

A RADIO-CONTROLLED TRENCHER FOR ACCURATE INSTALLATION OF SHALLOW DITCHES AND PIPELINES

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ABSTRACT

An inexpensive, radio-controlled, rotary trencher was developed for installing partially-buried surface pipes on an accurate grade. The method was developed for use with the Cablingation automated surface irrigation system and other gated pipe systems. The trencher is mounted on a farm tractor and offset to cut the trench behind the rear tractor wheel. The grade is remotely controlled by an operator sighting through an ordinary surveying instrument and adjusting the cutting depth via a radio control. Tests have shown that the trench grade can be controlled to an accuracy of ± 10 mm (0.03 ft). The trencher and control system costs about \$1500, not including the surveying instrument. **KEYWORDS.** Surface irrigation, Electronic controls, Radio control.

INTRODUCTION

Optimum water distribution with surface irrigation requires accurate installation of head ditches or pipelines which distribute water to furrows, borders or corrugates. Automated or manual gated pipe systems are becoming more popular. Cablingation, a low cost method of automating surface irrigation, was first described by Kemper et. al. (1981). This system uses a cable-controlled plug moving through a gated pipe to continuously move a furrow irrigation set across a field. The pipe is installed on a slope and the gates remain open. As the plug moves past a particular outlet, the piezometric head (and flow rate) starts at some maximum value and gradually decreases to zero. For Cablingation to function properly, the pipe must be installed to an accurate grade.

Installation is a major cost with Cablingation systems. Most Cablingation systems to date have been installed by manual methods. Several systems were installed with a laser-controlled rotary trencher mounted on a 3-point tractor hitch. The cutter head was centered on the tractor and elevation control was achieved by controlling the 3-point lift mechanism of the tractor. This arrangement was unsatisfactory because of the extreme control adjustments necessary to maintain grade. Laser control systems cost about \$15,000. Pipe installation with laser controlled machines usually costs about \$0.50 per foot.

Some farmers install portable pipe for Cablingation systems and remove the pipe at the end of each season. An inexpensive means of accurately installing the pipe is

needed. Also, it is usually desirable to lay the pipe as close as possible to the upper edge of the field, adjacent to an existing ditch, fence or road.

The objective of this study was to develop and evaluate an inexpensive method to control a trencher and to accurately construct a shallow (<300 mm) trench for laying surface pipe.

ACCURACY CRITERIA

In general, the lower the pipe slope, the lower the piezometric head range and the more accurately the pipe must be installed. Kemper et. al. (1987) showed how the total water applied to a furrow is affected by outlets placed above or below the design grade and the effect of slope on potential flow deviations. Kincaid (1984) presented equations to determine the initial and average flow rates and outlet heads for Cablingation as a function of pipe slope, pipe size, roughness, total flow, outlet size, and spacing.

The allowable deviation in pipe elevation can be specified as a percentage of average outlet head (the average head is approximately equal to one half the initial head). For example, to maintain flows within $\pm 10\%$, the elevation deviation should be less than 20% of average head. The process is similar for conventional gated pipe systems, although the head is less dependent on pipe slope.

An additional problem with Cablingation is that outlets set too far below the desired grade may not shut off completely but continue to flow indefinitely, depending on the normal depth of flow upstream from plug effects. The normal flow depth in the pipe can be determined approximately (adapted from Chow, 1959) by:

$$y/D = 0.7 Q/Q_0 + 0.2 \quad (1)$$

where

y = normal flow depth,

D = pipe diameter,

Q = total flow rate, and

Q_0 = total flow capacity with friction slope equal to pipe slope.

The distance from the top of the pipe to the water surface is $D(1-y/D)$. The allowable drop in the pipe from average grade can be specified as:

$$h = D(0.8 - 0.7 Q/Q_0 - h_0) \quad (2)$$

where

h_0 = distance the outlets (inverts) are set below the top of the pipe.

Article was submitted for publication in August 1990; reviewed and approved for publication by the Soil and Water Div. of ASAE in January 1991.

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For example, if the flow is 85% of capacity, the pipe diameter is 200 mm (0.66 ft), and the outlets are set 20 mm (0.066 ft) below the top of the pipe, the allowable grade deviation is 21 mm (0.069 ft).

TRENCHER DESIGN

An offset rotary ditch cleaner built by a local machine shop was modified for installing pipe. The machine mounts on a standard three-point hitch and is powered by the tractor's PTO (550 RPM). The weight of the machine is carried on a sled which travels in the trench behind the cutter head. The tractor hitch links are allowed to float and control alignment only. The three-point hitch is sized such that lines passing through the upper and lower links in the vertical plane converge at a point near the front tractor wheels. This arrangement minimizes control adjustments necessary to maintain the cutter head on grade.

The rotating, transverse-mounted cutter head follows the left rear tractor wheel. This enables the trench to be cut close to the edge of a field. Also, after the first pass, the left tractor wheels travel in the partially cut trench, further reducing control adjustments for successive passes.

A sighting target is mounted on the trencher directly above the cutter head. The cutting depth is remotely controlled by a second operator located behind the tractor, who sights through a transit or tiltable level and maintains the target in a fixed position relative to the telescope crosshair. A radio is used to transmit control signals to the machine.

Figures 1 and 2 show the trencher mounted on a tractor. Figure 3 shows the trencher and depth control. The 3-point hitch clamps to a toolbar such that the trencher can be moved laterally to adjust its offset from 610 to 915 mm (2 to 3 ft) from center. The cutter head is powered by a chain drive (ANSI #80) from the power takeoff. Safety shields used on the drive chain are not shown in figure 3. The drive chain length must be changed when changing the offset.

Figure 4 shows the cutter head design. The cutter head is attached to the drive shaft by means of two bolts [6 mm

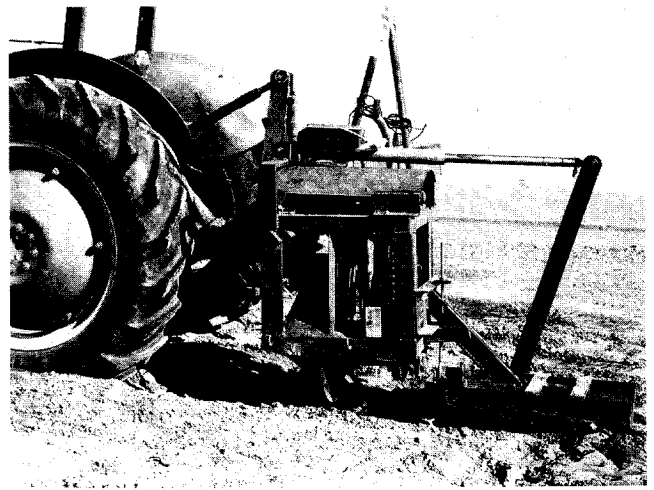


Figure 2—Side view of trencher and leveling mechanism.

(1/4 in.) dia.] which serve as safety shear bolts. The cutter head speed was increased to about 600 RPM by using a sprocket ratio of 1.13. The cutter head is sized slightly larger than the pipe being installed, and the diameter used in these tests was 315 mm (12.4 in.). The cutter head is shielded on the top and sides by adjustable baffles which direct the soil to one or both sides depending on the depth of trench.

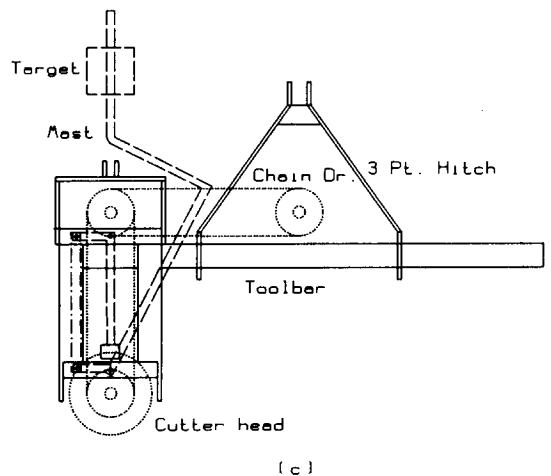
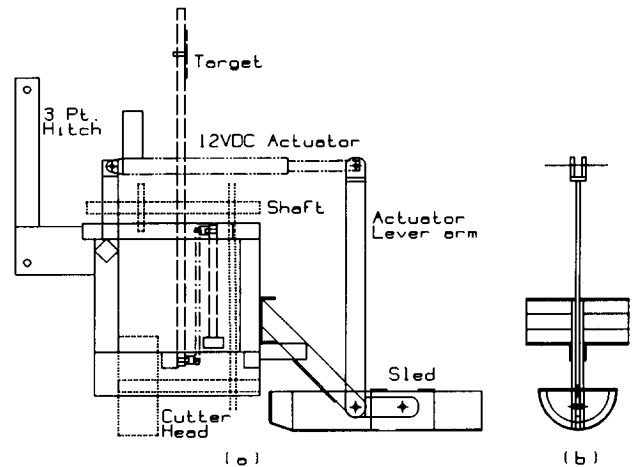


Figure 3—Trencher design details: a) side view; b) rear view of sled, lever arm and bracket; and c) rear view without leveling mechanism.

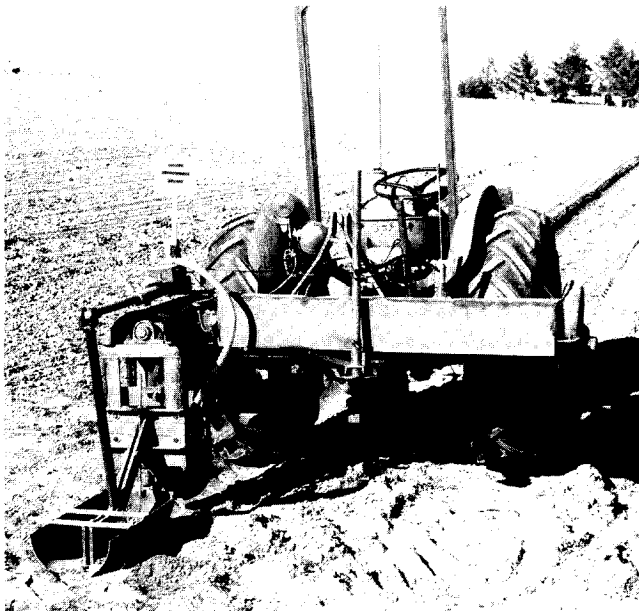


Figure 1—Rotary trencher mounted on a tractor.

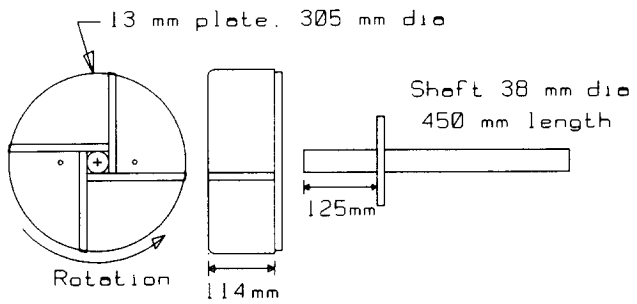


Figure 4—Detail of cutter head and shaft (305 mm = 1 ft).

The cutting depth is adjusted by a 12 VDC (supplied by the tractor battery) electric linear actuator operating a lever attached to the sled (fig. 3a). The actuator has a stroke of 460 mm (1.5 ft) and travels about 30 mm (0.1 ft) per second. The lever arm was designed to give a range of 90 mm (0.3 ft) of vertical movement of the cutter head.

The target mast is pivoted near the center of the cutter head and incorporates a folded-pendulum self-leveling device as shown in figure 5. This device levels the target as the machine tilts laterally due to field surface conditions outside the trench, making it easier for the grade control operator to accurately assess needed changes.

RADIO CONTROL

Trencher grade is controlled by an observer using an ordinary surveyors transit, theodolite, or non-automatic level set in line with the trench. A radio control of the type

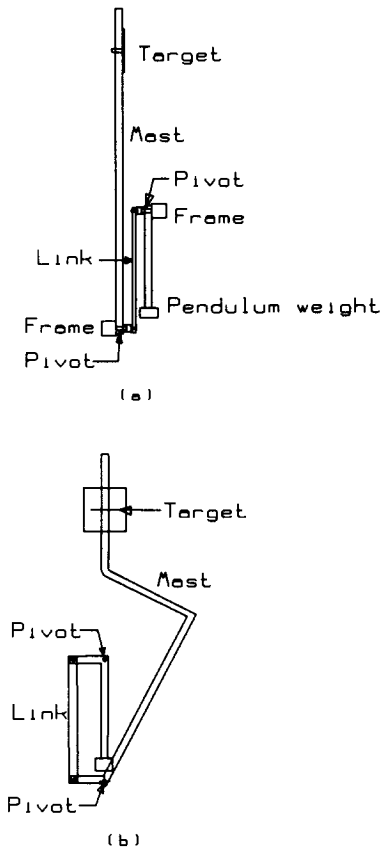


Figure 5—Target leveling mechanism: a) side view; b) rear view.

used for model airplanes is used to transmit control signals from the transit location to the trencher. The receiver was modified to control a relay which switches 12 V current to the linear actuator. The maximum range of the radio control is about 800 m (2600 ft). The receiver-actuator interface circuit is shown in figure 6. The receiver package was mounted in a small box attached to the actuator. A citizens-band type antenna was used on the receiver and placed as high as possible to maximize the range.

The trencher could be adapted to laser control by replacing the radio receiver with a laser-beam sensor and switching circuit. The radio control method could be used with other types of trenchers or ditchers if a target could be mounted at a fixed elevation above the cutting mechanism.

OPERATION OF THE TRENCHER

The trench centerline is marked along the soil surface, or flags are placed to guide the tractor operator. The transit is set up directly over the trench centerline, about 10 m (30 ft) beyond the starting end. The instrument is adjusted to the desired alignment and grade. The height of the target above the bottom of the cutter head is set equal to the vertical distance from the line of sight to the desired trench bottom.

Most tractors travel about 1500 to 3000 m/h (5000 to 10000 ft/h) in low gear, which is faster than most trenchers. Thus, it is recommended that the depth of cut per pass be limited to about 100 mm (0.3 ft), and at least two passes be made to obtain optimum accuracy.

For the initial pass, the target is usually set low so that the initial cut will be shallow, and it may be less accurate than subsequent passes. The desired grade can be estimated and an initial shallow cut made to determine the elevation contour across the field. This eliminates the need for detailed preliminary surveying. The grade can be readjusted and the target raised for subsequent passes until the desired depth and grade are reached. For Cabling on low slopes, it is usually desirable to maximize the pipe slope by setting the pipe as deep as possible at the lower end, and shallow at the upper end.

The trencher is initially positioned close to the transit and the trench is cut in the direction away from the transit. One person drives the tractor and maintains horizontal

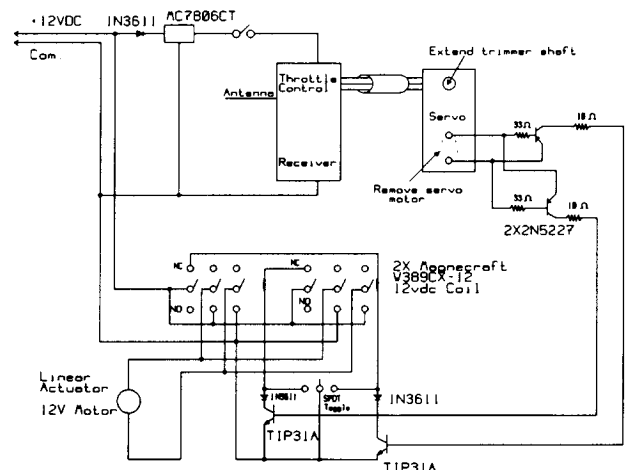


Figure 6—Electronic radio receiver-actuator interface circuit.

alignment. A second person sights through the transit on the target and maintains grade by operating the radio control to raise or lower the target (and thus the cutter head) in relation to the line of sight. The transit operator makes adjustments as needed to maintain a horizontal line on the target as close as possible to the transit crosshair.

FIELD RESULTS AND DISCUSSION

Figures 7 and 8 show data from a series of test runs on a 126 m (413 ft) trench. Elevations were measured with an automatic level on 3 m (10 ft) intervals prior to the first pass and after each pass. After the first pass, the trencher target was raised 30 mm (0.1 ft) for each subsequent pass. Maximum deviations from a straight line fitted through all data were 12, 11, and 7 mm (0.04, 0.04, and 0.02 ft) after the first through third passes, respectively. It appears that the limit of accuracy is about ± 10 mm (0.03 ft) with this equipment.

Figure 9 shows the results of installing a 350 m (1148 ft) trench for a Cabling system. Rod readings were taken on 6 m (20 ft) intervals after the second pass. Maximum measured deviations from the 0.0021 grade were 15 mm (0.05 ft). From equation 2, if $D = 250$ mm (0.82 ft), $h_0 = 16$ mm (0.052 ft), and $Q/Q_0 = 0.9$, then $h = 27$ mm (0.088 ft). The computed average outlet head for this system was about 40 mm (0.13 ft) using 44 mm (0.14 ft) diameter outlets spaced 762 mm (2.5 ft) apart. The desired maximum deviation was 20 percent of 40 or 8 mm (0.03 ft). Thus, the system satisfied the allowable drop criteria but did not satisfy the outlet head criteria. A third pass may have improved the accuracy. Since this was a very low head system the desired accuracy was difficult to achieve. A small increase in slope would improve this system.

Accuracy tends to decrease with distance from the transit. This is dependent on the quality of the instrument optics and the skill of the operator. The maximum distance for acceptable accuracy is about 400 m (1300 ft), and for Cabling on slopes less than 0.003, the distance should be limited to 200 m (650 ft). Longer systems can be installed in sections by matching the line of sight for successive sections. Some systems are divided into sections with different grades to reduce leveling of the field.

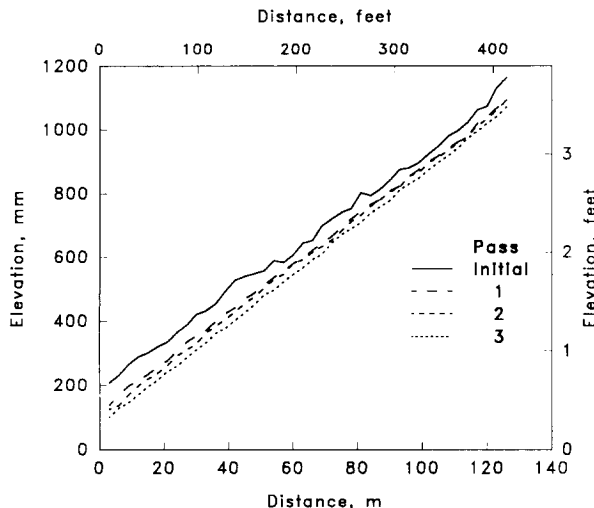


Figure 7—Elevation profiles from a test trench after multiple passes.

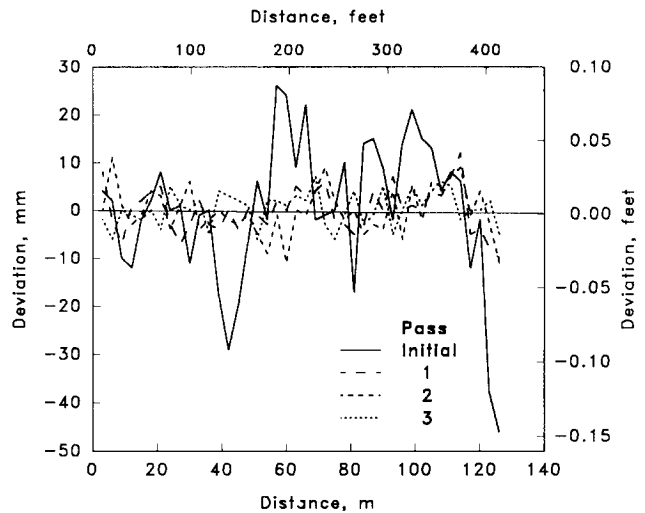


Figure 8—Deviations from a straight grade line after multiple passes.

Some systems require curved pipe alignment to follow the head end of the field. For curved alignments, first set the telescope line of sight perpendicular to the vertical axis, and then tilt the instrument axis to the desired grade. The operator then swings the telescope to follow the trencher along the desired path. This results in a trench installed on a sloping plane surface, with an average grade less than the plane grade. The actual slope at any point on the plane is

$$S = S_0 \cos A \quad (3)$$

where

S_0 = slope of the plane, and

A = angle between the offset trench line and the fall line of the plane.

For example, if $A = 20^\circ$, $\cos A = 0.94$ and the actual slope will be 6% less than the plane slope.

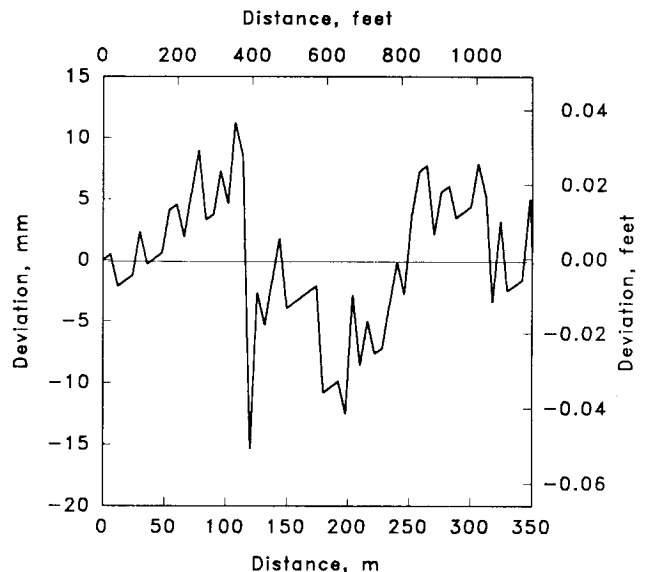


Figure 9—Grade deviations for a Cabling installation.

COST OF THE SYSTEM

The trencher used here was built by a local machine shop for an estimated cost of \$1000. Other components added were as follows:

1. Actuator- Duff-Norton 6405 series*, 12V DC \$250
2. Airtronics VT-2P Two channel radio control system \$100
3. Relays, etc. \$50

SUMMARY AND CONCLUSIONS

A radio-controlled rotary trencher was described for use in installing shallow ditches and surface gated pipe irrigation systems. The trencher is mounted on a tractor 3-point hitch. A surveyors transit and radio control are used to provide semiautomatic grade control. The limit of

accuracy is about 10 mm (0.03 ft) deviation from desired grade, which is acceptable for most Cablegation or gated pipe installations.

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*Name of manufacturers are given for information only and do not imply endorsement by the USDA.