Automatic Controls on Construction Equipment: State of the Art

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The use of electronic devices for automatic control of construction equipment has increased steadily since the inception in 1958. Seventy percent of the state highway departments in the United States have required automatic control at some time or another, and 65 percent regularly specify automatically controlled equipment. Highway departments in Canada have been leaders in the use of this automatic equipment, and United States and European plant manufacturers are experiencing an increasing demand for electronic guidance systems on road construction machinery. A description of typical electronic control devices now on the market is included in this evaluation. Examples are given of the smoothness that may be expected with electronically controlled pavers when conditions are favored by good workmanship and good equipment. Although automatic controls reduce the dependence on operating personnel, there is injected the added problem of setting and maintaining the controls. Personnel properly trained in automatic controls must be available on the job.

•AUTOMATIC CONTROL of construction equipment has been a fairly recent development in spite of its similarity to the type of control used for 20 or 30 years on aircraft, ocean liners, and factory fabricating devices. It was not until 1958 that Honeywell, Barber-Greene, Cedarapids, and Pioneer developed screed control systems using Honeywell components based on a device patented by R. P. Shea (1).

The relatively late advent of automation may have been due in some degree to a failure of engineers to foresee the benefits in quality control and savings in man-hours that can result from electronic devices. Road-building with crushed aggregates and asphalt or cement mixes is really not a very old operation itself. Only recently has road-building fallen into the routine category that makes automation and mass production profitable.

POPULARITY OF AUTOMATIC EQUIPMENT

The decision by Canadian highway departments and some United States agencies to specify automatically controlled pavers may be more responsible for the recent trend toward the use of electronic controls than anything else. Since 1965, practically all bituminous paving contracts in Ontario have specified automatically controlled screeds (2).

The results of an inquiry to state highway departments for this evaluation indicated that 70 percent of the states have required automatically controlled devices at some time or another, and 65 percent regularly specify automatically controlled equipment. Most of the states agree that automatically controlled equipment has not affected the bid price of construction work. Some states expressed the opinion that automatically controlled equipment has reduced bid prices.

Paper sponsored by Committee on Highway Equipment and presented at the 49th Annual Meeting.

Sixteen percent of the states require automatic wire control for fine grading of the base, and 74 percent of the state highway departments leave this matter optional with the contractor.

All states reported that some of their projects had been constructed with automatic equipment, regardless of whether or not it was specified. Two-thirds of the states reported at least 50 percent of their projects constructed with automatically controlled equipment, and one-third of the states reported at least 90 percent of their asphalt-mix pavements being placed with electronic controlled machines. The tolerance and related data reported by the states answering the questionnaire are given in the Appendix. Manufacturers of paving equipment in the United States estimate that 3 automatically controlled machines are being manufactured for every one machine that can be only manually controlled. British firms making asphalt finishers are now fitting guidance systems to between 25 and 50 percent of their new machines, and the same is true on the European continent (3).

SCOPE OF THIS REPORT

Electronic controls of one type or another are used in highway construction today on everything from pile drivers to sidewalk finishers. Probably the greatest application of electronic controls for overall guidance and grade control has been on machines that place or finish grade courses of material on a roadway. This report is limited to an evaluation of the electronic controls on pavers and motor graders available on the market in the spring of 1969.

GENERAL TREND IN DESIGN

Many equipment manufacturers who were contacted to secure information for this report expressed their intention to place automatically controlled equipment on the market at some later date. Because of the rapid advancement in diode and transistor manufacture, automatic equipment that comes on the market a year or so from now is likely to be somewhat different from equipment on the market today. The silicone-controlled rectifier may simplify and reduce the cost of equipment that formerly depended on expensive amplifiers. However, the relay-solenoid-hydraulic cylinder type of control has proved to be very dependable for heavy duty control, and in all probability it will be in use for years to come.

EVALUATION PROCEDURE

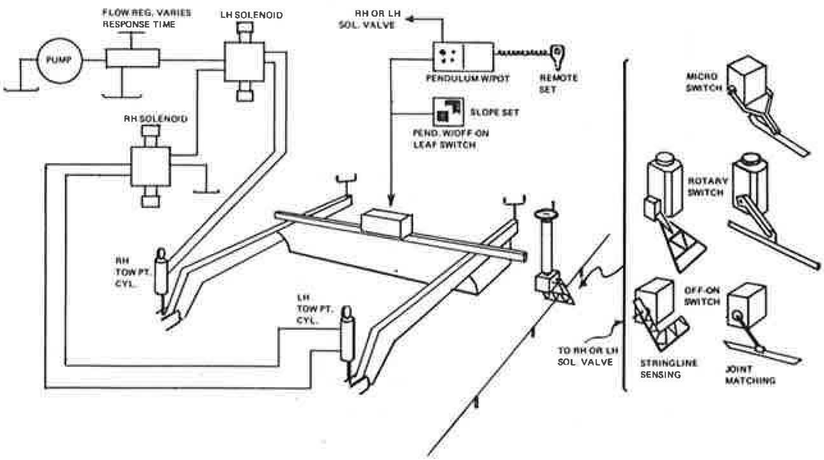
Systems of control employed by the various manufacturers of pavers and graders have been investigated for this report. In general, manufacturers of pavers have used either hydraulic cylinders activated by solenoids and valves or servomotors to vary either the elevation of the paver frame, the elevation of the screed, or the angle of the screed arm with reference to the roadway surface.

Figures 1 through 8 show typical methods of automatic controls and contain remarks about the general field performance of each system. Table 1 gives a comparison of the different types of control.

AUTOMATIC CONTROL OF GRADERS

Although electronic controls on paving equipment have proved to be efficient and reliable, there has been difficulty in applying similar controlling devices to motor graders and dozers. The difficulty is undoubtedly due to the difference in operation of the 2 types of equipment. Whereas the pavers operate steadily on a wide uniform grade, motor graders and dozers are generally purchased to do "pioneering" work on rough terrain as the need arises.

In 1958, a Texas firm adapted automatic controls to a motor grader. The "Educated Blade," as the contractors called it, generally controlled grade elevations within 0.03 ft. Even on a parabolic crown, the motor grader was reported to have operated well by resident engineers and contractors (4). However, the controls did require special



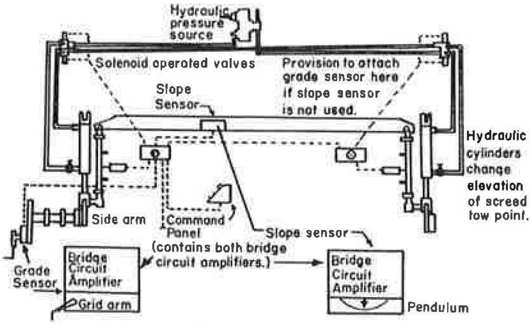
12V system operates solenoid valves to control direction of movement of tow point cylinders. Flow regulator varies system volume controlling response time (speed) of tow point cylinders, giving adjustment for varying job conditions. Sensing components can control either side of the machine and can be interchanged or mixed. Paver wiring and hydraulics common for all available control systems.

Micro Guide – Joint matching sensor requiring higher actuating force utilizes microswitches to operate solenoid valves. No transverse slope control, but dual micro guides can be used for controlling both sides.

Honeywell Grademaster – Stringline mobile or rigid reference may be used for grade control by use of low force off-on switching to operate solenoid valve. Slope control uses pendulum with variable resistance in balanced bridge circuitry to proivde output to operate solenoid valve. This unit provides a remote slope set point device.

Long Grad-Line – Stringline—Same as above.
By use of low force rotary off-on switch energizes relays to operate solenoid valves. Slope control uses pendulum-leaf switch energizing relays to operate solenoid valves. Unit has integral slope setting.

Figure 1. Barber-Greene—automatic screed control systems.



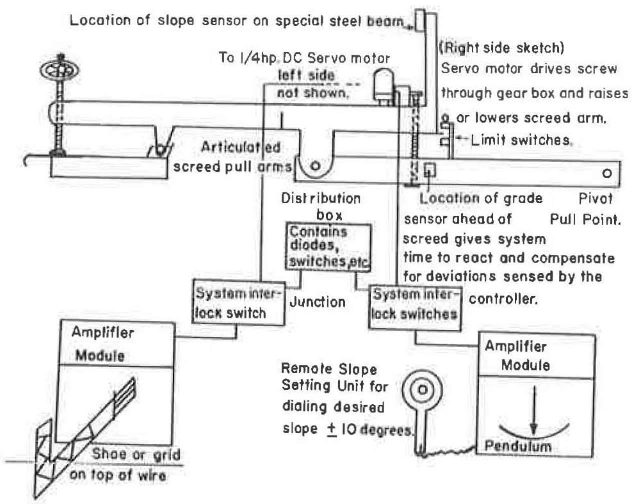
When the elevation of the side arm changes with respect to the reference surface, the grid is rotated, thus varying the resistance of the sensor. This variance is recorded in a bridge circuit and produces a current flow across the bridge circuit. This current is amplified and actuates a solenoid operated hydraulic valve. The valve in turn actuates a hydraulic cylinder that is attached to the tractor frame and forward end of the side arm. The side arm is then raised or lowered until the tow point is again at the present elevation with respect to the reference surface.

With both sides on automatic, if the grade sensor is not connected, the slope sensor will try to control both sides of the screed, which it cannot do. One or both sides will go to their limit of travel and stop the operation.

A pendulum type sensor, which senses level with respect to gravity, is mounted on a beam supported by the side arms. A change in slope of the beam varies the resistance reading of the sensor. This variance, like the variance in the grade sensor, is fed into a bridge circuit. The resulting signal or current flow is amplified and used to control a solenoid operated valve and ram on the side opposite the grade controller. The control panel has a dial on it whereby any slope from 0 to 10% can be dialed in, and the pendulum sensor will automatically adjust the position of the tow points accordingly. When paving around a curve, the slope of the curve can be dialed in by the operator.

Correlation between the beam and the screed is dependent on the setting of the screed adjustment screws. For this reason, caution must be exercised in using the dial for determining the absolute slope of the finished mat.

Figure 2. Blaw-Knox—Blaw-Kontrol for asphalt paver showing the system used to change elevation of the screed tow point for automatic control during paving operations.



Spring loaded ON-OFF Grade Controller

Sensor may be connected to either or both sides of the machine, but two grade controllers are not used if the slope controller is used.

An over deflection mechanism allows the grid to rotate an additional 50 angular degrees either side of the active selector. This enables the grid to override the grade stakes or other means of supporting the grade reference string.

Skis are available in lengths of 9, 29, 30, and 40 feet.

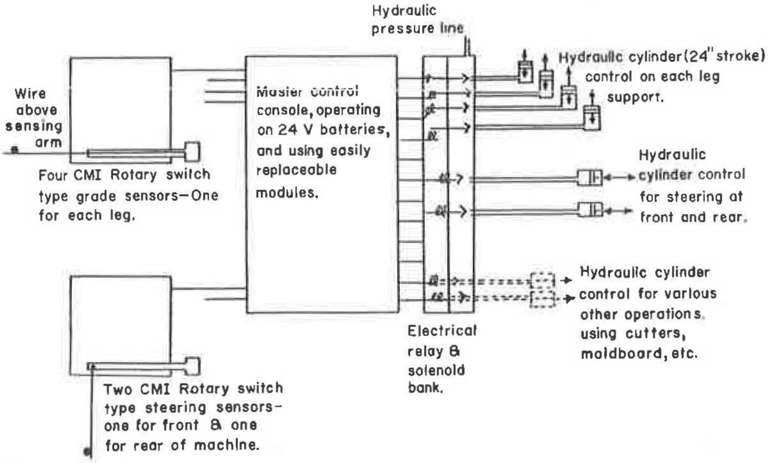
Slope Controller

The slope controller furnishes true horizontal reference. It is a slave of the grade sensor, and maintains the same slope regardless of grade sensor position.

The pendulum microsyn, along with the slope control potentiometer in the command station, forms a bridge circuit. For a specific setting of the slope control knob, there is a corresponding angular position of the Slope Controller housing at which the bridge is balanced. A balanced bridge condition indicates that the predetermined slope is being maintained.

Changes are necessary with the slope knob when paving runs into a super-elevated turn. If a change is not made, the machine will try to take all super-elevation out of the new mat.

Figure 3. Cedarapids—all-electric screed control system.

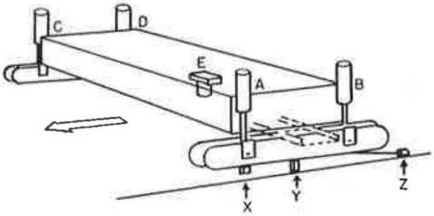


Sensors use a counterbalanced rod touching the side (for steering) or underside (for grade control) of a string line for good stable control. The machine has been observed to operate accurately in 40 mph winds if string line is tight and well supported. The sensors will also follow a form line or skid.

Available also is the Autolevel Control System using a single wire reference and "cross slope control" which can be operated on either side of the machine at the discretion of the operator.

The 24 inch stroke vertical hydraulic cylinder action in each leg is so great that it makes it possible for the machine to crawl up or down over bridges and structures while maintaining a uniform-grade roadway.

Figure 4. CMI Corporation—automatic profile and steering control.



Steering Sensor X

A sensor located at the front and left side of the machine detects deviation from wire line and automatically adjusts crawler to follow the wire.

Elevation Sensor Y

A sensor located at front of machine on the left side controls the front height of the machine for longitudinal travel parallel to guide wire. It is intended to maintain the surface smoothness without affecting the pavement depth. Cylinder (A) raises or lowers to follow the wire.

Elevation Sensor Z

The elevation sensor on the left side at the rear sets the pavement height. Cylinder (B) raises or lowers to maintain required height.

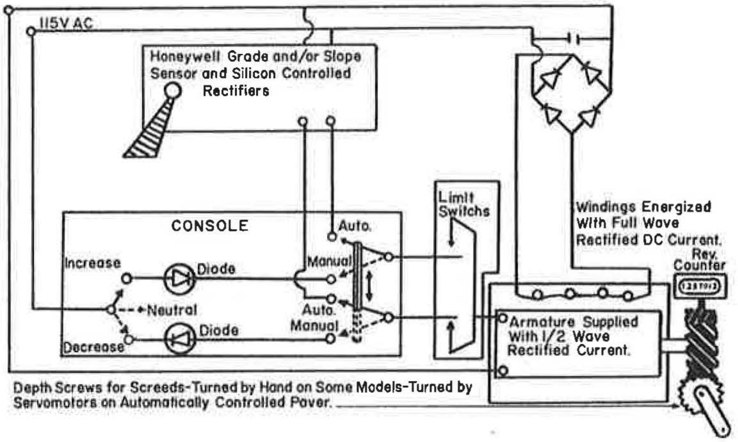
Cross leveling of the machine is set with an oil dampened pendulum (E).

Cylinder (D) raises or lowers to maintain balanced "zero" reading. The cross slope can be set by means of a micrometer adjustment.

Four point suspension is completed with Cylinder (C). Actuated by a torsion bar, the cylinder raises or lowers to correct any machine twisting action. Each point of the 4-point suspension system is thus established in a common plane. Paving from grade reference may be also established.

Note: Sketch and write-up taken from Koehring-Johnson brochure; actual machine not evaluated for this report.

Figure 5. Koehring-Johnson—slipform paver with automatic control.



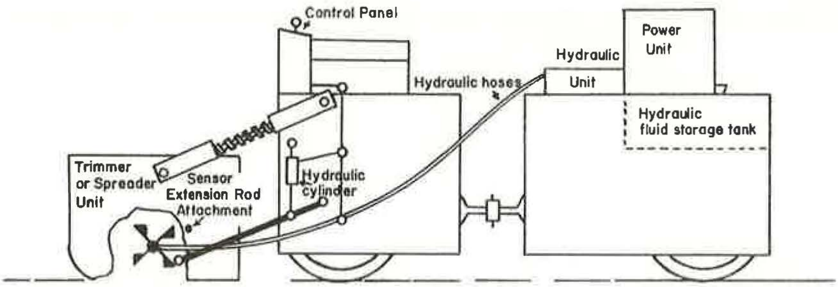
Grade sensor uses a lightweight grid follower along a string line set on the ground or on a traveling string line in the center of a framework towed along the side of the paver.

A slope controller or pendulum may be combined with the grade sensor to control the opposite side from that controlled by the grade sensor for maintaining a predetermined slope. The slope can be manually adjusted or changed by use of the "Remote Slope Control Set". The remote slope control set knob allows changes to be dialed in with the paver in operation, but it must be done gradually. "Manual Automatic" selector switch is provided on each side to change from the automatic grade or slope control to a manual control.

Because mat thickness changes are made by raising or lowering the metering element, or oscillating screed, it becomes feasible to eliminate the manual hand wheels and motorize the depth screws directly. Applying the automation in this manner, eliminates zeroing or adjusting the automatic stroke at the tow-point, and allows a thickness from zero to maximum during the course of a job.

Each side of the paving section is electrically independent, allowing any combination of manual or automatic control. The revolution counters on the depth screws aid in setting the "angle of attack." If records are kept of the counter readings for various thicknesses, the angle of attack can be accurately reset to again lay this thickness.

Figure 6. Pioneer—grade master slope and grade controller.



Automatic steering involves an electric pickup located at either end of the cutting head to sense from single string line or curb. A signal is transmitted to solenoid valves that control the steering system itself.

Grade control is achieved by either a one-line control or a two-line (one on each side of the machine) control. Two line control is recommended for highway construction where an accurate system is necessary and speeds of 50-100 feet per minute are expected.

Grade control may be maintained from a single line if operating speed remains at under 25 feet per minute. In this case a special mercury cross level control patented by RAHCO is brought into play.

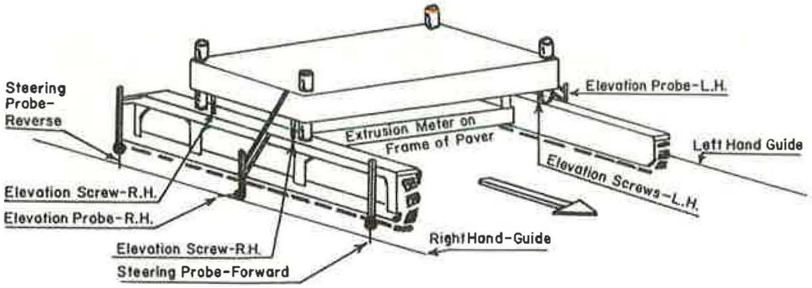
Normally the same reference line that is used to control steering is used to control grade. The mercury control transmits electric impulses to solenoid valves, and they in turn activate control cylinders which in turn raise or lower the cutting head.

For most accurate control, the sensor should be located on a direct line with the cutting or paving head. The closer such control is located to the active head, the better the grade, and the more responsive it appears.

Figure 7. RAHCO—automatic grade and steering control.

calibration and attention that many contractors felt to be excessive. This automatic control equipment was never mass produced.

In 1962, the Gurries Manufacturing Company of San Jose, California, introduced an automatically controlled motor grader. It provided both slope and grade control, but features of its construction and operation were not investigated for this study because of its hydraulic principle. There were no electronics in the system (5).



Pointers of probes are attached to rotating armatures which center themselves between excited coils. Displacement of the probes by the wire guides unbalances the circuits and signals a solenoid to open or close a valve to a hydraulically operated screw jack to raise or lower the frame.

Any deviation in the machine movement immediately displaces the armature, the induced coil voltage is sensed, and, through a control system, a command is then sent to correct for this deviation.

The allowable deviation that can take place before a correction command is initiated, is controlled by a special sensitivity adjustment. This sensitivity control is provided to meet the requirements for all existing job variations — i.e., soil conditions, vehicle speed, etc. If the sensitivity setting is too high, it may cause the machine to hunt or oscillate about the required set point; however, if the setting is too low, this will not provide the desirable results.

Note: Sketch and write-up taken from Rex Chainbelt, Inc., brochure; actual machine not evaluated for this report.

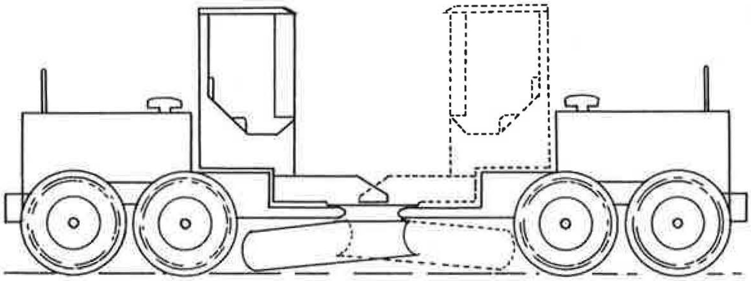
Figure 8. REX Chainbelt, Inc.—automatic guidance controls.

TABLE 1

SYSTEMS USED FOR AUTOMATIC CONTROL OF PAVERS

Manufacturer	Adjusted Point on Frame	Activating Unit	Sensor Control	Sensor Type
Barber-Greene (Fig. 1)	Elevation of tow point	Solenoid valves and hydraulic cylinder	Grade and slope	Microswitch, rotary switch, pendulum (Honeywell)
Blaw-Knox (Fig. 2)	Elevation of tow point	Solenoid valves and hydraulic cylinder	Grade and slope	Variable resistance, pendulum
Cedarapids (Fig. 3)	Pull arm angle	Servomotor	Grade and slope	Rotary switch, pendulum (Honeywell)
CMI (Fig. 4)	Leg height	Solenoid valves and hydraulic cylinder	Grade, slope, and steering	Rotary switch, pendulum
Koehring-Johnson (Fig. 5)	Leg height	Solenoid valves and hydraulic cylinder	Grade, slope, and steering	Microswitch (grade), inductive transducer for slope
Pioneer (Fig. 6)	Depth screws	Servomotor	Grade and slope	Rotary switch, pendulum (Honeywell)
RAHCO (Fig. 7)	Elevation of cutting head	Solenoid valves and hydraulic cylinder	Grade, slope, and steering	Rotary switch and mercury switch
REX Chainbelt, Inc. (Fig. 8)	Hydraulically operated screws at frame corners	Servomotor	Grade, slope, and steering	Rotary induction sensor

Recently, Construction Machinery, Inc., of Oklahoma City and Caterpillar of Peoria have placed electronic controlled motor graders on the market. Both machines will operate from a single line or from a ski or wheeled sensor. They provide both grade and slope control. They depend on an operator for steering. Details of their operation are shown in Figures 9 and 10.

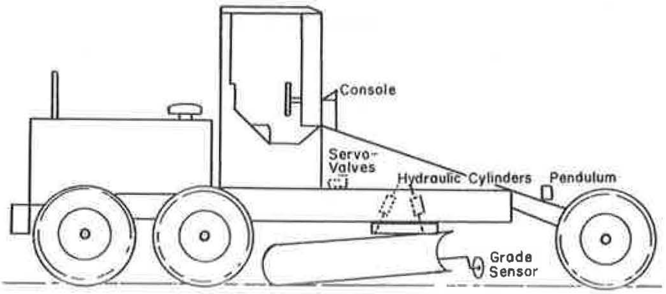


The Autoblade can be guided in both alignment and grade from a single stringline reference, or it can trace a profile from an existing pavement.

Sensors are the CMI Rotary Switch type using counterbalanced rods touching the side or bottom of the string.

The grade controller can make use of skiis as well as a string line. It has cross slope control for automated depth cutting and blading.

Figure 9. CMI Corporation—Autograde Autoblade.



Caterpillar Automatic Blade Control is offered on a factory installed basis for the No. 16, No. 14E and No. 12F Motor Graders. Field installation is not recommended on new or used machines due to the complexity of installation and high cost involved.

Electronic devices for the Automatic Blade Control include:

1. Automatic slope and grade control with integral hydraulic system and blade lift cylinders.
2. Two moldboard attachments for reference grade pick-up purposes, one is a wire follower and the other a wheel follower.

The Control console mounts directly above and forward of the steering wheel. By actuating one or more of the switches the operator has the following choice of control functions: automatic slope and grade control simultaneously, automatic slope control only, automatic grade control only, or manual controls for conventional blading work. The control console is made up of solid state circuitry with replaceable modules.

The desired slope is maintained by use of a powered pendulum, two electric servo-valves, and two hydraulic blade lift cylinders. The operator rotates the slope control dial to the desired percent of slope. The powered pendulum senses this desired change in slope and sends current to one of the two electric servo-valves. The valves allow hydraulic pressure to raise or lower the left cylinders.

Figure 10. Caterpillar—automatic motor grader control.

PROVISIONS FOR SHUTDOWN

Several experimental pavers (not described in this report) have been used in highway construction in the past 10 years with discouraging results because of the failure of the manufacturer to provide immediate "shutoff" in case of sensor malfunction. The sensors on standard automatic equipment in good working order now are provided with auxiliary contacts that are used as paver-stopping circuits in the event that the grid or ski becomes disconnected. Limit switches are provided as protection to the machine and for safety to the operators.

Where there is a chance of conflicting signals being sent to the machine, such as when the grade sensor calls for an upward movement and the slope sensor calls for a downward movement, the signals are routed through a junction box of some type to stop the operation or sound an alarm. On some pavers, it is impossible to connect the slope control if both grade controllers are connected.

The entire sensor unit on the Caterpillar motor grader is designed to come off if struck by a rock or unyielding object. This provision not only prevents the blade from malpositioning, but it also protects the sensor unit from serious damage. On almost all machines, indicating lights are mounted in a conspicuous place on the sensor or on a console in front of the operator.

RESULTS TO BE EXPECTED BY THE USE OF AUTOMATIC CONTROL

When completing the questionnaire for this evaluation, construction engineers from several states mentioned that not all of the results from the use of automatic control were good. During the field evaluation of the different electronically controlled machines, it was noted that automatic control does not ensure a project against imperfections. However, the difficulties were general in nature and could not be associated with the type of electronic control. They were more often associated with the ski or shoe that activated the sensor.

Some of the reported difficulties associated with the performance of automatically controlled machines are as follows:

1. Ski or shoe guided sensors may at times operate under very wobbly conditions. A shoe traveling across a base course or the first asphaltic-mix lift will provide grade control, but control for a leveling up operation is questionable. A 30-ft ski may in some cases be inadequate to bridge humps that should be taken into consideration. Many so-called "rigid trusses" now provided by the manufacturers of pavers are equipped with wheels on each end. Reports indicate a grid following a line on this wheeled frame (even with the most rigid frame) is subject to some bouncing so that the $\frac{1}{8}$-in. control indicated by some manufacturers may not always be achieved. It would appear that a well-established string line attached to ground supports might be a more reliable means of activating a sensor for positive control of a predetermined grade. The apparent advantages of the stationary string-line method of guidance was illustrated by the research performed in Canada in 1965 (6).
2. Unless a ground-supported string line is used, there is a very definite need for the operator or an assigned individual to follow along the side of the machine to clear the pebbles and debris left by the trucks and transfer operations ahead of the paver. This is particularly true when the paver travels over a surface that has been tacked with liquid asphalt. Every particle on the roadway appears to stick to the surface directly in the path of the sensors.
3. There is a tendency for contractors to purchase automatically controlled equipment and place it in the hands of inexperienced operators, or attempt to provide experience for the operators during actual construction. When the finished product is something less than perfect, the casual observer becomes critical of the automatic control system. Manufacturers have attempted to build into their machines systems as foolproof as possible, but operators who make no attempt to study the operations of their machines before using them are very definitely hampering the progress of automatic operation.

Good consistent results with automatic controlled equipment depend on the desire of the contractor's personnel to produce the best surface possible, the condition of the equipment as a whole (not just the automatic controls), and rapid evaluation of results being obtained so that necessary corrective measures can be taken during the progress of the work.

A study made in Texas in 1967 illustrates the results of automatic operation (7). The test site had a flexible base placed with a CMI machine using electronically controlled grade apparatus and was quite smooth and true to cross section. Two asphaltic concrete mats were placed using bituminous pavers with electronically controlled screeds. The roughness was determined with the Reinhart profilograph and consisted of obtaining a profile over areas in which the paver has stop-and-go operation and areas over which different paver speeds were used. Considerable roughness was found in the areas where the paver paused for a change of trucks, and increased roughness was experienced as the paver speed increased.

In 1969, roughness tests were made on a multilift paving project at 50 mph using the Colorado accelerometer attached to the rear axle of a pickup truck. The emulsified asphalt mix base was placed with an electronically controlled CMI machine. Succeeding lifts of asphalt mix were placed with a Blaw-Knox paver using a 30-ft reinforced, aluminum, I-beam ski with spring-loaded feet. Average roughness values after laydown for each layer are given in Table 2.

Slope variance values as low as four have been measured with the CHLOE profilometer on pavements laid with one pass of the CMI paver using the stationary string-line method and good construction procedures.

Figures 11 and 12 show graphs taken from a Reinhart profilograph to illustrate the smoothness that may be expected from both good and bad operation of an automatically controlled paver placing a $1\frac{1}{2}$-in. overlay on a curled concrete pavement. On an asphalt overlay, the roller operation may be as responsible for a rough surface as the control of the paver. On a concrete pavement, the surface smoothness is primarily a result of paver control.

TABLE 2
AVERAGE ROUGHNESS VALUES

Item	Thickness (in.)	Slope Variance or Calif. in./mi	Equivalent BPR Roughness	Present Serviceability Index $PSI = 5.03 - 1.91 \log (1 + \overline{SV})$
Base course	4	20	150	2.6
First lift	2	8	115	3.2
Second lift	1½	5	90	3.6
Final lift	1½	3	45	3.9

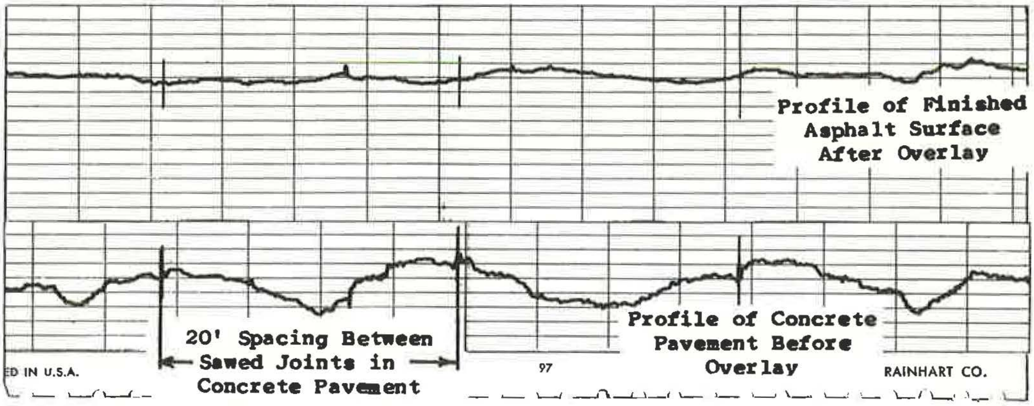


Figure 11. Surface smoothness on an asphalt overlay where the paver was well controlled.

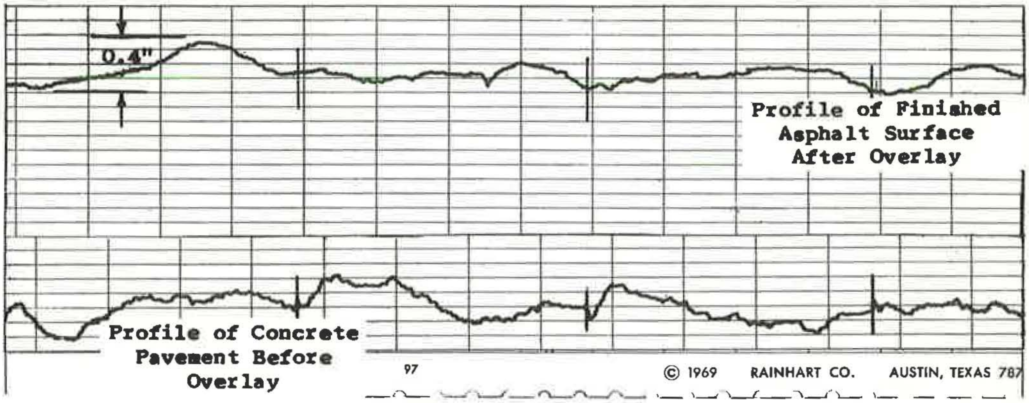


Figure 12. Surface smoothness on an asphalt overlay where the automatically controlled paver underwent a stop-start operation and the steel wheel roller could not remove the resulting depression and hump.

BASIS FOR SPECIFYING AUTOMATICALLY CONTROLLED PAVERS

Engineers from several of the 50 states contacted for this evaluation submitted copies of specifications used to require automatically controlled pavers. The method of wording varied from the simple statement, "Pavers shall be equipped with the necessary attachments, designed to operate electronically, for controlling the grade of the finished surface," to detailed requirements spelled out for each part of the operation.

A more detailed specification is as follows:

> The paving machine shall be equipped with an automatic control system which shall control the elevation of the finished pavement surface, and which is automatically actuated by a system of sensor-operated devices which sense and follow reference lines or surfaces on one or both sides of the machine as required.
>
> Failure of the automatic control system to function properly will be cause for suspension of the paving operations until such time as the automatic control system has been made operative and is functioning properly.
>
> The automatic control system shall be capable of working with the following items, and when required, they shall be furnished with the machine:
>
> Ski-type device at least 40 feet in length.
> 5,000 feet of control line and stakes.
>
> The control line, when required, shall be installed by the contractor and shall be maintained taut and to the grade and alignment established.

The contracting agency should be careful to specify a control system that it feels will provide the best results obtainable, within economic limits. Careful consideration should be given to single-layered pavement projects. On projects constructed with a multilayered pavement structure, this careful consideration may not be as important. Indications are that the short ski or wheeled truss may not provide desired results in some cases, and some laydown results have indicated that even a long rigid ski with or without spring-loaded feet might require several passes to provide a really smooth surface. It is also pointed out that, in addition to the particular type of laydown equipment or controls used, many other factors enter into the final pavement results.

The Ontario Department of Highways studied each hot-mix paving project to determine whether the use of automatically controlled pavers would be advantageous (2). A decision not to specify automatic pavers is usually made when the project is of a small stopgap nature or if the construction is to be of only one lift. Its experience, and the experience of many other agencies, has been that at least one leveling course is required below the surface course to allow the electronic controls to correct irregularities in the grade.

COST OF AUTOMATIC CONTROL

The cost of automatic control for construction equipment does not appear to have retarded its development. Manufacturers provide automatic control for approximately 7 percent more than the cost of the manually operated models. Automatic controls may be installed on most pavers, but Caterpillar does not recommend field installation of electronic controls on the motor grader because of complexity of installation and the high cost involved.

FUTURE USE

Much has been written about the possibilities for remote control of construction equipment by radio and light (laser beam) rays. At this time, there is little if any standard equipment such as this on the market. When an electronic device making use of radio or light beams is assembled and tried on some project, the write-ups make headlines that give hope to everyone awaiting the push-button age. Actually, development appears to be more along the line of reliability and more in line with economics.

By 1970 it appears that the trend will be toward more contractors using available automatic devices rather than some contractors using more sophisticated types of automatic control. The construction engineers from all states contacted for this study expressed the opinion that the use of automatically controlled construction equipment was increasing.

ACKNOWLEDGMENT

All references pertaining to manufactured equipment have been cleared with the manufacturers.

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Appendix

A summary of the information obtained from the 50 states on automatic control and tolerances are given in the following tabulations.

SUMMARY OF INFORMATION ON AUTOMATIC CONTROL AND TOLERANCES FROM 50 STATES

N = No
Y = Yes
? = Unknown

While all possible care has been taken to insure the accuracy of this summary, no responsibility can be taken by compilers for omissions or errors.

State	Do Specs Require Automatic Controls?	Do Specifications Specify a Thickness Tolerance and Final Surface Smoothness Tolerance for: Sub-grade		Subbase				Base Course				Pavement Asphalt / Concrete				Tolerance Changed Since Automatic Control?	Does Availability of Auto Control Affect Bid Prices?	% of Pavement Placed With Automatic Control	Do Contractors Use Auto Controls on Motor Graders?	USAGE		Remarks
		Smoothness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Yes-No		Asph PCC		Increasing	Decreasing	
Ala	Y	Y	½"	Y	½"	Y	8%	Y	¼"	Y	8%	Y Y	¼" 1/8"	N Y	- ¼"	N	N	85 65	Y	Y		Automatic control encouraged on all projects and require'l by specs on some.
Alaska	N	N	-	N	-	N	-	Y	3/8"	Y	3/8"	Y Y	3/16" 1/8"	Y Y	3/16" 0.2"	N	N	20 -	N	?	?	
Ariz	Y	N	-	-	-	-	-	Y	3/8"	N	-	Y Y	3/16" 7"/Mi	N Y	- .2"	Y	Y	100 100	Y	Y		Auto control brought on the 3/16" and 7"/Mi tolerance
Ark	Y	N	-	N	-	Y	±1"	N	-	Y	±1"	Y Y	1/8" 1/8"	- Y	- .5"	N	N	75 75	Slope Con-trol	Y		Specs require auto control on Asph paving only
Calif	Y	Y	±.1'	Y	±.08'	N	-	Y	±.05'	N	-	Y Y	.01' .02'&7"	N Y	- .01'	Y	Y	30 90	Y	Y		Specs require auto control on special projects only
Colo	Y	Y	±¼"	Y	¼"	Y	¼"	Y	¼"	Y	¼"	Y Y	3/16" 1/8"	N Y	- .2"	N	N	90 90	Y	Y		Subgrade smoothness tolerance can be nil
Conn	N	Y	2"	N	-	Y	-1"+ 3/4"	N	-	Y	-3/4" + ½"	Y Y	¼" 1/8"	Y Y	½" .25"	N	?	1 1	Y	Y		1 PCC & 2 subgrade in last 2 years with auto control
Del	Y	Y	1/8"	N	-	N	-	Y	¼" Asph 1/8" PCC	N	-	Y Y	¼" 1/8"	- Y	- 0.2"	N	N	80 80	Y	Y		Auto control required for Asph paving only
Fla	Y	Y	½"	-	-	-	-	Y	¼"	Y	½"	Y Y	3/16" 1/8"	Y Y	.5" .5"	N	N	90 90	N	Y		Tolerances on Base & Pavement are for pavement only
Ga	Y	Y	¼"	Y	¼"	Y	½"	Y	¼"	Y	½"	Y Y	1/8" 1/8"	Y Y	.25" .5"	N	Y	50+ 50+	N	Y		Specs require auto control on subbase & bases under high type pave
Hawaii	Y	N	-	N	-	N	-	N	-	N	-	Y -	3/16" -	Y -	.02' -	N	N	15 -	N	?		Auto control required on special projects only
Idaho	Y	N	-	N	-	N	-	Y	¼"	Y	½"	Y Y	¼" 1/8"	N Y	- 0.2"	N	N	100 100	N	Y		Specs require auto control for asphaltic concrete only
Ill	N	Y	1/8"	Y	3/8"	Y	90%+	Y	¼"	Y	1/8"	Y Y	1/8" 1/8"	- Y	- 10% Plan	N	N	? ?	N	Y		Auto control increasing only for fine grading. Penalty if pave thickness < 1/8"

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State	Do Specs Require Automatic Controls?	Do Specifications Specify a Thickness Tolerance and Final Surface Smoothness Tolerance for: Sub-grade		Subbase				Base Course				Pavement Asphalt / Concrete				Tolerance Changed Since Automatic Control?	Does Availability of Auto Control Affect Bid Prices?	% of Pavement Placed With Automatic Control	Do Contractors Use Auto Controls on Motor Graders?	USAGE		Remarks
		Smoothness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Yes-No		Asph PCC		Increasing	Decreasing	
Ind	Y	Y	½"	Y	½"	N	-	Y	½"	N	-	Y Y	1/8" 1/8"	N Y	.5" .5"	N	Y	100 35	Y	Y		Auto control not required for concrete pave. No tolerance for subbase under PCC
Iowa	Y	Y	.05'	Y	.05'	N	-	Y	.05'	N	-	Y Y	1/8" 1/8"	N Y	- .15"	N	N	60 60	Y	Y		Auto control required on base & on surface courses more than 1" thick
Kan	Y	N	-	N	-	N	-	Y	¼"	N	-	Y Y	3/16" 1/8"	N Y	- .2"	N	Y	100 1	CMI	?		Specs require auto control on asph paving only. Min. Sub Th =4".
Ky	N	Y	½"	Y	½"	Y	½"	Y	¼"	Y	¼"	Y Y	1/8" 1/8"	Y Y	1/8" .2"	N	N	50 50	Y	Y		
La	N	N	-	N	-	N	-	N	-	Y	3/4"	Y Y	1/8" 1/8"	Y Y	¼" .2"	N	N	Low	Y	Y		
Me	Y	Y	1"	Y	½"	N	-	Y	3/8"	N	-	Y Y	3/16" 1/8"	N Y	- .2"	N	?	20 0	N	Y		Specs require auto control on Interstate paving only
Md	Y	Y	-	Y	½"	Y	½"	Y	¼"	Y	½"	Y Y	1/8" 1/8"	N Y	- .20"	N	N	90 0	N	Y		Auto control mandatory for grade control only
Mass	N	Y	1"	Y	3/8"	N	-	Y	3/8"	N	-	Y Y	¼" 1/8"	Y Y	¼" .25"	Being Con-sidered	?	1 1	Y	Y		Auto control specified as alternate for sub-base & base const.
Mich	Y	Y	.1'	Y	3/4"	Y	3/4"	Y	¼"	Y	½"	Y Y	¼" 1/8"	Y Y	¼" .2"	N	N	5 0	Y	Y		Supplemental specs often require auto control
Minn	N	Y	.1'	Y	.05'	Y	.05'	Y	.05'	Y	.05'	Y Y	¼" 1/8"	Y Y	.5" .1"	N	Y	60 90	Y	Y		Auto control has helped to hold down costs
Miss	Y	Y	1"	Y	1"	Y	1"	Y	½"	Y	1"	Y Y	1/8" 1/8"	N Y	- .2"	N	N	100 0	Y	Y		Auto control specified for asph paving only
Mo	Y	Y	½"	Y	¼"	-	-	Y	¼"	N	-	Y Y	1/8" 1/8"	N Y	- .2"	N	N	80 0	Y	Y		Auto control specified for asph paving only
Mont	Y	Y	1/10'	Y	.08' for 1½" Mtl	N	-	Y	.06' to .04'	N	-	Y Y	3/16" 1/8"	N Y	- 1/8"	Y+1/16"	N	70 70	N	Y		Auto control specified for asph paving only

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State	Do Specs Require Automatic Control?	Do Specifications Specify a Thickness Tolerance and Final Surface Smoothness Tolerance for: Sub-grade		Subbase				Base Course				Pavement Asphalt Concrete				Tolerance Changed Since Automatic Control?	Does Availability of Auto Control Affect Bid Prices?	% of Pavement Placed With Automatic Control	Do Contractors Use Auto Controls on Motor Graders	USAGE		Remarks
		Smoothness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Yes-No		Asph PCC		Increasing	Decreasing	
Neb	Y	N	-	N	Reasonable close conformity							Y Y	1/8" 1/8"	Y Y	¼" .25"	Y	Y	85 85	N	?		A thickness tolerance of ½" has been set on CTB since auto control
Nev	Y	Y	.05'	Y	.05'	N	-	Y	¼"	N	-	Y Y	¼" 7"/Mi	N Y	- .01'	N	N	20 20	Y	Y		
N.H.	N	N	1"*	N	½"*	N	-	N	½"*	N	-	Y Y	3/16" 1/8"	N N	- -	N	Y	5 5	Y	Y		Tolerances shown for subgrade, subbase and base are unwritten*
N.J.	N	N	-	N	-	N	-	N	-	N	-	N Y	- 1/8"	Y Y	8% -	N	N	5 5	N	Y		Thickness tolerances are as directed by the engineer
N.M.	Y	Y	.05'	N	-	Y	½"	Y	3/8"	Y	½"	Y Y	3/16" ¼"	N Y	- .2"	Yes-AC ¼ to 3/16	N	100 0	Y	Y		Specs require auto control on asphaltic concrete only
N.Y.	Y	N	-	Y	½"	N	-	Y	¼"	N	-	Y Y	¼" 1/8"	Y Y	¼" .5"	Yes-PCC 12"/Mi	?	10 10	Y	Y		Auto control used selectively by special specs only
N.C.	Y	Y	.05'	N	-	Y	1"	N	-	Y	1"	Y Y	1/8" 1/8"	N Y	- .25"	N	N	55 55	Y	Y		Auto control required on asphaltic paving & PCC when using slipform
N.D.	Y	N	-	N	-	N	-	Y	¼"	N	-	Y Y	¼" 1/8"	N Y	- .2"	N	N	90 90	Y	Y		Auto control specified on selected projects
Ohio	Y	Y	½"	Y	½"	N	-	Y	3/8"	N	-	Y Y	¼" 1/8"	Y Y	5% Yield .1"	N	N	75 0	Y	Y		Auto control specified on selected projects
Okla	N	Y	½"	Y	½"	Y	½"	Y	½"	Y	½"	Y Y	3/16" 1/8"	Y Y	RC* .2"	N	Y	60 60	N	?		*RC = Reasonable conformity
Ore	Y	* RC	-	Y	.04'	Y	0.10'	Y	.04'	Y	0.1' **	Y Y	.015' .01'	N N	- -	Y	Y	95 95	Y	Y		*Reasonable Conformity **C.T.B. 0.04'
Pa	Y	Y	½"	Y	½"	Y	½"	Y	½"	Y	½"	Y Y	3/16" 1/8"	Y Y	¼" .25"	N	Y	0 42	N	Y		Auto control specified on slip-form pavers only
R.I.	N	N	-	N	-	N	-	Y	3/8"	Y	3/8"	Y Y	3/8" ¼"	Y Y	¼" 3/8"	N	N	30 0	Y	Y		

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State	Do Specs Require Automatic Control?	Do Specifications Specify a Thickness Tolerance and Final Surface Smoothness Tolerance for: Sub-grade		Subbase				Base Course				Pavement Asphalt Concrete				Tolerance Changed Since Automatic Control?	Does Availability of Auto Control Affect Bid Prices?	% of Pavement Placed With Automatic Control	Do Contractors Use Auto Controls on Motor Graders	USAGE		Remarks
		Smoothness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Smoothness	Tolerance	Thickness	Tolerance	Yes-No		Asph PCC		Increasing	Decreasing	
S.C.	Y	N	-	N	-	Y	¼"	Y	¼"	Y	½"	Y Y	1/8" 1/8"	N Y	- 0.2"	N	?	70 ?	Y	Y		Auto control specified for grade control occasionally
S.D.	Y	N	-	N	-	N	-	N	-	N	-	Y Y	¼" 1/8"	N Y	- .2"	N	N	90 90	N	?		
Tenn	Y	Y	Close	Y	Close	N	-	Y	3/8"	N	-	Y Y	¼" 1/8"	N Y	- .25"	Y	N	100 100	Y	Y		"Close" means reasonable close conformity to line and grade
Tex	Y	Y	½"	Y	½"	Y	½"	Y	¼"	Y	½"	Y Y	1/8" 1/8"	N Y	- .25"	N	Y	90 90	N	Y		Specs requite auto control on ACP primarily
Utah	N	Y	.1'	-	-	-	-	Y	.5"	Y	.5"	Y Y	1/8" 1/8"	Y Y	¼" .25"	Y	N	75 90	N	Y		
Vt	Y	Y	½"	Y	¼"	Y	1"	Y	¼"	Y	¼"	Y Y	¼" 1/8"	Y Y	¼" .25"	N	Y	20 20	Y	Y		Auto control specified on all major paving projects
Va	N	Y	Elev. .5"	Y	*	Y	.5"	Y	*	Y	.5"	Y Y	3/16" 1/8"	Y Y	.5" .2"	N	N	1 1	N	Y		* Abrupt changes in grade prohibited
Wash	Y*	Y	.1'	Y	±.05'	Y	-.025' to-4%	Y	.02'	Y	-.025' to-4%	Y Y	1/8" 7"/Mi	Y Y	.01'-.025' -.00'	Y	N	? 100	Y	Y		* On 70 MPH design or above
W.Va	N	Y	½"	Y	1"	Y	1"	Y	½"	Y	½"	Y Y	¼" 1/8"	Y Y	¼" 1/8"	Y	N	100 100	Y	Y		
Wis	Y on Asph	N	-	N	-	N	-	Y	1/8" Asph	Y	.2"	Y Y	1/8" 1/8"	N Y	- .20"	Y	Y	75 75	N	Y		Contractors must request permission to use auto control on final course
Wyo	Y	N	*	N	*	Tons/ft		N	*	Tons/ft		Y Y	3/16" 1/8"	N Y	- .2"	Y	N	98 90	Y	Y		* Tolerance depends upon rideability
Wash D.C.	N	N	-	N	-	N	-	N	-	N	-	Y Y	1/8" 1/8"	N Y	- 1/8"	N	?	? 0	N	?		