 74LS74, a logic storage memory device. The logic level present at the data input D was transferred to the output, Q, during positive-going transition of the radar sensor signal, refer to Figure B1.

Data input to the D flip-flop was provided by gating the signals from the BCC52 and Q', output from the D flip-flop, with an AND gate. Q' being the logical opposite signal of Q. The AND gate controlled the start of the counting sequence, hereafter referred to as the start AND gate. Whenever the BCC52 signal was a logic 0, output of the AND gate was logic 0. When clocked, the D flip-flop would produce a logic 0 output at Q which was sent both to the counter enable input and an input to a second AND gate. This AND gate controlled when the 125 KHz clock frequency reached the counter circuit, hereafter referred to as the counter AND gate. The counter circuit was disabled when the counter enable signal was at logic 0. It was enabled with a logic 1. Whenever Q output was logic 0, counter enable input was disabled and output of the counter AND gate was logic 0. The other input to the counter AND gate was the 125 KHz clock frequency.

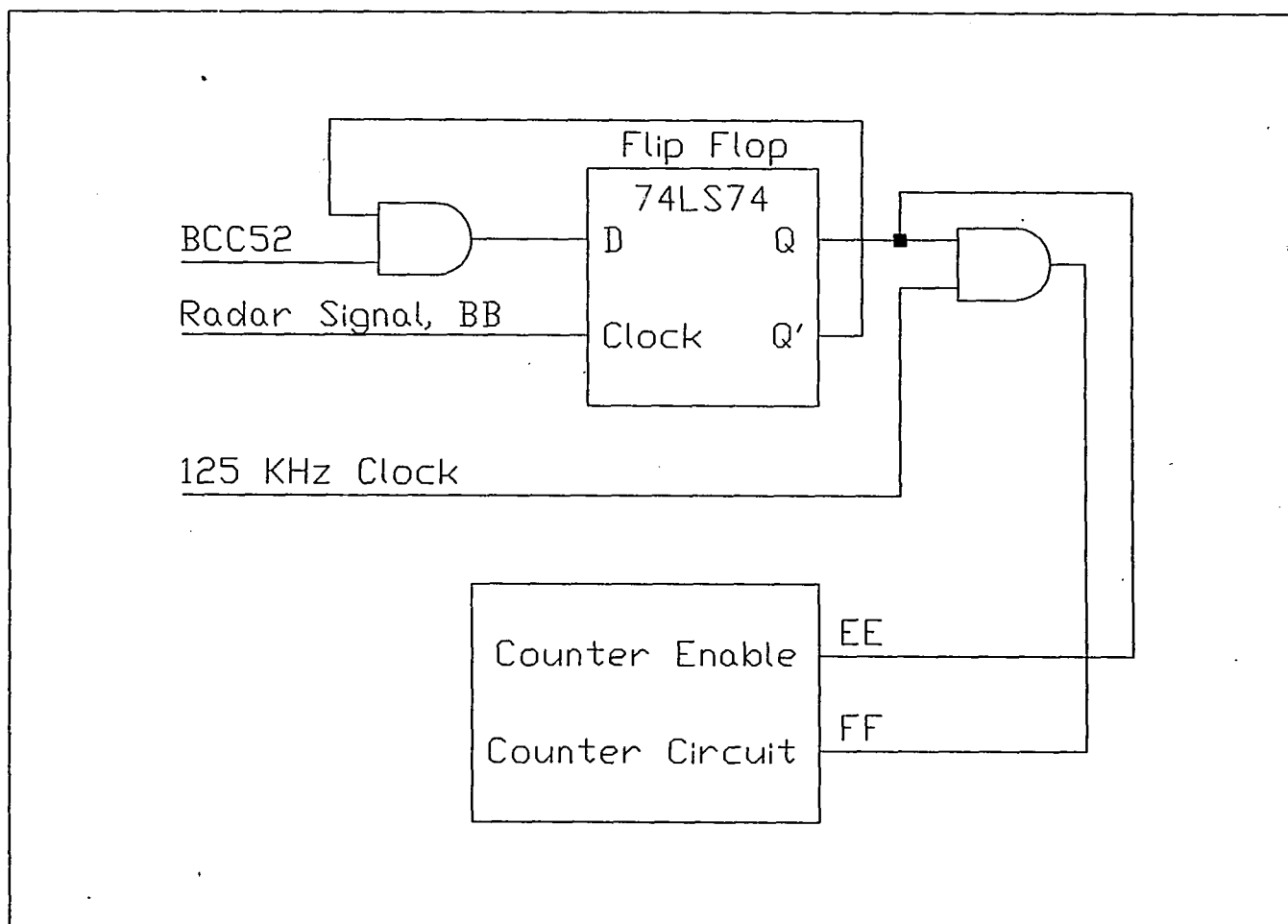


Figure B1. Logic Diagram

When the program asked for the speed of the implement, the BCC52 sent a logic 1 to the start AND gate. Since Q was logic 0, Q' was logic 1. Output of the start AND gate then became logic 1, that being the D input to the flip-flop. On the next rising edge of the radar signal sent to the clock input, Q changed to logic 1. With Q being logic 1, the 125 KHz clock was allowed to pass through the counter AND gate into the counter circuit. The counters counted the number of clock pulses, from the 125 KHz clock, during one complete cycle of the radar signal. Q' was toggled to logic 0 and output of the start AND gate was changed to logic 0 which was the input to D of the flip flop. On the next rising edge of the radar signal, the D flip-flop was clocked. Output Q went to logic 0 and disable the counters. Also the signal from the BCC52 went to logic 0 making the output from the start AND gate into the input of the D flip-flop logic 0. Thus the output was logic 0, on the succeeding clock pulses, disabling the counters.

The BCC52 then made the signal on line A, Figure A3, logic 0 which enabled the octal D-type latch, 74LS373, to transmit the low byte information onto the data bus and to the BCC52. After the low byte information was passed to the BCC52, the signal on line A was changed to a logic 1 to put the 74LS373 into a tri-stated condition. The BCC52 then made

the signal on line B, Figure A3, logic 0 which enabled the other 74LS373 to transmit the high byte information to the BCC52. After the high byte information was passed into the BCC52, the signal on line B was changed to a logic 1 to put the 74LS373 into a tri-stated condition. A logic 0 was then sent on PC6, Figure A3, to clear the counters and prepare for the next counting cycle.

APPENDIX C
TORQUE AND MOMENT OF
INERTIA CALCULATIONS

The following torque and mass moment of inertia calculations relate to the torque required to start the pulling wheels from rest. All assumptions that were used in the calculations are stated where appropriate. Also the worst case scenario, that being when a full supply reel of tubing was mounted and started from rest at the start of a lateral, was also calculated.

Torque to start the pulling wheels from rest:

Assumptions:

Constant acceleration

Implement reached 4.8 km/h in 1.4 m

$$v = 4.8 \text{ km/h}, x = 1.4 \text{ m}$$

Frictionless bearings

The pulling wheel consisted of a tire and rim of mass 12.6 kg with an assumed radius of gyration of 0.146 m. It also contained a hub and axle of 2.9 kg with an assumed radius of gyration of 0.06 m. The pulling wheel had a total mass of 15.5 kg and an assumed radius of gyration of 0.13 m.

Radius of gyration of pulling wheel: $k = 0.13 \text{ m}$

Given:

Mass of pulling wheel: $m = 15.5 \text{ kg}$

Radius of pulling wheel: $r = 0.26 \text{ m}$

The Summation of Moments is equal to the quantity of
 $I * \alpha$

α = angular acceleration

I = Mass moment of inertia

$$= k^2 * m$$

$$= (0.13 \text{ m})^2 * 15.5 \text{ kg}$$

$$= 0.26 \text{ kg-m}^2$$

$$\alpha = a_t / r$$

$$a_t = v^2 / (2 * x)$$

$$a_t = (4.8 \text{ km/h})^2 / (2 * 1.4 \text{ m})$$

$$a_t = 0.63 \text{ m/s}^2$$

$$\alpha = (0.63 \text{ m/s}^2) / 0.26 \text{ m}$$

$$= 2.42/\text{s}^2$$

$$\text{The Summation of Moments} = (0.26 \text{ kg-m}^2) * 2.42/\text{s}^2$$

$$= 0.63 \text{ N-m (per pulling wheel)}$$

$$\underline{\text{Total Sum of Moments} = 1.26 \text{ N-m}}$$

Hydraulic Motor Specifications:

Measured pressure drop across motor = 2760 kPa

Specifications: For a 2760 kPa drop across the hydraulic
 motor, it generates 24.9 N-m torque

(General Purpose Hydraulic Motors, 1988).

$$(1.26 \text{ N-m}) / (24.9 \text{ N-m}) = 0.05$$

The moment of force for the two pulling wheels is approximately 5% of the hydraulic motor's capacity.

Torque to start a full supply reel of tubing from rest:

Assumptions:

$$v = 4.8 \text{ km/h}, x = 1.4 \text{ m}$$

Constant acceleration

$$a_t = 0.63 \text{ m/s}^2$$

Assumed mass of full supply reel = 27.2 kg

Assumed radius of gyration: $k = 0.2 \text{ m}$

The Summation of Moments is equal to the quantity of

$I * \alpha$

$$I = k^2 * m$$

$$= (0.2\text{m})^2 * 27.2 \text{ kg}$$

$$= 1.09 \text{ kg-m}^2$$

$$\alpha = 2.42/\text{s}^2 \text{ (from before)}$$

$$\text{The Summation of Moments} = (1.09 \text{ kg-m}^2) * 2.42/\text{s}^2$$

$$= \underline{2.64 \text{ N-m}}$$

The total moment of force to start both the pulling wheels and the full supply reel:

$$\text{Total Moment of Force} = 1.26 \text{ N-m} + 2.64 \text{ N-m}$$

$$= \underline{3.90 \text{ N-m}}$$

$$(3.9 \text{ N-m}) / (24.9 \text{ N-m}) = 0.16$$

The total moment of force to start both the pulling wheels and the full supply reel from rest is approximately 16% of the hydraulic motor's capacity.

APPENDIX D
PROGRAM LISTINGS OF THE MAIN
CONTROLLER UNIT AND THE
PULLING WHEEL SPEED SENSOR

THE CONTROLLER PROGRAM
FOR THE MAIN CONTROLLER UNIT

Note: The actual program stored in the EPROM on the BCC52 board did not contain the REMark statements that are listed below. These are included only for clarification purposes.

MTOP = OFFFH : REM MOVES THE TOP OF RAM THAT IS ASSIGNED TO BASIC TO MEMORY LOCATION OFFFH

```

01  REM  THIS PROGRAM IS FOR THE BCC52 CONNECTED TO THE
02  REM  MAIN CONTROLLER UNIT.  IT RECEIVES A SIGNAL FROM
03  REM  THE RADAR VELOCITY SENSOR AND CONVERTS THE SIGNAL
04  REM  TO THE GROUND SPEED OF THE IMPLEMENT.  THE PULLING
05  REM  WHEEL PERIPHERAL SPEED IS RECEIVED AS INPUT.
06  REM  ERROR IS THEN CALCULATED, ADJUSTED BY A
07  REM  DAMPENING RATIO, AND THEN ADDED TO THE OUTPUT.
08  REM  THE OUTPUT IS THEN SENT TO THE MAIN CONTROLLER
09  REM  UNIT.  PORT A IS INPUT, PORT B IS OUTPUT, AND PORT
10  REM  C IS OUTPUT COMMAND SIGNALS.
12  XBY(0C803H) = 90H : REM PORT A IS INPUT, PORTS B AND C
    ARE OUTPUT
15  O = 40 : REM INITIAL STEP RESPONSE
17  Z = 0 : REM SET COUNTER TO ZERO
21  GOSUB 1000 : REM SUBROUTINE TO RECEIVE THE SIGNAL FROM
    THE RADAR VELOCITY SENSOR
22  IF R = 0 THEN 15 : REM IF SPEED IS ZERO THEN START OVER
25  IF Z > 5 THEN 60 : REM IF THERE ARE MORE THAN FIVE STEP
    INCREASES IN THE OUTPUT THEN GO TO CONTROLLED
    OUTPUT
28  IF ((R - E)/R) > 0.1 THEN 31 ELSE 60 : REM IF THE
    DIFFERENCE BETWEEN THE PULLING WHEEL SPEED AND THE
    GROUND SPEED IS GREATER THAN TEN PERCENT THEN SEND
    A STEP RESPONSE ELSE SEND A CONTROLLED RESPONSE
31  Z = Z + 1
34  IF Z = 1 THEN 37 ELSE 43 : REM SMALLER STEP RESPONSE TO
    BRING OUTPUT CLOSER TO ACTUAL GROUND SPEED
37  O = O + 40 : REM LARGE INITIAL STEP RESPONSE
40  GOTO 46
43  O = O + 5 : REM SMALLER STEP RESPONSE TO BRING OUTPUT
    CLOSER TO ACTUAL GROUND SPEED

```

```

46  IF O > 200 THEN O = 200 : REM PREVENTS OUTPUT SIGNAL
    FROM EXCEEDING 200 (200 = 8 VOLTS)
47  XBY(0C801H) = 0 : REM OUTPUT SIGNAL IS SENT OUT
    THROUGH PORT B
49  XBY(0C802H) = 4H : REM PORT B IS OPENED
52  XBY(0C802H) = 5H : REM OPEN PORT A TO RECEIVE PULLING
    WHEEL PERIPHERAL SPEED SIGNAL
55  E = XBY(0C800H) : REM PULLING WHEEL PERIPHERAL SPEED
    SIGNAL
59  GOTO 20
60  XBY(0C802H) = 5H : REM OPEN PORT A TO RECEIVE PULLING
    WHEEL PERIPHERAL SPEED SIGNAL
65  E = XBY(0C800H) : REM PULLING WHEEL PERIPHERAL SPEED
    SIGNAL
70  O = O + (R - E)*0.4 : REM ERROR EQUALS GROUND SPEED
    MINUS PULLING WHEEL PERIPHERAL SPEED. ERROR IS
    THEN ADJUSTED BY THE DAMPENING RATIO, (0.4), AND
    THEN ADDED TO THE OUTPUT SIGNAL
75  IF O < 0 THEN O = 0 : REM PREVENTS OUTPUT SIGNAL FROM
    GOING NEGATIVE (NEGATIVE VOLTAGE)
80  IF O > 200 THEN O = 200 : REM PREVENTS OUTPUT SIGNAL
    FROM EXCEEDING 200 (200 = 8 VOLTS)
85  XBY(0C801H) = 0 : REM OUTPUT SIGNAL IS SENT OUT
    THROUGH PORT B
90  XBY(0C802H) = 4H : REM PORT B IS OPENED
100 GOTO 20

999 REM SUBROUTINE TO RECEIVE GROUND SPEED INFORMATION
    FROM THE RADAR VELOCITY SENSOR.
1000 W = 0
1005 GOSUB 4000 : REM CHECK TO SEE IF THE SWITCH TO DISPENSE
    EXTRA TUBING IS ACTIVATED
1010 XBY(0C802H) = 0C7H : REM ENABLES COUNTERS AND THE
    COUNTER CIRCUIT
1015 W = W + 1
1020 XBY(0C802H) = 47H : REM DISABLES COUNTERS AND THE
    COUNTER CIRCUIT
1025 FOR V = 1 TO 5 : NEXT V : REM ALLOWS TIME FOR COUNTERS
    TO STABILIZE
1030 XBY(0C802H) = 42H : REM TRANSMIT LOW BYTE
1035 L = XBY(0C800H) : REM LOW BYTE IS RECEIVED FROM PORT
    A
1040 IF W > 15 THEN 1045 ELSE 1055 : REM IF PROGRAM LOOPS
    THROUGH TOO MANY TIMES THEN SEND SIGNAL TO AD558
    TO STOP FLOW TO MOTOR
1045 XBY(0C801H) = 0 : REM OUTPUT SIGNAL TO STOP MOTOR
1050 XBY(0C802H) = 44H : REM OPENS OUTPUT SIGNAL LATCH
1051 R = 0 : O = 40

```

```
1053 GOTO 1075
1055 IF L = 0 THEN 1005 : REM IF PROGRAM LOOPED THROUGH TO
      FAST BEFORE RECEIVING THE GROUND SPEED INFORMATION
      THEN LOOP AND TRY AGAIN
1060 XBY(0C802H) = 43H : REM TRANSMIT HIGH BYTE
1065 H = XBY(0C800H) : REM HIGH BYTE IS RECEIVED FROM
      PORT A
1070 R = 56270/(H*256+L) : REM CONVERTS COUNTS TO A BINARY
      SIGNAL. 200 EQUALS 16.1 KM/H.
1075 RETURN
```

```
3999 REM SUBROUTINE TO DETERMINE IF SWITCH IS ACTIVATED TO
      DISPENSE EXTRA TUBING.
4000 XBY(0C802H) = 6H : REM OPEN LATCH
4005 C = XBY(0C800H) : REM SIGNAL FROM THE SWITCH TO
      DISPENSE THE EXTRA TUBING
4010 X = C.AND.1H : REM CHECK TO DETERMINE IF TUBING IS TO
      BE ADVANCED
4015 IF X = 1H THEN 4020 ELSE 4035 : REM IF TRUE THEN TUBING
      IS TO BE ADVANCED
4020 XBY(0C801H) = 85 : REM CONSTANT OUTPUT SIGNAL TO THE
      MAIN CONTROLLER UNIT TO ADVANCE THE EXTRA TUBING
4025 XBY(0C802H) = 4H : REM OPENS AD558
4030 GOTO 4000 : REM LOOPS UNTIL SWITCH IS
      DE-ACTIVATED
4035 RETURN
```

THE CONTROLLER PROGRAM
OF THE PULLING WHEEL
SPEED SENSOR

Note: The actual program stored in the EPROM on the BCC52 board did not contain the REMark statements that are listed below. These are included only for clarification purposes.

```

01  REM  THIS PROGRAM WILL CALCULATE THE PULLING WHEELS
02  REM  PERIPHERAL SPEED.  THE SIGNAL IS THEN SENT TO THE
03  REM  MAIN CONTROLLER UNIT.  PORT A IS INPUT, PORT B IS
04  REM  OUTPUT, AND PORT C IS OUTPUT COMMAND SIGNALS.
05  REM
10  XBY(0C803H) = 90H : REM PORT A IS INPUT, PORTS B AND C
    ARE OUTPUT
20  CLOCK1      : REM TURN REAL TIME CLOCK ON
30  XBY(0C802H) = 6H : REM RESETS HCLT-2000
40  XBY(0C802H) = 7H : REM STARTS COUNTING
50  DBY(71) = 0      : REM SET INTERNAL CLOCK TO ZERO
60  IF DBY(71) < 19 THEN 60 ELSE XBY(0C802H) = 1H : REM
    WHEN THE INTERNAL CLOCK REACHES 95 MILLISECONDS,
    STOP COUNTING, AND THEN SET INHIBIT AND READ THE
    HIGH BYTE
70  H = XBY(0C800H)
80  XBY(0C802H) = 5H : REM READ THE LOW BYTE
90  L = XBY(0C800H)
100 B = (H*256 + L) * 0.3528 : REM CONVERTS THE PULLING
    WHEEL ROTATIONAL SPEED TO THE PERIPHERAL SPEED.  A
    BINARY SIGNAL OF 200 EQUALS 16.1 KM/H.
110 IF B > 200 THEN B = 200
120 XBY(0C801H) = B : REM OUTPUTS THE SIGNAL ONTO THE
    DATA BUS THROUGH PORT B
130 GOTO 30

```

The XBY(0C802H) = xx commands in the program listings and the corresponding logic signals sent to the port connections.

Command	:	Port connections								
	:	:	:	:	:	:	:			
XBY (0C802H)	:	PC7	:	PC6	:	PC2	:	PC1	:	PC0
	:	:	:	:	:	:	:	:	:	:
4H	:	0	:	0	:	1	:	0	:	0
5H	:	0	:	0	:	1	:	0	:	1
6H	:	0	:	0	:	1	:	1	:	0
42H	:	0	:	1	:	0	:	1	:	0
43H	:	0	:	1	:	0	:	1	:	1
44H	:	0	:	1	:	1	:	0	:	0
47H	:	0	:	1	:	1	:	1	:	1
C7H	:	1	:	1	:	1	:	1	:	1

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