(Figs 2 & 3 corrected)

Watch your drainage plow speed

Plowing-in corrugated plastic drainage tubing with a trenchless system which is automatically controlled by a laser beam grading system is a modern method of subsurface drainage installation that is receiving rapid acceptance throughout the world. Most draintube plows today are based upon the principle of a long floating-beam to assist in grade control; the floating-beam is a physical beam (figure 1) or an 'imaginary' beam depending upon plow design. The design or shape of the plow blade or shank and the structural features of the plow govern to a large extent the draft required to operate the unit. Undoubtedly, the more critical factors relating to grade control accuracy are the ability to determine the optimum position for mounting the laser receiver unit on the draintube plow frame, and in determining the maximum ground speed permissable to maintain grade control accuracy as frequent grade control corrections or adjustments are made by the automatic laser system. Most draintube plows today can accurately install corrugated plastic drains to grade if properly adjusted and operated.

I will concentrate my discussion upon three fundamental principles related to operation and grade control:

(a) Basic response characteristics
(b) Laser receiver position
(c) Ground speed

Basic response characteristics

In studies of the basic response characteristics of a long floating-beam plow (Fouss, 1971 and Fouss, et al., 1971) it was shown that in a silt-loam soil, changes in plowing depth in response to changes in hitch height were approximately linear, but not directly proportional: For example, a 1 inch vertical displacement of the hitch (held constant after change) resulted in a 1.25 inch change in plowing depth (after the plow had regained a steady state). This characteristic response occurs for all drainage plows and is governed somewhat by plow blade design but is influenced more by changes in soil resistance on the moving blade as plowing depth changes. Due to changes in soil consistency within the path of a plow blade operating at a given depth, the plowing depth may change due to the change in forces on the blade and where the hitch point height is not changed. Therefore, for a wide range of topography and changing soil types in the field, accurate grade control for the long floating-beam plow cannot be achieved by controlling the hitch such as it travels on a line parallel to the desired drain gradient.

Laser receiver position

The plow dynamics relationships also indicate the characteristic time lag of response, in that if the hitch height is changed one unit, the moling depth will change to a new equilibrium value but only after several feet of ground travel; for some plows a 1 inch change in hitch height will result in a new equilibrium moling depth only after about 50 to 70 feet of ground travel has occured. This latter time delay factor implies that in order to return the plowing depth to a corrected or desired level for grade control, it is necessary to over-correct the hitch height in order to speed up the dynamics of a plow depth change.

For a receiver position directly over the hitch, deviations of the hitch height are detected directly (1:1) by the receiver, but variations or changes in plowing depth are not detected; this receiver position ($x = 0$) maintains the hitch point such that it travels on a path parallel to the desired drain grade, but this does not provide positive grade control because the plowing depth is not directly related to hitch height, it also depends on blade altitude. Where the laser receiver is positioned directly above the plow blade (i.e., $x = b$), variations in hitch height are not detectable until the plow blade actually varies from its desired depth of operation, thus resulting in significant fluctuations in the plowing depth and the drain channel gradients due to the sluggish dynamics of the long-beam plow.

Therefore, a compromising receiver position is somewhere between the hitch and blade of the plow. Based on computer simulation results and field testing it was proposed that a value of $x/b = 0.833$ be used as a general 'guideline' for 'good' automatic grade control with a long-floating beam draintube plow (re: Fouss, 1971). Figures 2 and 3 show field test results for the ARS plow for the cases x/b of 0.28 and 0.84, respectively; it is noted through the standard deviation ** of the moling depth from the desired depth that the laser receiver position of $x/b = 0.84$ improved grade control accuracy. These tests were conducted at a ground speed of approximately 150 ft per min (a moderately high speed) using a laser system (for details of the system characteristics, see Fouss, et al., 1971). Grade control accuracy as expressed in terms of standard deviation from desired depth was noticeably improved by decreasing forward ground speed (but detailed test data is not available for direct comparison with the results shown).

Figure 4 illustrates a problem condition where the laser receiver indicates that the plow is operating on grade but in fact the drain is being laid above the desired grade line (the deviation from grade sketched in figure 4 is exaggerated in scale); this condition occurs when the plow encounters soil requiring greater draft and therefore a greater suck angle on the plow point in order to maintain depth. The laser grade control system causes the hitch to be lowered until the receiver is again within the laser beam, but the attitude of the entire machine is such that the drain is installed at the wrong depth. The further the laser receiver is ahead of the plowing blade, the worse this condition becomes. Attempts are being made to use a combination of depth control and slope control (or attitude control) system to correct this problem, but

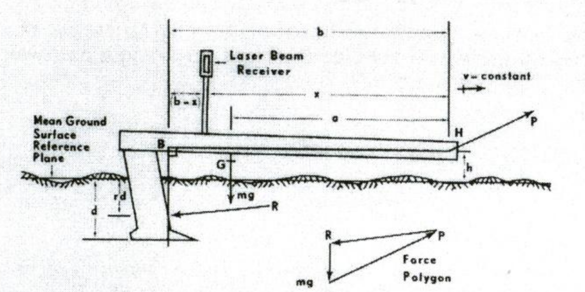

fig. 1.

Principal steady-state forces and geometrical relationships of laser controlled floating-beam draintube plow.

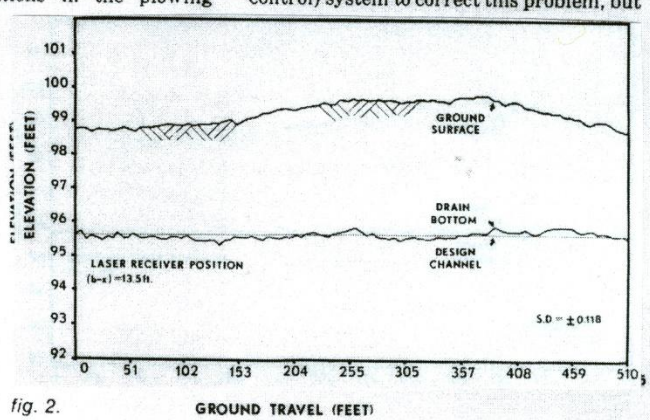

fig. 2.

Field test evaluation for ARS plow with laser grade controls x/b = 0.28.

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and laser receiver position

by James L. Fouss

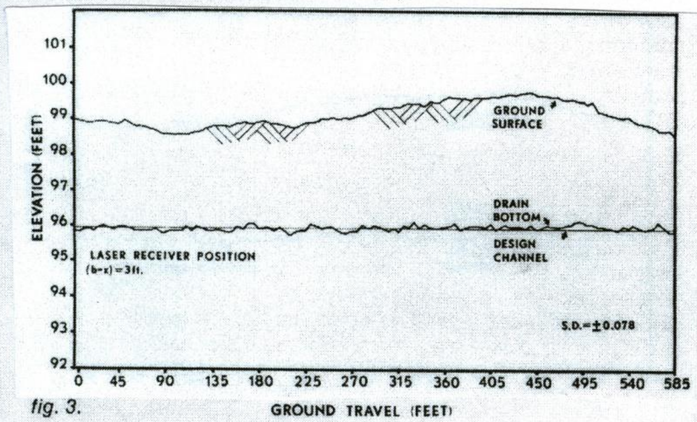


fig. 3.

Field test evaluation for ARS plow with laser grade controls x/b = 0.84.

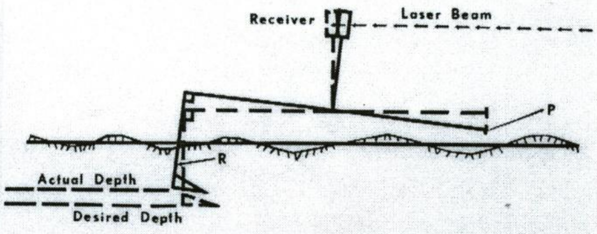


fig. 4.

Poor grade control can result from improper laser receiver position on a draintube plow when encountering increasing draft conditions.

in some cases it will require that force be used to either cause the plow to penetrate to the deeper depth in the harder soil or in the case of soft soil to hold it out of the ground, and therefore depth fluctuations could increase in magnitude if ground speed is not reduced significantly. Of course, in a condition in which the plow tends to settle to a deeper depth because of the soft soil condition, the reverse of the situation described in Figure 4 occurs; that is, the hitch is in an elevated position, the laser receiver is right on beam, but the plow depth is such that the tube is installed too deep. Thus, the selection of the optimum position for the laser receiver is paramount for good grade control accuracy under a wide range of soil conditions.

Ground speed

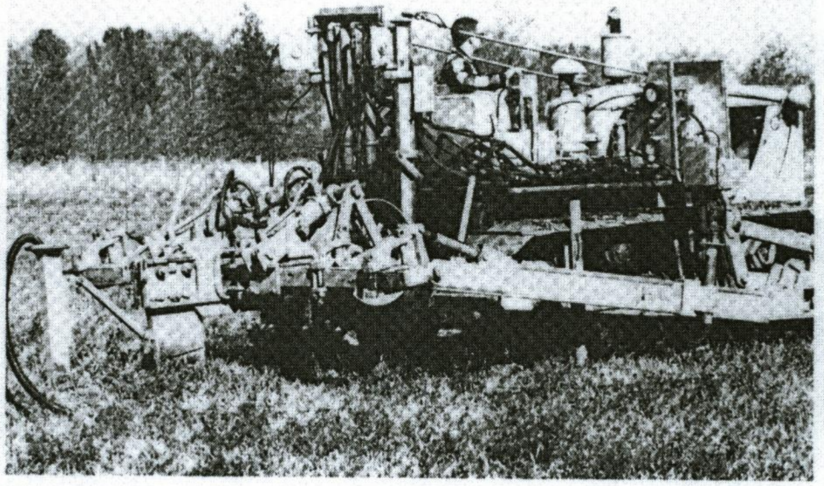
The effects of excessive ground speed can exaggerate the effects of improper or slightly less than optimum positions for the laser receiver. If the plow tends to drift off grade, then the faster the plow is moving, the further it will drift off grade before it is corrected back to the desired grade line. Therefore, it is recommended that ground speed always be reduced when large numbers or frequent corrections in grade are being made with the laser system, for example in very uneven ground, such that laser grade control corrections are not constantly over-compensating or getting behind. Many contractors know that performance can be improved at any given ground speed by increasing the rate of hydraulic cylinder movement to make the corrections, and this is true for some soil conditions, however, as the plowing speed slows down, the high speed hydraulics tend to cause the control system to 'hunt' rapidly. In effect then we may need a 'gain control' on the hydraulics to compensate for this, provided that we don't over-do the job by trying to maintain an extremely high ground speed.

I have noted a practice among contractors to move the laser receiver further ahead, thus 'settling down' the grade control system. This works by appearance but in fact can cause the plow to drift at a low frequency above and below the desired grade line (see Figure 3). One of the simplest ways of checking this on any given machine, and especially a plow (since the bottom of the plow trench is not readily available), is to set the laser grade control up on a completely horizontal line and drive the plow along a predetermined path (it is not necessary to lay pipe for this test). After the plow has travelled several feet (say, 75 to 100 feet), one can set up a conventional surveyor's level behind the machine and aim at a spot on the plow blade to coincide with the cross-hairs of the level as the machine is driven away — this observation gives you a direct indication of the vertical deviations from grade line of the plow blade. This type of test or quick check on every machine is recommended from time to time, especially as new soil types are encountered. ■

1. *Fouss, J. L. 1971. Dynamic response of automatically controlled mole-drain plow. Unpublished Ph. D. dissertation. The Ohio State University.*

2. *Fouss, J. L., N. R. Fausey, and R. C. Reeve. 1971. Draintube Plows: Their operation and laser grade control. ASAE Conference Proceedings: National Drainage Symposium, p. 39-42, 49.*

***The statistical standard deviation of the moling depth was computed from elevations taken in the bottom of the plow trench at 5 foot intervals along the drain; this can be thought of as an average deviation. The accuracy of this below ground level surveying measurement was considered to be - 3/8 inch (or - 0.03 ft.).*



USDA-ARS tool-bar mounted, floating-beam mole plow adapted to install corrugated plastic drainage tubing.

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