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ADVANCED RETRO TECHNOLOGY, INC.

AUTOMATED PAINT RESTRIPING RECOGNITION AND GUIDANCE SYSTEM

PHASE 1 FINAL REPORT

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Advanced Retro Technology, Inc.

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AUTOMATED PAINT RESTRIPING RECOGNITION AND GUIDANCE SYSTEM

PHASE I FINAL REPORT

1.Ø INTRODUCTION

A breadboard of the Laser Scanning/Guidance System has been developed for an Automated Paint Restriping Recognition and Guidance System as proposed in RFQ #9Ø-DA1Ø58, 199Ø. The laser scanning/guidance system uses three laser beams scanning on the pavement and detecting the position of the old stripe. The system analyzes the signal detected by the laser scanner and sends out an analog voltage output which is proportional to the lateral position of the stripe. The system also detects the longitudinal position of the skip stripes and sends out a digital (binary) signal for controlling the paint gun on and off.

Using the laser beam as the light source the system can significantly reduce the influence caused by the ambient luminance. Without any other light source or other means of help the system can work with nearly the same performance as under direct sunshine, under shadow, in cloudy weather or at night.

The laser scanning/guidance system utilizes the retroreflection principle to increase the signal/noise ratio. With a fairly small observation angle (less than Ø.3 degrees) the system can easily differentiate the retroreflective stripes from the other objects on the pavement even in the case where the other objects may be visually brighter than the stripe.

The system uses three laser beams to determine the lateral position of the stripe. By using a quadratic curve fit the analytical error in lateral position for a 5Ø feet radius curve is less than Ø.Ø2 inches which is much less than the Ø.5 inches requirement. In the same situation, one scanner cannot determine even the direction of the stripe. The two beam scanner can determine only the straight line. For the 5Ø feet radius curve the two beam scanner may have a analytical error as much as 7.7 inches which is far beyond the required Ø.5 inches and about 4ØØ times larger than that of the three beam system.

The laser scanning/guidance system uses the GESPAC computer as its major data manipulation and analysis computer. The GESPAC computer used in the laser scanner/guidance system has an MC68020 CPU and a 16 MHZ speed. The GESPAC computer with the instrumentation interface board (IIB) which is specially developed for the system by **Advanced Retro Technology, Inc. (ARTI)** can conduct an on-time data requisition, data analysis and the system control. The GESPAC computer and its G-96 bus are compactly designed. The whole computer with the IIB board can be installed in a case as small as 7.13" X 5.25" X 4.38". It is an ideal computer to be installed (in the phase II development) within the same enclosure as the laser scanner system.

A laboratory and field test were conducted to ascertain the performance of the system. The lab test showed that the system can successfully detect the lateral position of the stripe within the required ±0.5 inch accuracy. The analog voltage output is proportional to the lateral position of the stripe. The output voltage with respect to the lateral position maintains excellent linearity and repeatability. The longitudinal detection accuracy is also within the contractual requirement of ±4 inches. The field test showed that the system works well for both the solid line and the skip line which had only 40% - 60% retroreflectivity of the new stripe at a vehicle speed as great as 40 mph.

2.0 LASER SCANNING/GUIDANCE SYSTEM DESIGN

2.1 General System Design

The first decision in the system design is the location of the scanner. It can be located either directly on the MB vehicle or on the outrigger of the paint gun assembly. Since the final output is the lateral distance between the stripe and the paint gun, if the scanner is located on the MB vehicle, the system needs to detect both the positions of the stripe and the paint gun assembly. If the scanner is located on the outrigger of paint gun assembly, only the position of the stripe need to be detected. To reduce the complexity and the cost of the system, the laser scanning/guidance system is designed to attach on the top of the outrigger of the paint gun assembly. The position of the laser scanning/guidance system on the MB vehicle is illustrated in Figure 1.

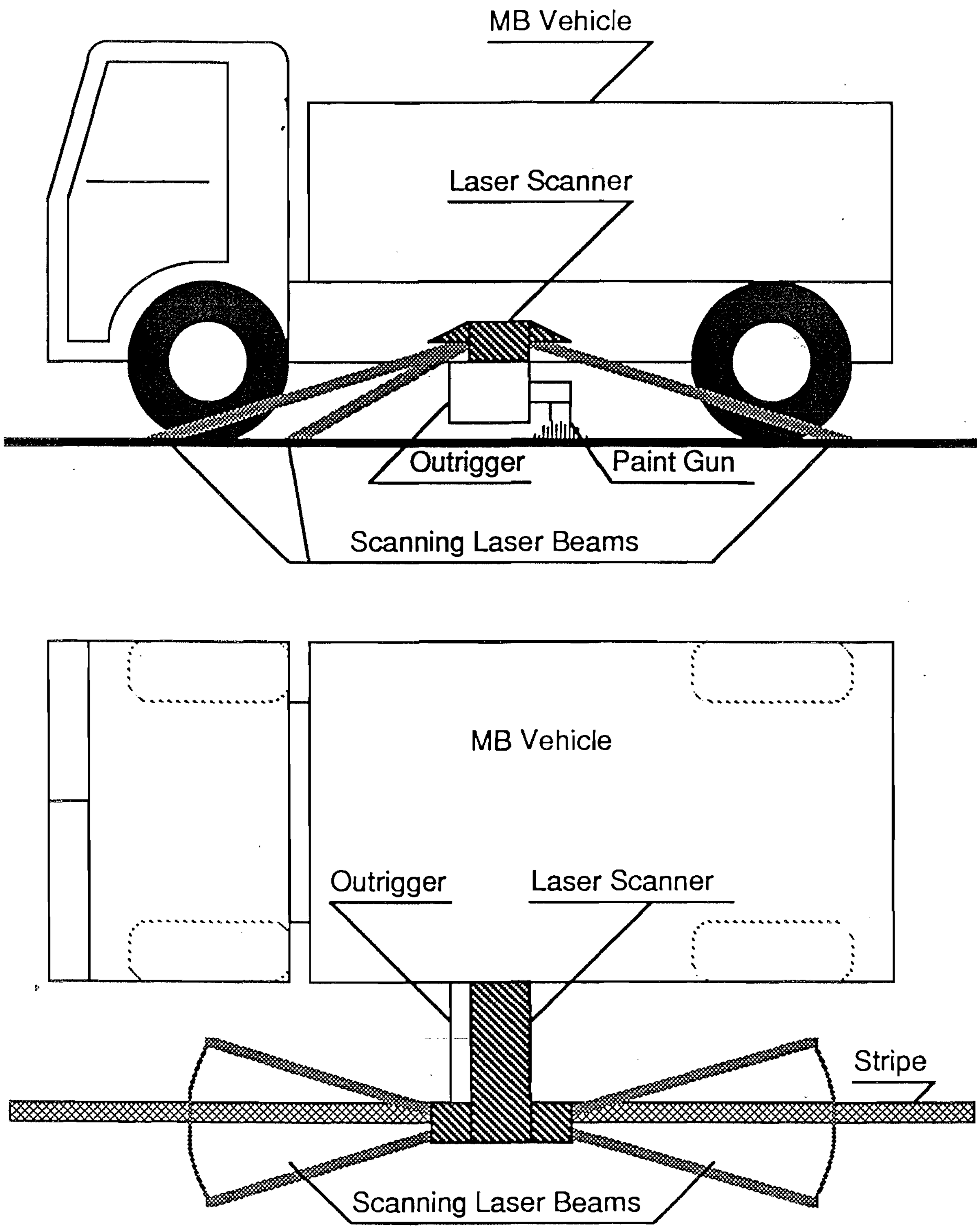


Figure 1 Laser Scanner Attached on Outrigger of MB Vehicle

According to the requirements proposed in RFQ #90-DA1058 the system should be able to detect the stripe on the pavement under various lightening environments. Under roadway or natural lighting, the pavement and the stripe may be quite different from the result under shadow. The luminance contrast between the sun illuminated area and a shadowed area may be higher than the contrast between the stripe and the pavement. To solve this problem, a laser scanning system has been developed. Since the laser beam has a single wavelength, with a narrow-band optical filter (1 nm), the system can reduce the influence of the lighting environment to a minimum. The laser scanning system also utilizes the retroreflection property of the stripe to increase the signal/noise ratio. Since the old stripe still retains a certain amount of retroreflectivity while most other objects are not retroreflective, the laser scanning system can detect the stripe from the other objects even when the other objects are visually brighter.

The system is required to work on both the straight line and the curve sections of the roadway, so the laser scanning/guidance system should be able to detect the direction and the radius of the stripe. The system, thus, requires multiple laser beams. A single beam scanning system can only determine the position where the laser beam is scanning. It cannot tell the position of the paint gun assembly even if it is working on a straight stripe. The two beam scanning system can determine the lateral position of the straight stripe but not curves. For example, if a two beam scanning system has one beam scanning at the position of 8 feet in front of the scanner and the other beam scanning at 8 feet behind the scanner, the analytical error for a 50 feet radius curve is about 7.73 inches. This obviously exceeds the requirement of 0.5 inches in lateral position accuracy proposed in RFQ #90-DA1058. To detect accurately the curved stripe, the system needs at least three scanning laser beams. If an extra beam scanning at 5 feet in the front of the scanner is added to the two beams mentioned before, the three beam system with a quadratic curve fit can make the lateral analytical error less than 0.02 inches.

The longitudinal detection accuracy requirement proposed in RFQ #90-DA1058 is ±4 inches under the maximum vehicle speed of 40 mph. To meet the longitudinal accuracy requirement, the gap between two scans should be less than or equal to 4 inches at the maximum speed of 40 mph. The calculated scan frequency is 4Ø x 528Ø x 12 / 36ØØ / 4 = 176 scans per second (sps). The scanner must generate 176 sps or 1Ø56Ø scans per minute (spm). The lateral detection accuracy requirement is ±Ø.5 inches. If the gap between the two data point is less than Ø.5 inches, for a 3 feet scan width the number of data collected for every scan should be more than 3 x 12 / Ø.5 = 72 (points). In every scan, the scanner must collect at least 72 data points for the 3 feet scan width. To make the lateral position more accurate, the data collection points for every 3 feet scan width is designed with approximately 144 (72 * 2) points. The resolution of the lateral position detection is about Ø.25 inches. The number of data points collected per scan is finally determined in the IIB board design.

Based upon the analysis just presented, the laser scanning/guidance system has the following characteristics:

1) The system is attached to the outrigger assembly of paint guns.
2) The system uses laser beams as its light source.
3) It is a scanning system.
4) The system utilizes the retroreflective property of the stripe.
5) The system has three scanning laser beams.
6) The scan frequency is 176 scans per second.
7) The number of data points collected for a 3 feet scan width is at least 72 and is presently designed for approximately 144.

2.2 Laser Scanner Design

The layout of the laser scanner is shown in Figure 2 and a more detail blueprint is included in Appendix A. The laser beam used in the system is a random orientation 7 milliWatt (mW) Helium-Neon continuous CW laser. The laser unit emits the laser light at the single wavelength of 632.8 nm. The laser beam is about $\frac{1}{4}$ inch in diameter at 8 feet. The main laser beam is then split into three (3) beams with approximately equal irradiance. These three beams are directed to three different facets of an octagonal scanning mirror. According to the general system design the octagonal scanning mirror is rotated at a velocity of 176 / 8 = 22 revolutions per second (rps) or 132Ø revolution per inute (rpm). As shown in Figure 2 and Appendix A, two of the laser beams are reflected forward by the scanning mirror and the third one is directed to the

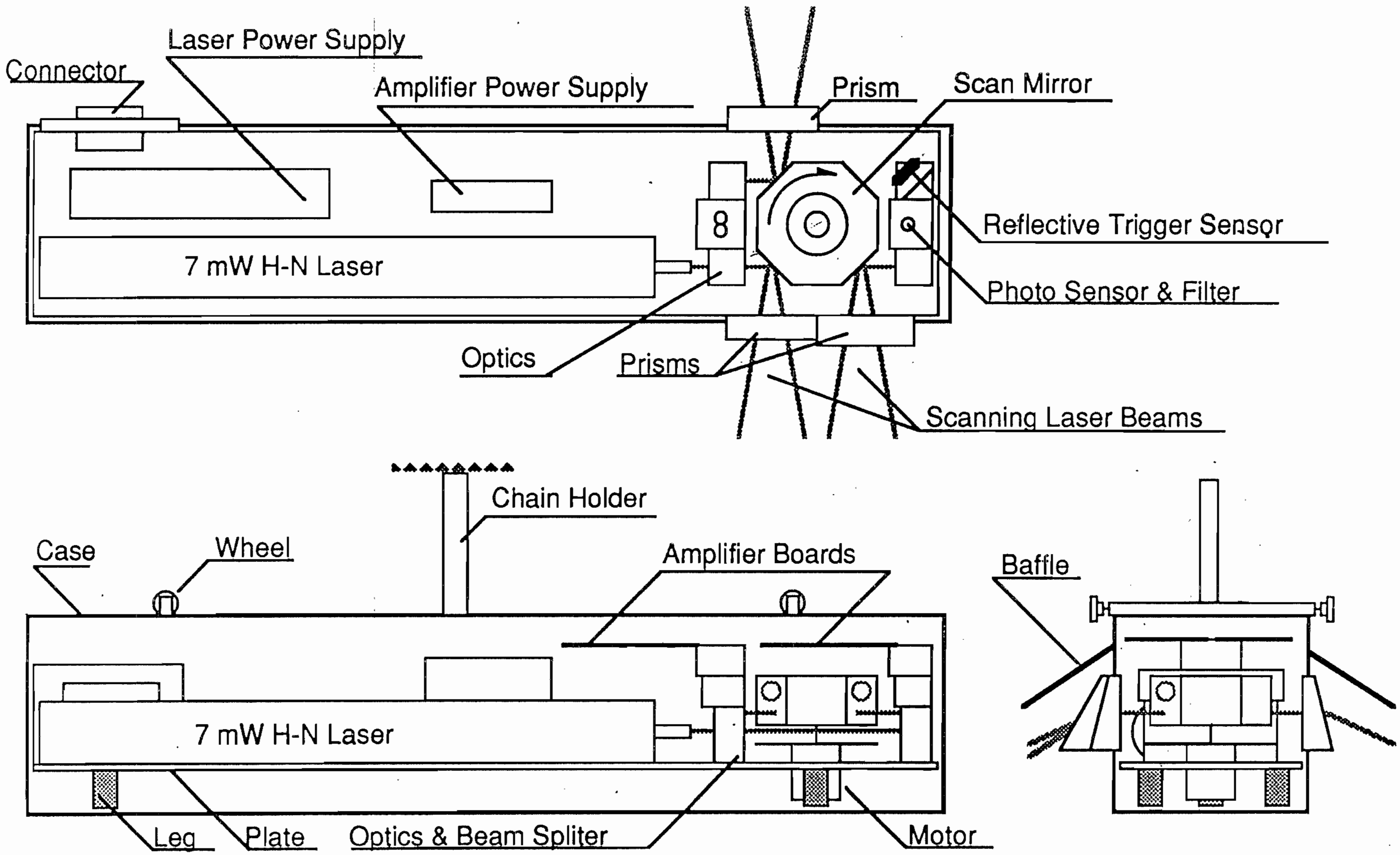


Figure 2 The Layout of the Scanner

rear. Glass prisms mounted on the housing windows refract the laser light downward to the pavement taking the time delay of the hydraulic systems for the paint gun assembly valves and the motion control of the outrigger assembly in consideration, the three beams scan the pavement at the positions of 8 feet forward, 5 feet forward and 8 feet to the rear respectively. Based upon the dimension of the MB vehicle, the scanners optical axis is located about 34 inches above the ground. The angle between the laser beam and the horizontal surface of the pavement is about 19.5 degrees for the 8 foot beams, and about 29.5 degrees for the 5 foot beams.

The scan width is designed for 3 feet (±1.5 feet, at the lateral movement of the outrigger assembly) at the 8 feet scan distance, scanning angle 21.6 degrees. Because the scanning laser beams are reflected by the scan mirror, the mirror will turn only 10.8 degrees for the 21.6 degrees scanning angle.

The retroreflected radiant flux is collected through the same prisms and reflected off the same facets of the octagonal scanning mirror and directed to optical systems located just above the laser beams. Located within each of the optical systems is a field stop used to limit the field of view of the collection beam. The size of the field stops is about 4 times larger in diameter than the laser beams at the pavement distances. Interposed in the beams before the silicon photodetectors are narrow-band (1nm) interference filters which reduce the ambient light to a very small amount. A hermetically sealed reflective sensor assembly, positioned opposite one of the scanning octagonal mirror facets, supplies a trigger signal for the scans. The three amplifier boards for three silicon photodetectors are mounted close to the detectors and completely shielded.

The scanning mirror and motor assembly is manufactured by the Lincoln Laser Company. The scanning mirror is made of aluminum and coated with gold. The reflectance of the mirror for the 632.8 nm wavelength laser beam is above 95%. The scanning mirror and motor assembly is controlled by a driver board made by the Lincoln Laser Company under ARTI's specifications. The motor speed is controlled by a fixed frequency crystal oscillator located on the driver board. The scanning mirror and motor assembly is carefully balanced in the factory. According to the specification data provided by the manufacturer, both the lays perpendicular to datum and parallel to datum are within ±30 seconds of arc.

The laser unit, scanning motor and mirror, and the optics are assembled on a 0.375 inch thick 6061-T6 aluminum tooling plate. The plate is supported by three legs to the case. The case is fabricated from a 6 inches square tube with a wall thickness of 0.187 inches. The length of the case is 26 inches. Two windows are located on two sides of the case. Several prisms are mounted on the windows through which the laser beams pass. They are covered with external baffles to prevent sunlight or objects falling onto the prisms, and restrict the direct view of the laser beams. Two connectors for the scanner power supply and the electronic signal respectively are located at the other end of the case. There are four tracking wheels and one chain connector located on the top of the case.

2.3 Determination of Lateral and Longitudinal Positions

The lateral position of the stripe at the paint gun assembly is determined by the lateral position of the stripe detected by the three scanning laser beams. As mentioned previously, the three laser beams scan at 8 feet and 5 feet in the front of the scanner, and 8 feet to the rear of the scanner. A quadratic curve is used to fit the curve of the stripe to be detected. Using the notation shown in Figure 3, the quadratic function can be written as

$$y = ax^2 + bx + c \tag{1}$$

where y is the lateral position of the point, x is the longitudinal position of the point, and a, b and c are the second order, the first order and the zero order of the constant coefficients of the quadratic curve respectively. If the three constant coefficients are known, the lateral position y of the stripe at longitudinal position x can be determined by Equation (1). The constant coefficients a, b and c can be obtained by the stripe positions detected by three laser beams. For this system laser beam 1 is scanning at the position where $x_1 = 8$, beam 2 at the position $x_2 = 5$ and beam 3 at the position $x_3 = -8$. The lateral positions of the stripe detected by the three beams are y_1, y_2 and

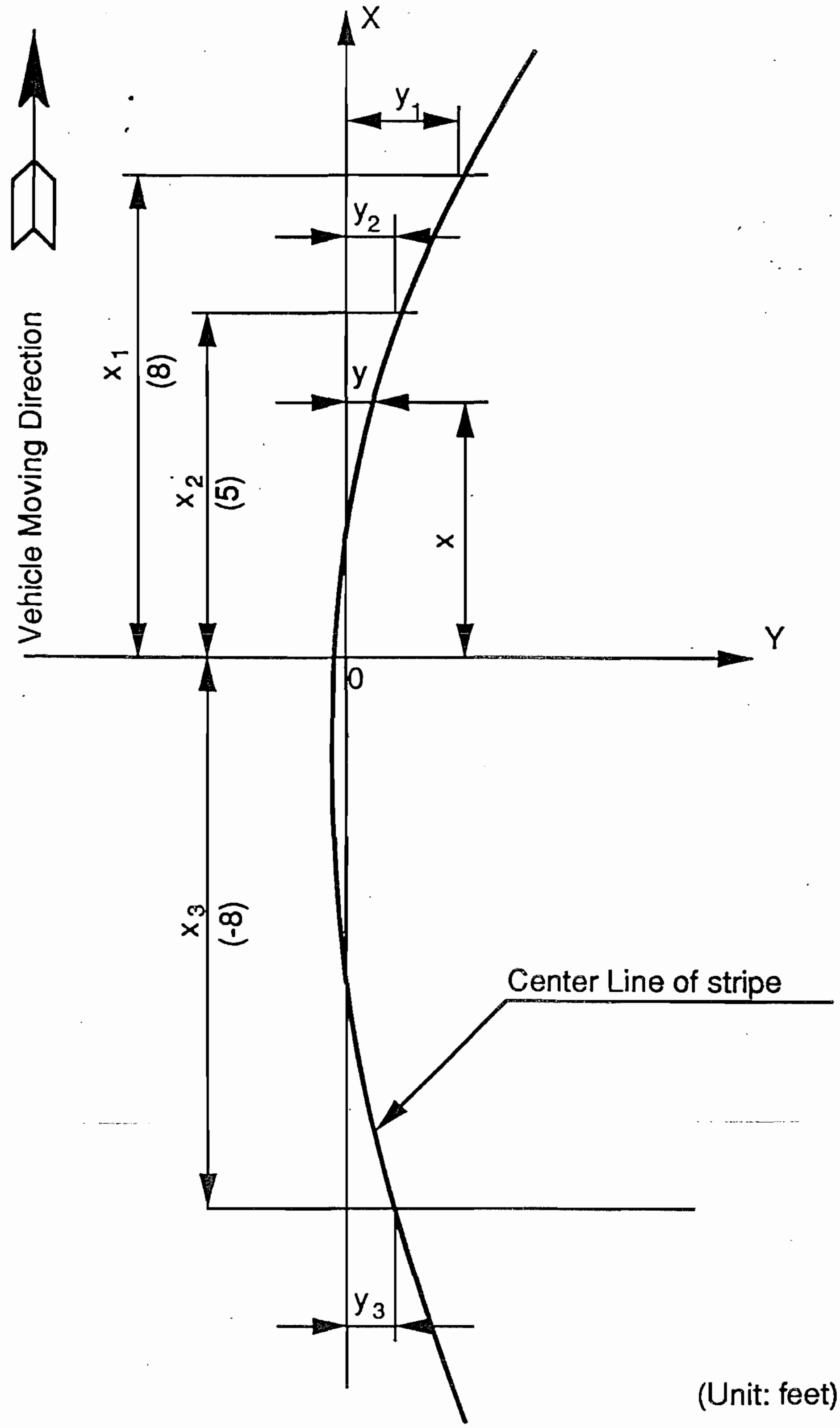


Figure 3 Coordinates of Laser Scanning System

To find the center of the stripe line, the system detects two edges of the stripe with a pre-set threshold value. The center of the stripe is determined by an average of the two edges. Figure 4 shows a typical data set collected by the laser scanner. From Figure 4 it can be seen that when the threshold values are 200 and 550, the center values differ by only 0.18. The center value is not very sensitive to the threshold as long as the threshold value is above the base noise and below the peak of the stripe signal. When the system is used to detect an old stripe, the stripe line itself will have some noise (discontinuities) on the edges. This noise in the position of the edges may cause an inaccuracy in the center position detection. To reduce the noise an average or moving average algorithm is applied. It is assumed that the worn out edges of the stripe are statistically symmetrical and statistically uniform. The final lateral position of the output is the weighted average value of the current reading and the past reading data. For the moving average algorithm, the output value at stage n can be determined by

$$y_n = (1 - \alpha)y'_n + \alpha y_{n-1} \tag{10}$$

Where y_n is the output at stage n, α is the weighting factor which is valued between zero and one ($0 < \alpha < 1$), y'_n is the current reading at n, and y_{n-1} is the output at n-1. Since the moving average is a kind of recursive process, the output at n-1 is

$$y_{n-1} = (1 - \alpha)y'_{n-1} + \alpha y_{n-2} \tag{11}$$

In general, for the nth scan, the output can be written as

$$\begin{aligned} y_n &= (1 - \alpha)y'_n + \alpha y_{n-1} \\ &= (1 - \alpha)y'_n + (1 - \alpha)\alpha y'_{n-1} + (1-\alpha)\alpha^2 y_{n-2} \\ &= (1 - \alpha)y'_n + (1 - \alpha)\alpha y'_{n-1} + (1 - \alpha)\alpha^2 y'_{n-2} + (1 - \alpha)\alpha^3 y'_{n-3} + \dots \\ &= (1 - \alpha) \sum_{i=0}^{n} \alpha^i y'_{n-i} \end{aligned} \tag{12}$$

The past data are weighted by α exponentially from the current value. If the value of α is between zero and one ($0 < \alpha < 1$), the past data to the current data, the less the weight it has. If α is equal to zero ($\alpha = 0$), no past data is

C

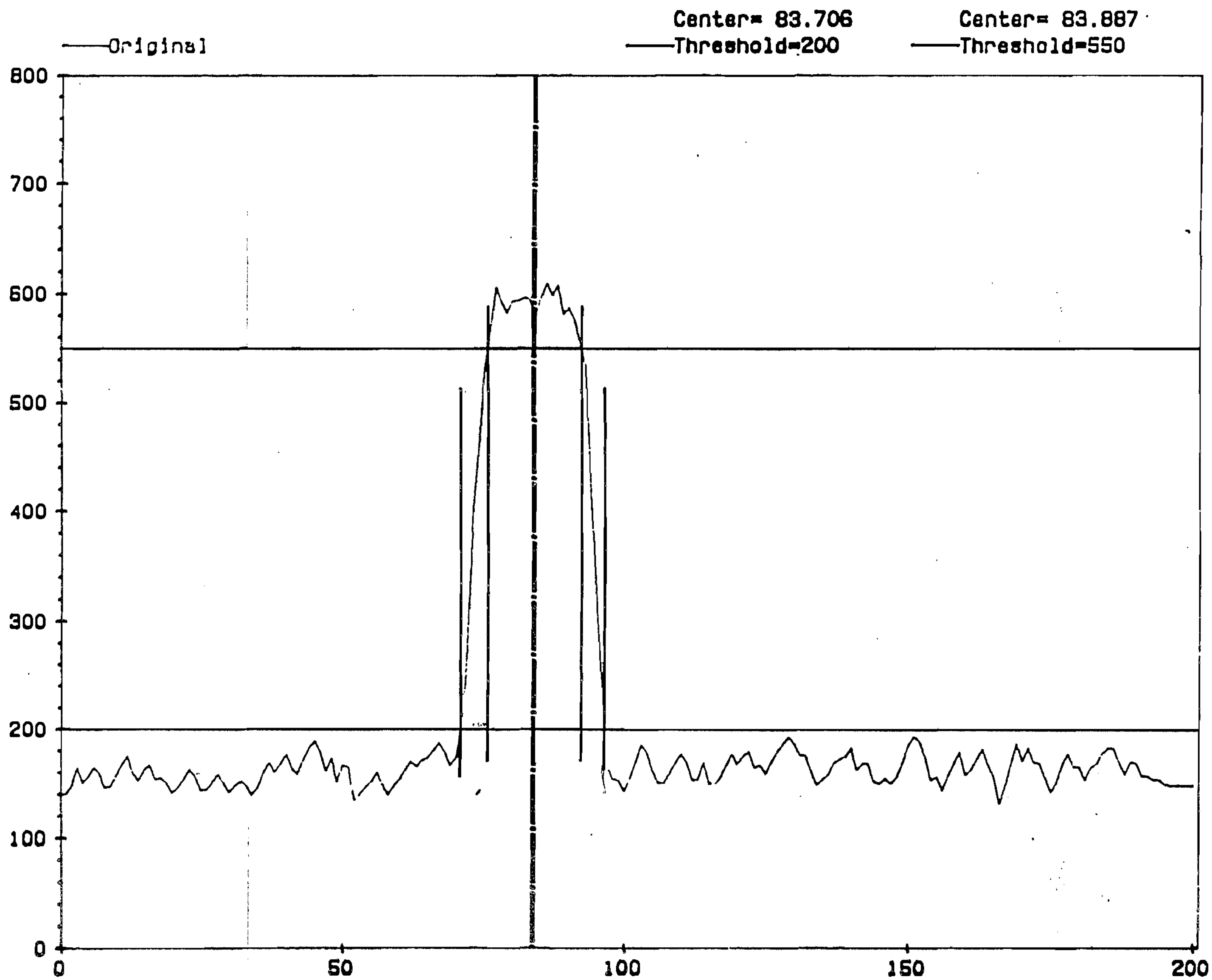


Figure 4 Typical Data and Center Position Determination

considered. If α is equal to one ($\alpha = 1$), no current data is considered. In the breadboard system, the value of α is 0.5. So Equation (10) becomes

$$y_n = 0.5\, y'_n + 0.5\, y_{n-1} = \frac{y'_n + y_{n-1}}{2} \tag{13}$$

In the GESPAC software, the actual algorithm is a quick binary calculation

$$y_n = (y'_n + y_{n-1}) >> 1. \tag{14}$$

Where symbol ">>1" means "shift one bit to the right" which is equivalent to "divided by two and truncated."

For the skip line, when there is no stripe, the system will keep the old position until the new stripe position is detected.

For the longitudinal position detection, the breadboard system uses the 8 foot forward laser beam to detect the start and ending point of the skip line. The system detects the starting or ending point of the stripe, adds an 8 foot increment to that point and stores the new point with the ON/OFF status into a temporary variable. For every scan, the system checks the current odometer reading to that odometer value stored in the temporary variable. If the current odometer reading is equal or larger to the temporary odometer value, the system will send out an ON/OFF signal based upon the status stored in the variable. Then the temporary variable is reset. For example, when a starting point of a skip line stripe is detected, the system reads the current odometer reading, and then sets the "turn-on" odometer counts to

$$od_{ON} = od_{CURR} + odo_{CF} \times 8 \tag{15}$$

where od_{ON} is the odometer count for turning on the paint gun assembly, od_{CURR} is the current odometer reading, odo_{CF} is the calibration factor of the odometer encoder (unit: counts/foot), and the number 8 means the 8 foot laser beam is used to detect the longitudinal position. Ideally, if the time delay of the paint gun assembly valve is known, the "turn-on/off" point for the paint gun assembly will be adjusted based on the speed of the vehicle. Such an input will be developed in Phase II of the project.

2.4 System Control

The laser scanning/guidance system is controlled by a GESPAC computer and an IBM-PC compatible laptop computer. Figure 5 illustrates the block diagram of the system control and the data collection. The GESPAC computer performs the real-time data collection, data manipulation, data analysis, and control of the output. The IBM-PC compatible laptop computer is basically a monitor and remote controller. For future development (Phase II), the GESPAC computer will be installed into the same enclosure of the scanner. The GESPAC has an MC68020 CPU with a 16 MHZ speed, a 20 Mb hard disk and a 3.5 inch floppy disk drive, a GESMFI-1 multi-function interface board, 2Mb Random access memory (RAM), and an instrumental interface board (IIB) which is designed and developed by ARTI. The GESPAC computer for this breadboard system is powered by 110VAC and will be powered by 12VDC for the phase II project. The IBM-PC compatible laptop computer has an Intel 8088 CPU, 30Mb multi-speed hard disk, 640k RAM and a CGA graphics adapter. The laptop computer is powered by 12VDC through the vehicle's cigarette lighter socket. The IBM-PC compatible laptop computer communicates with the GESPAC computer via the RS-232 serial communication port at the baud rate of 19,200. A data manipulation and control software for the GESPAC computer and a menu driven user friendly control software for the IBM-PC compatible laptop computer have been developed by ARTI.

From the IBM-PC compatible laptop computer, the operator can turn the laser beams on or off, read the odometer counter, set the system time of the GESPAC computer, observe the scanning data curves, start continuous scan/guidance operation, change the threshold values and set different system parameters such as the odometer calibration factor, scan size, scan width and so on. The pull-down menus of the control software for the IBM-PC compatible computer are listed in Appendix B.

2.5 IIB Board and Data Manipulation

The IIB board for the GESPAC computer was developed for data acquisition and control. Figure 6 is the flow diagram of the data acquisition by the IIB board. The analog signal after the amplifiers of the three scanners are received by a multiplexer (MX-850), the multiplexer sends the three channel

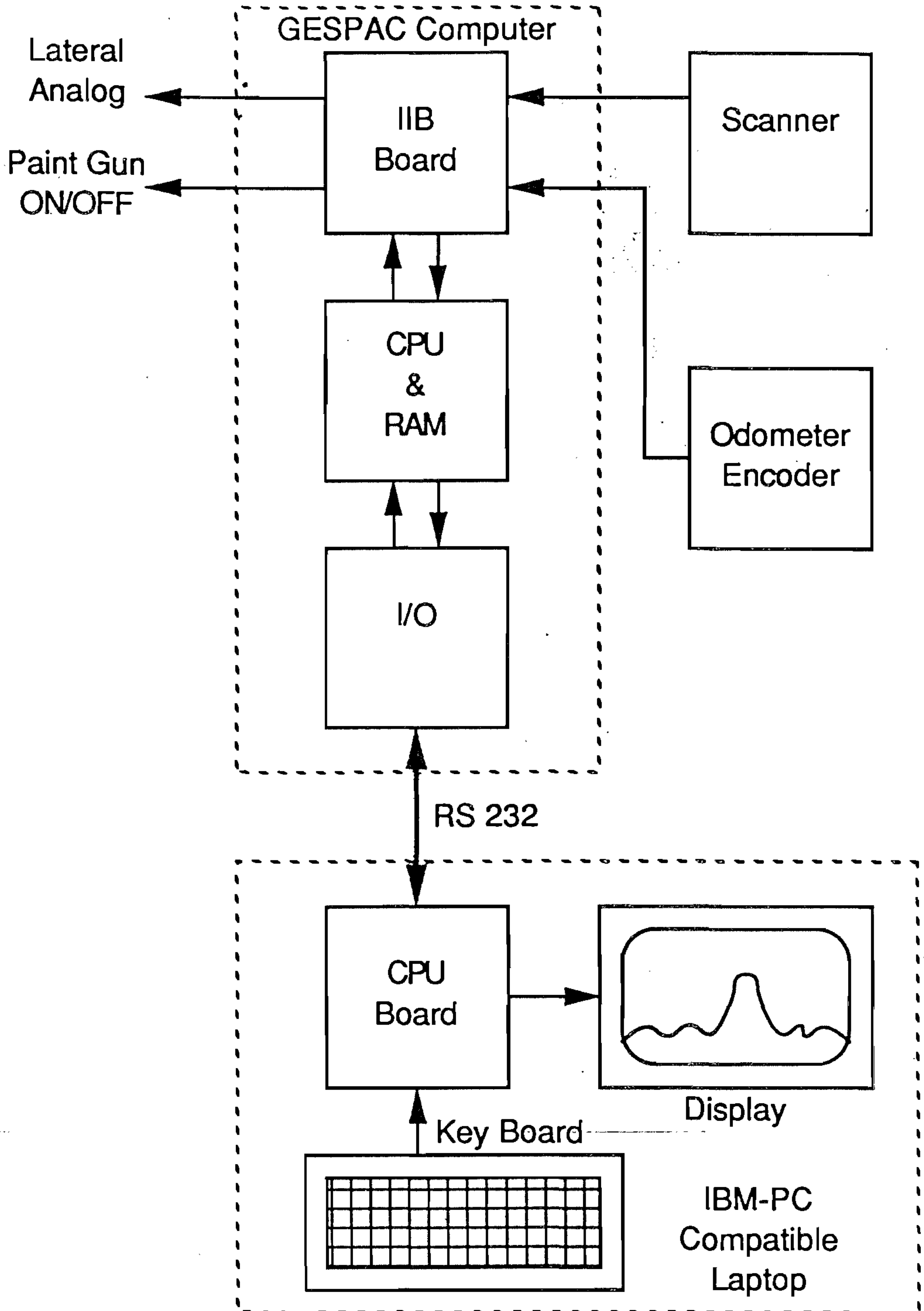


Figure 5 Laser Scan System Control Diagram

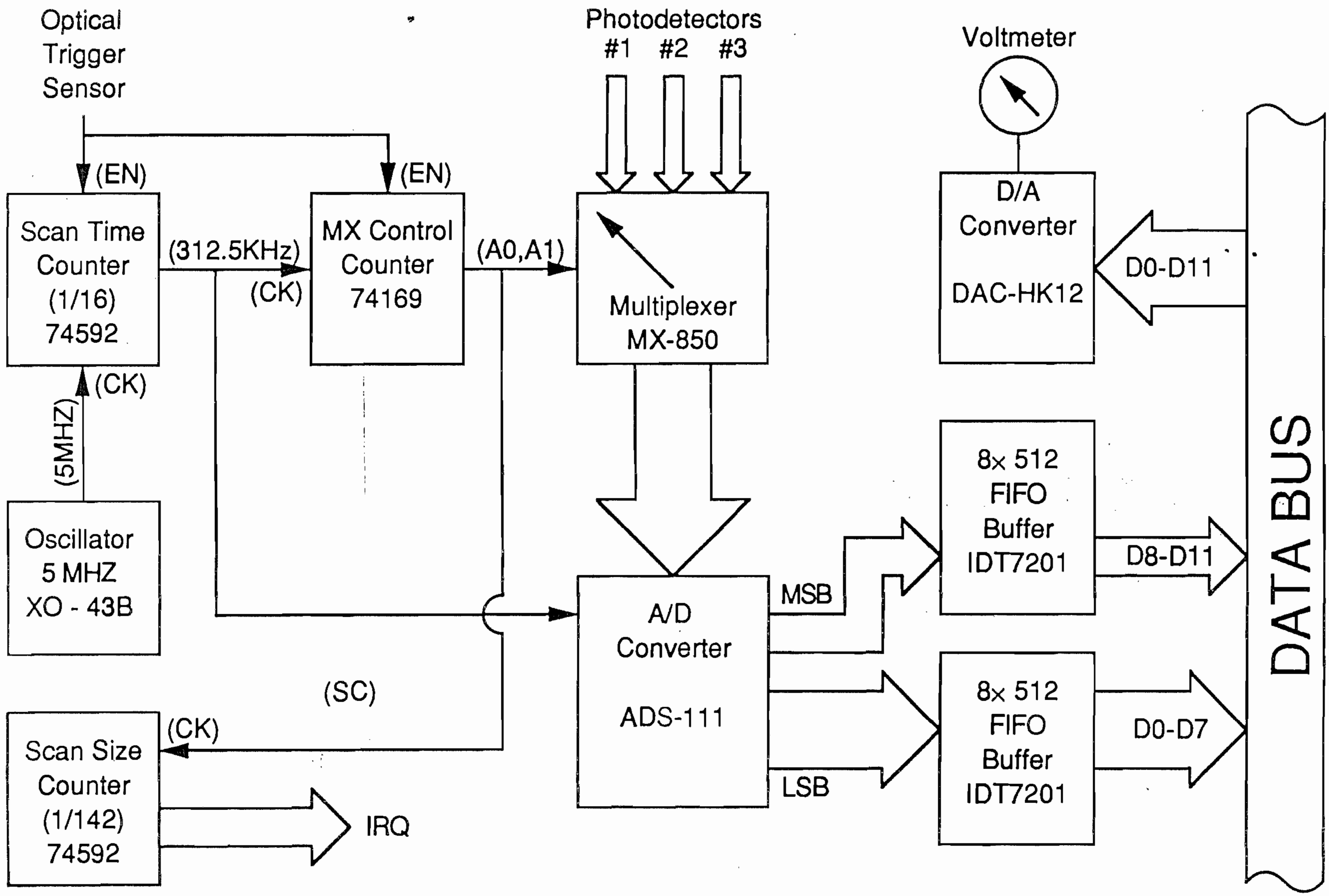


Figure 6 Block Diagram of IIB Board

signals into an A/D converter (ADS-111). The A/D converter transfers the analog data into the 12 bit digital signal data. Two 8 x 512 FIFO buffers store the data temporarily. When one scan is ended, the IIB board generates an interrupt signal which is sent to the CPU board in the GESPAC computer. The GESPAC CPU reads the data from the data buffer and then resets the interrupt status. The IIB board also reads the odometer encoder signal and accumulates the counts of the odometer in an 8 bit counter. When the counter is full, another interrupt signal to the GESPAC CPU is sent. The GESPAC CPU, at this time, increases the software counter and resets the odometer counter.

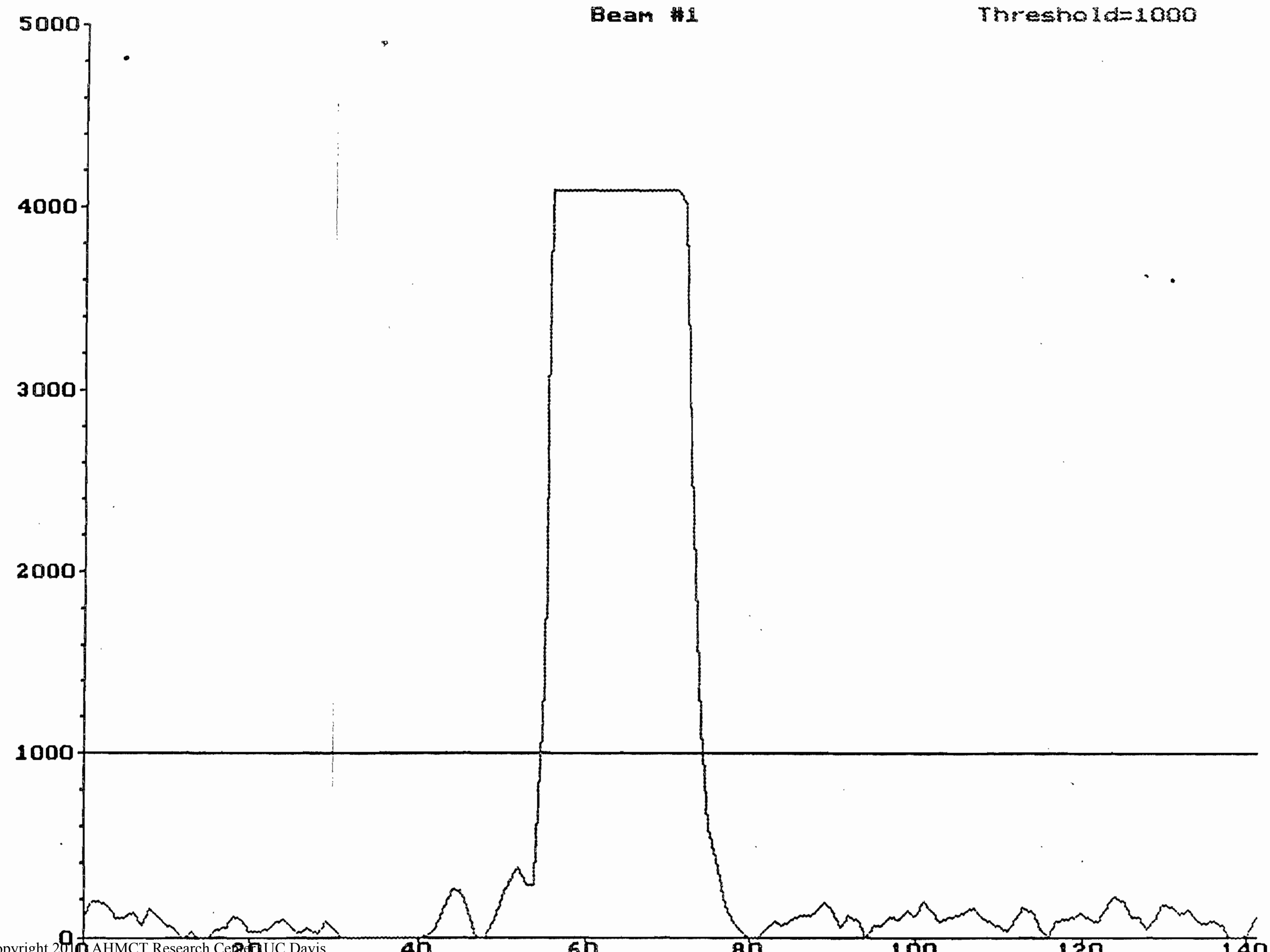
A crystal oscillator on the IIB board generates a 5 MHZ base frequency for the data process control. According to the scanner design, the scanner should collect approximately 144 data readings during the 3 foot scan. The angle of the scanning mirror is 10.8 degrees for a single scan. The speed of the scanning mirror is 1320 rpm or 22 rps, resulting in a data collection time of 10.8 / 360 / 22 = 0.0013636 seconds or 1.36 milliseconds (ms). Within this period, approximately 432 (144 x 3) data points could be collected. The ideal data collection frequency is 432 / 0.0013636 = 316,800 HZ or 316.8 KHZ. Using the 5 MHZ base frequency, the closest frequency generated by the crystal is 5,000,000 / 16 = 312,500 HZ or 312.5 KHZ. Recalculating the number of data points collected for each scan with 312.5 KHZ frequency, we have 312,500 x 0.0013636 / 3 = 142 points. So that the number of the data points collected for each 3 foot scan is 142 points. On the IIB board, one counter (74592) divides the 5 MHZ by 16 and generates a 312.5 KHZ data collection frequency. As shown in Figure 6, the 312.5 KHZ pulses are input into a control counter (74169) for the multiplexer and the A/D converter. The control counter controls the multiplexer switching among channels 1, 2 and 3 in a count down order. After each of the three channels takes one data point, one pulse is sent to the scan size counter (74592) to record the number of data collected. When the scan size counter reaches the number of the data for one scan (e.g., 142), an interrupt command is generated for the GESPAC computer to read the data. After the data is read, the interrupt status and all the counters mentioned above will be reset. For the analog output, a D/A converter on the IIB board converts the lateral position output value to a analog voltage signal. This voltage signal can be either used to display the lateral position on a voltmeter or control the hydraulic driver system of the outrigger.

3.Ø SYSTEM TESTING

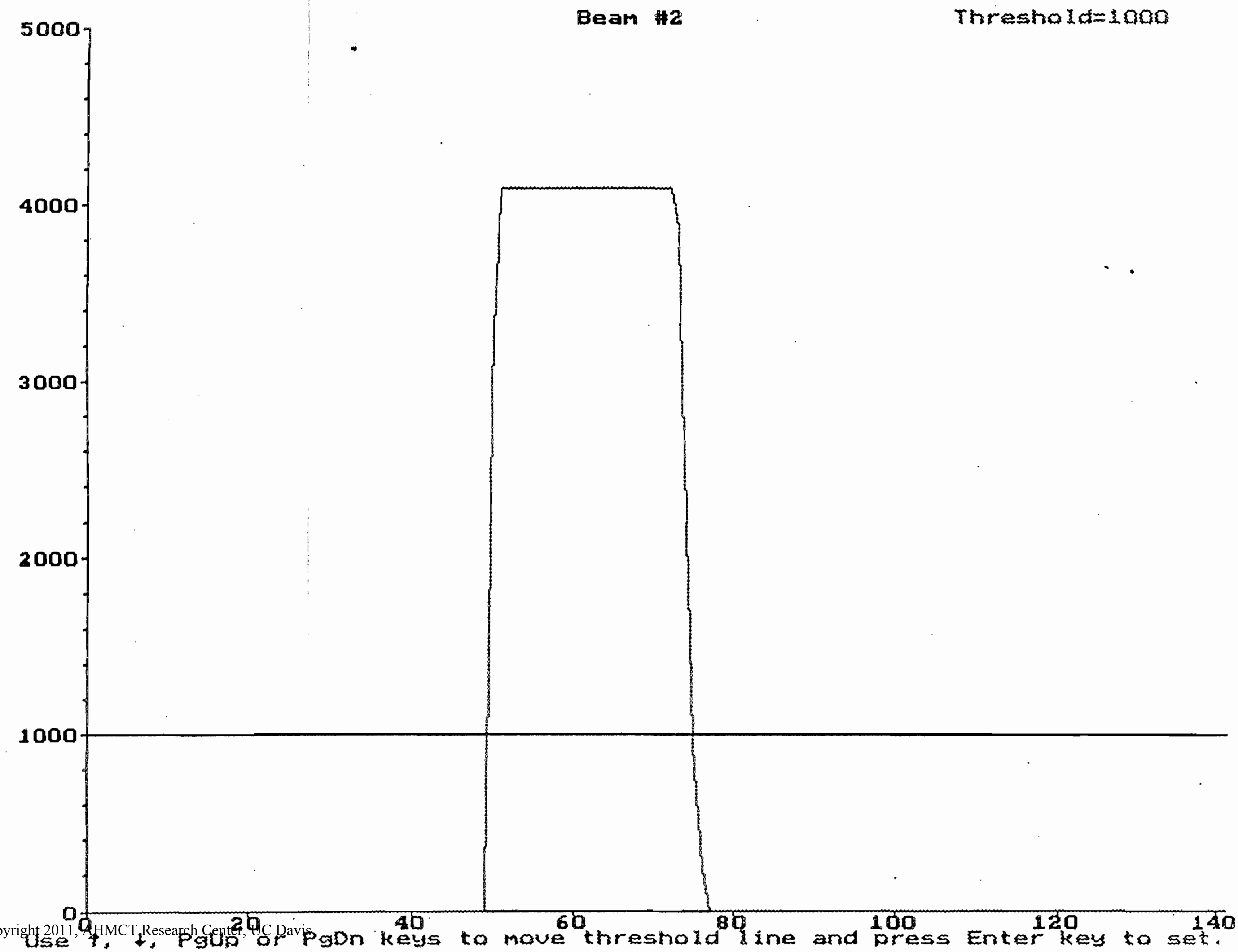
3.1 Laboratory Test.

The system was tested in the ARTI laboratory. Three retroreflective tape panels were used to simulate the stripe. The system has successfully detected the lateral and longitudinal position of the stripes in the lab tests. For the reflective tape, all the stripe signals were saturated. The typical data curve collected by beams 1, 2, and 3 are shown in Figures 7, 8, and 9. When the laser beam is off, the typical data curves for beams 1, 2, and 3 are shown in Figures 1Ø, 11 and 12.

A laboratory test was also conducted to test the lateral position detection capability. As shown in Figure 13, the laser scanner system was set on a mobile cart which could move back and forth laterally. The height of the optical axis of the scanner cart was 36 inches above the floor. Three four inch wide reflective tapes were placed on the floor where the laser beams were scanning. A digital DC voltmeter (FLUKE 73 multimeter, DC option) was connected to the lateral position analog output. A scale was placed on the floor to read the lateral position of the cart. During the experiment, the cart was moved from one inch reading to eleven inches in Ø.5 inch increments. The data was recorded from the 11 inch reading position to the 1 inch position (backward) first, and then from the 1 inch to the 11 inch (forward). At every Ø.5 inch increment, seven voltage readings were taken from the voltmeter. The result of the experiment is plotted in Figure 14. The seven readings at each step were so close that they look like one point on Figure 14. From Figure 14 it can be seen that the relations between the lateral position and the voltage output is a linear function. The voltage output is proportional to the lateral position of the stripe. Using the linear regression, the slope of the straight line function is -Ø.249 (Volt/inch), and the correlation coefficient for the fit is 1.ØØØ. The slope of the straight line can also be changed by the GESPAC computer software if necessary. The test showed that the system has good repeatability and good stability.



Use ↑, ↓, PgUp or PgDn keys to move threshold line and press Enter key to set.



Beam #2
Threshold=1000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
120
140
Use ↑, ↓, PgUp or PgDn keys to move threshold line and press Enter key to set.

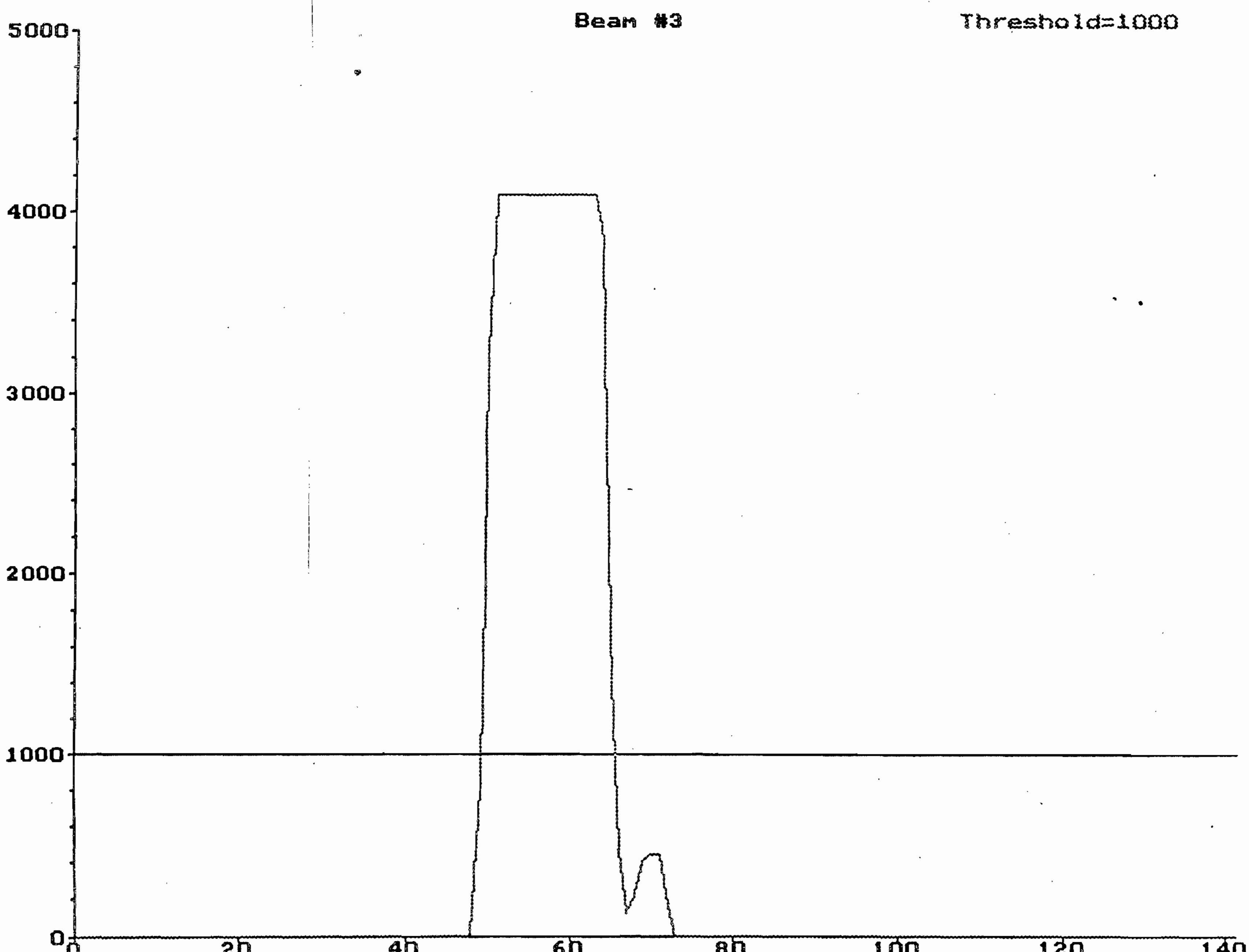
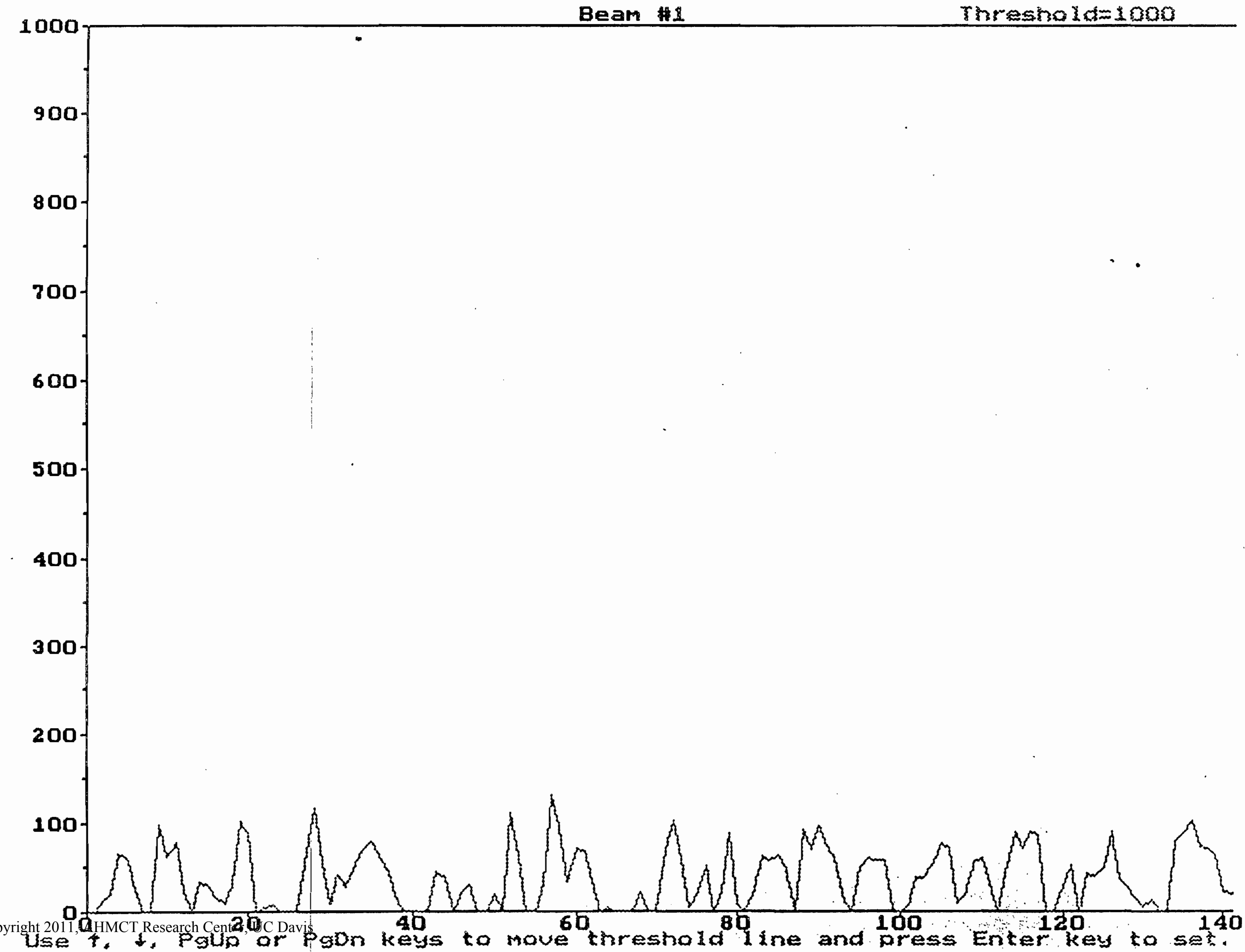
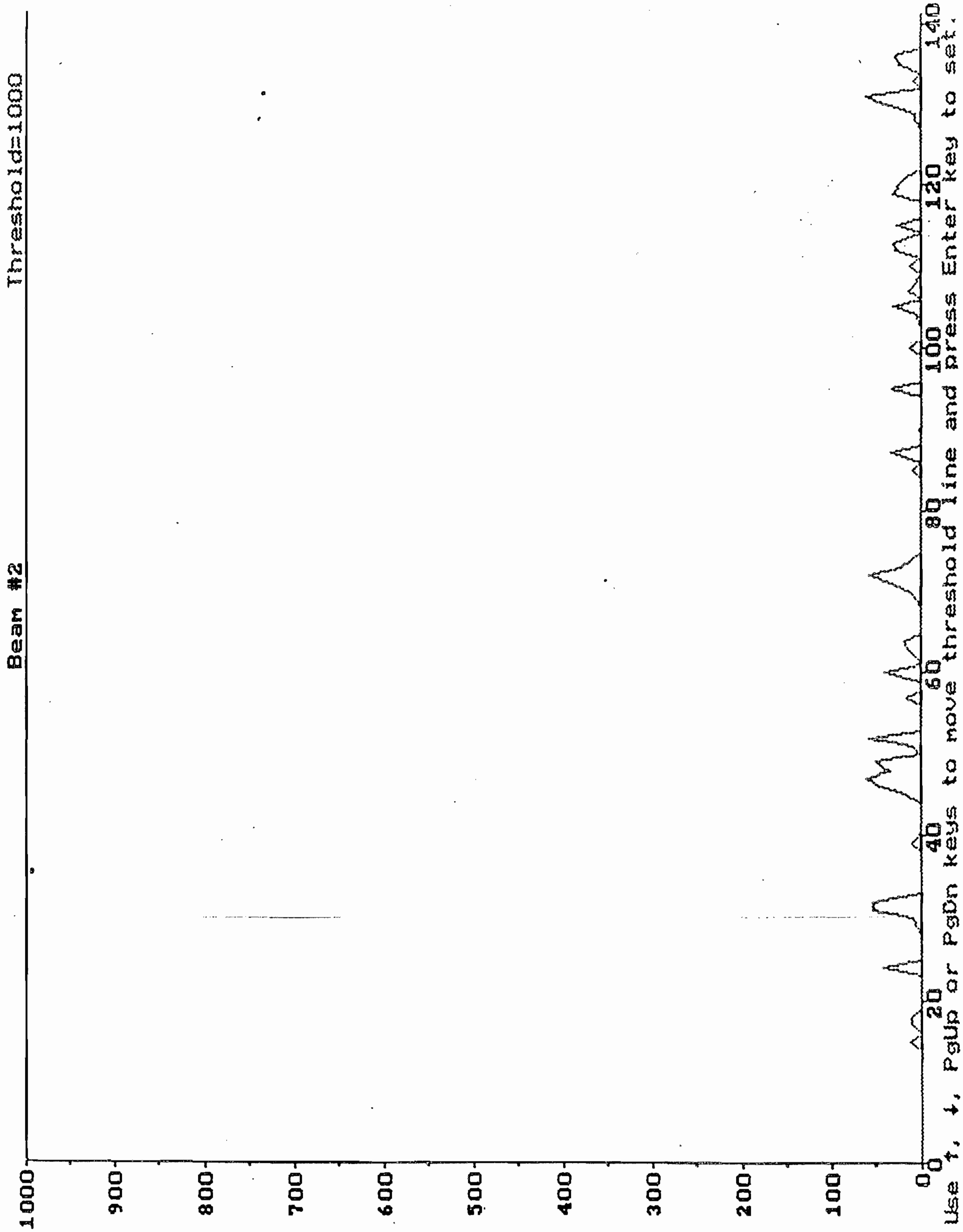
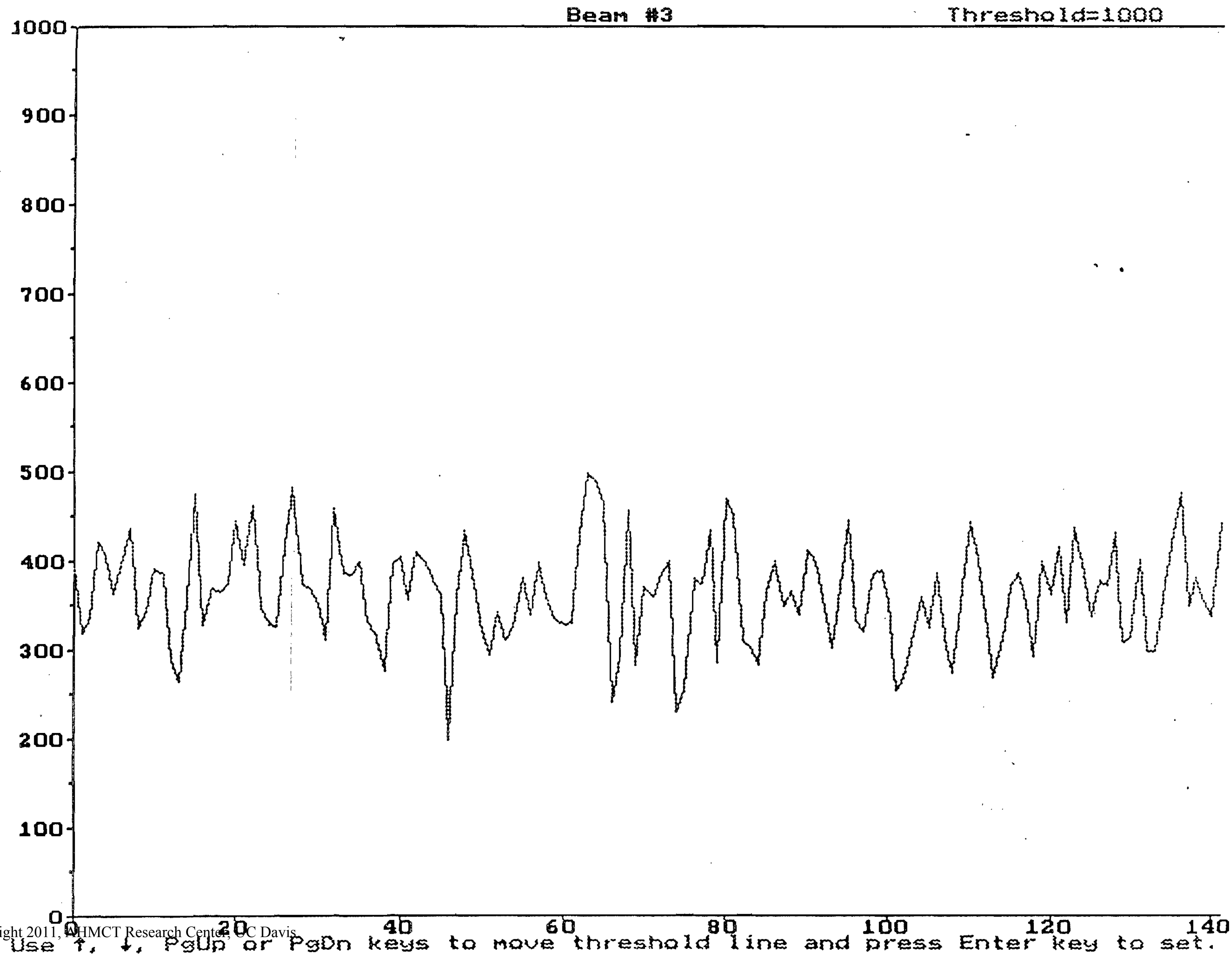


Figure 9. Scanning Data for Sensor 3 When Laser Beam is on


Beam #1
Threshold=1000
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
Use ↑, ↓, PgUp or PgDn keys to move threshold line and press Enter key to set.


Beam #2
Threshold=1000
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
Use ↑, ↓, PgUp or PgDn keys to move threshold line and press Enter key to set.


Beam #3
Threshold=1000
1000
900
800
700
600
500
400
300
200
100
0
20
40
60
80
100
120
140
Use ↑, ↓, PgUp or PgDn keys to move threshold line and press Enter key to set.

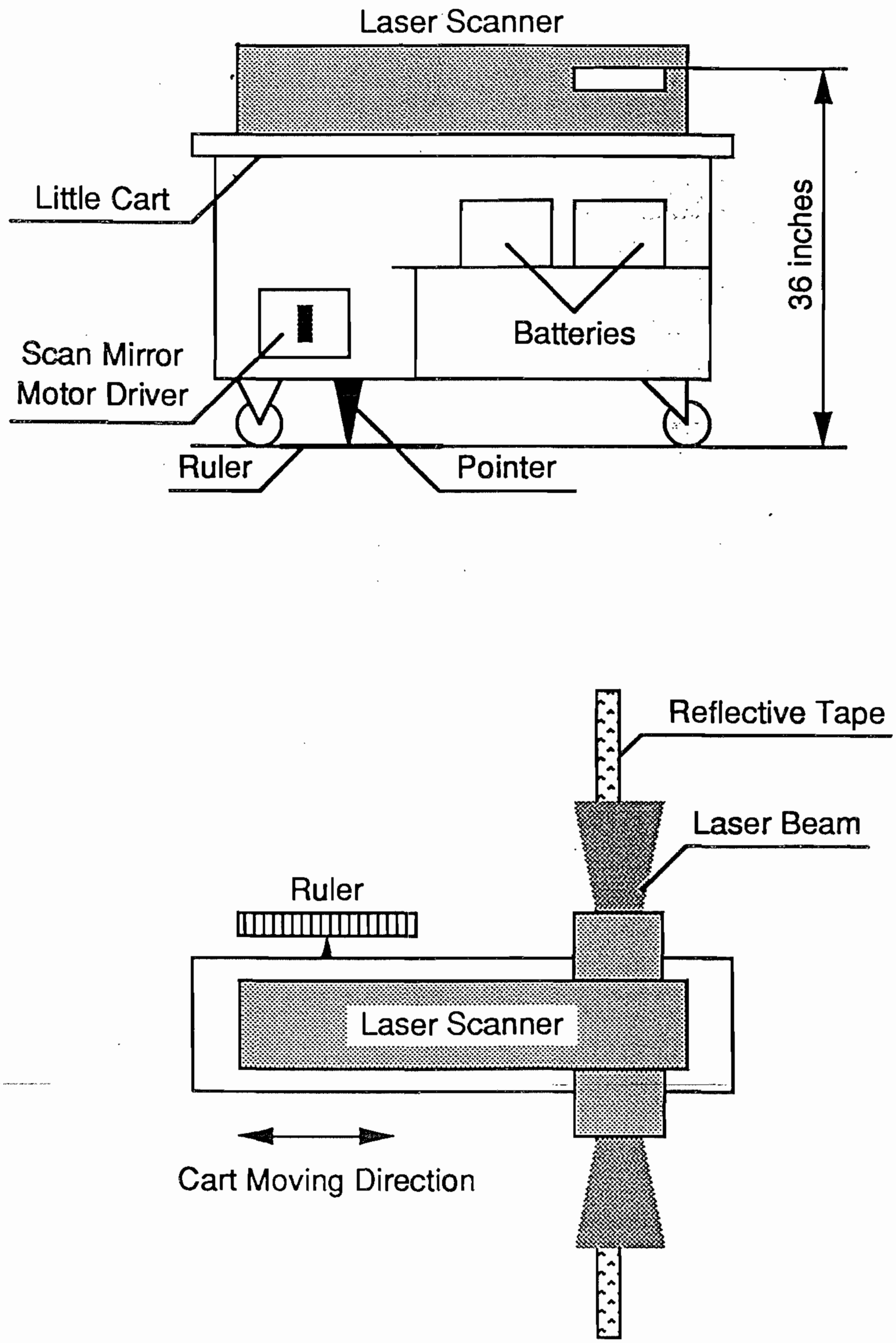


Figure 13 Layout of Lateral Position Detection Test

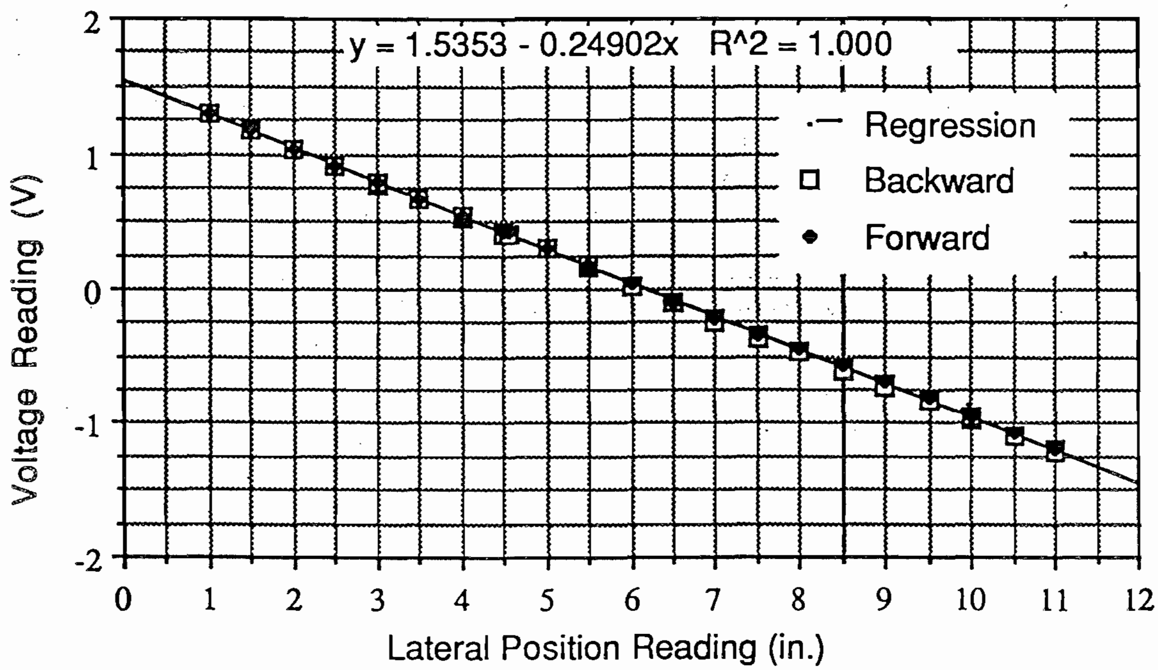


Figure 14 Voltage Output as a Function of Lateral Position

To test the accuracy of the longitudinal detection, a black baffle device (as shown in Figure 15), was set on the beam #1 stripe to simulate the skip line. A motor drives a black baffle, rotated to periodically block the laser. At the opposite end of the motor shaft an encoder was installed to simulate the odometer readings. The speed of the motor was 600 rpm. The encoder generated 100 counts per revolution. With the odometer calibration factor of 11.725 counts per foot (calibrated in the ARTI's pickup truck), the black baffle equipment simulated the scanning system on a vehicle moving at 58.15 mph. The GESPAC and the laptop computer software were then modified to be able to record the odometer readings when the paint gun assembly was triggered on or off. One computer printout of the test data is listed in Appendix C. Looking at the data printout "10179100.lrg" from Appendix C, the maximum variation in separation between "ON" and "OFF" periods is about 0.60 feet. If we reduce this error from the simulated 58.15 mph to 40 mph, the error becomes 0.35 feet or 4.2 inches. Considering that the total error includes errors at the beginning and the end of the period, the real longitudinal detection error for 40 mph speed is about 2.1 inches which is less than the required 4 inches.

3.2 Field Test

The field test was conducted in the University of the California at Davis campus. There were two field tests: the preliminary field test which was conducted on September 27, 1991, and the main field test which was conducted on October 30-31, 1991. A pickup truck was used as the experimental vehicle for the field test. To obtain the odometer increment signal, an electronic encoder was installed in the experimental vehicle's odometer driving train. The resolution of the encoder is 60 pulses per revolution (ppr). By the calibration, the resolution of the odometer encoder for the vehicle's driving system is 11.725 pulses per foot (ppf).

To attach the system to the truck, an aluminum frame was mounted on the top of the truck. There are two tracks on the frame which guide the laser scanner moving laterally. Figure 16 shows the layout of the experimental vehicle, frame, laser scanner and other field test apparatus for the field test. As shown in Figure 16, the laser scanner was mounted on the left side of the vehicle. The operator can move the laser unit back and forth by a chain (not

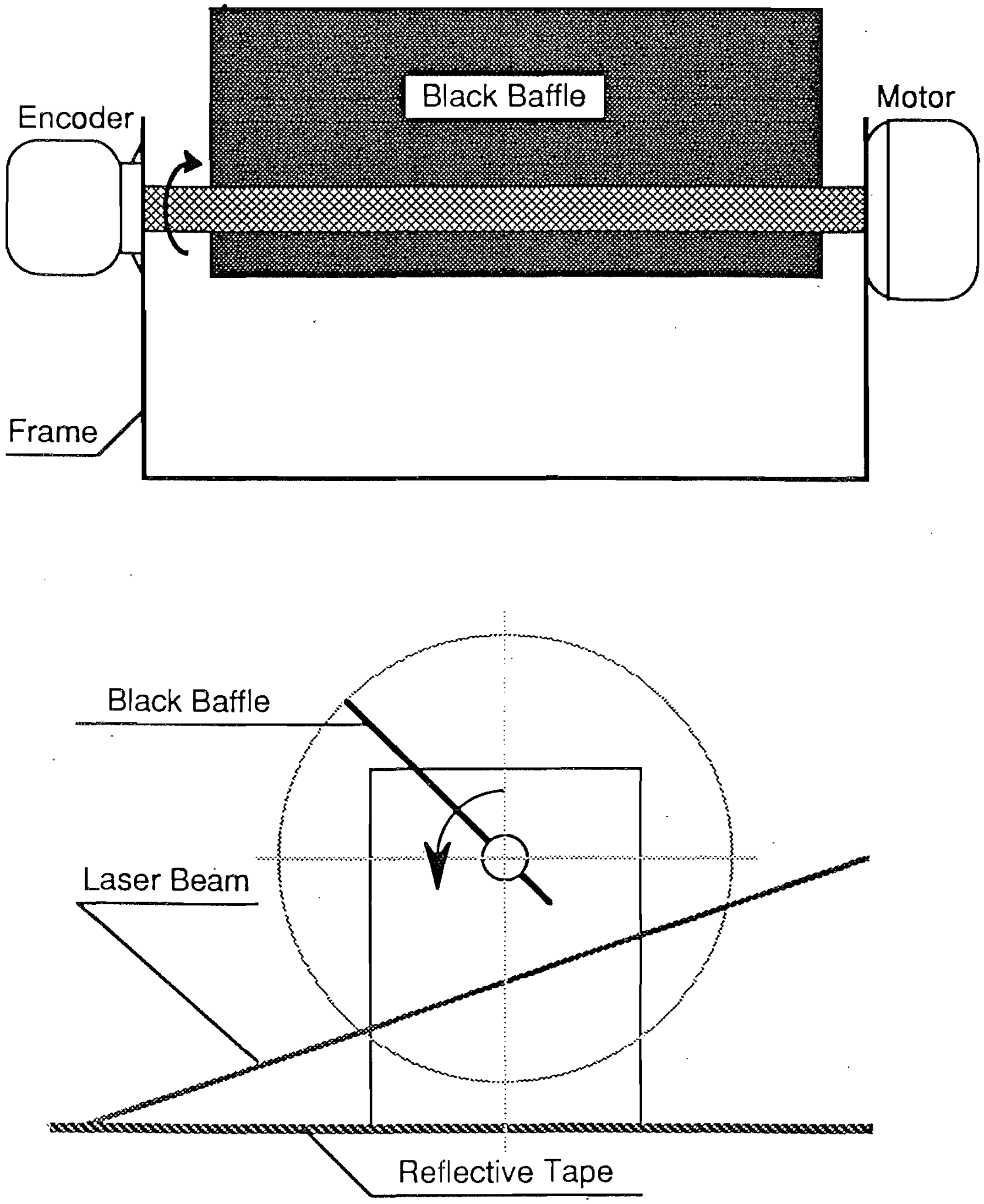


Figure 15 Block Baffle Equipment for Longitudinal Test

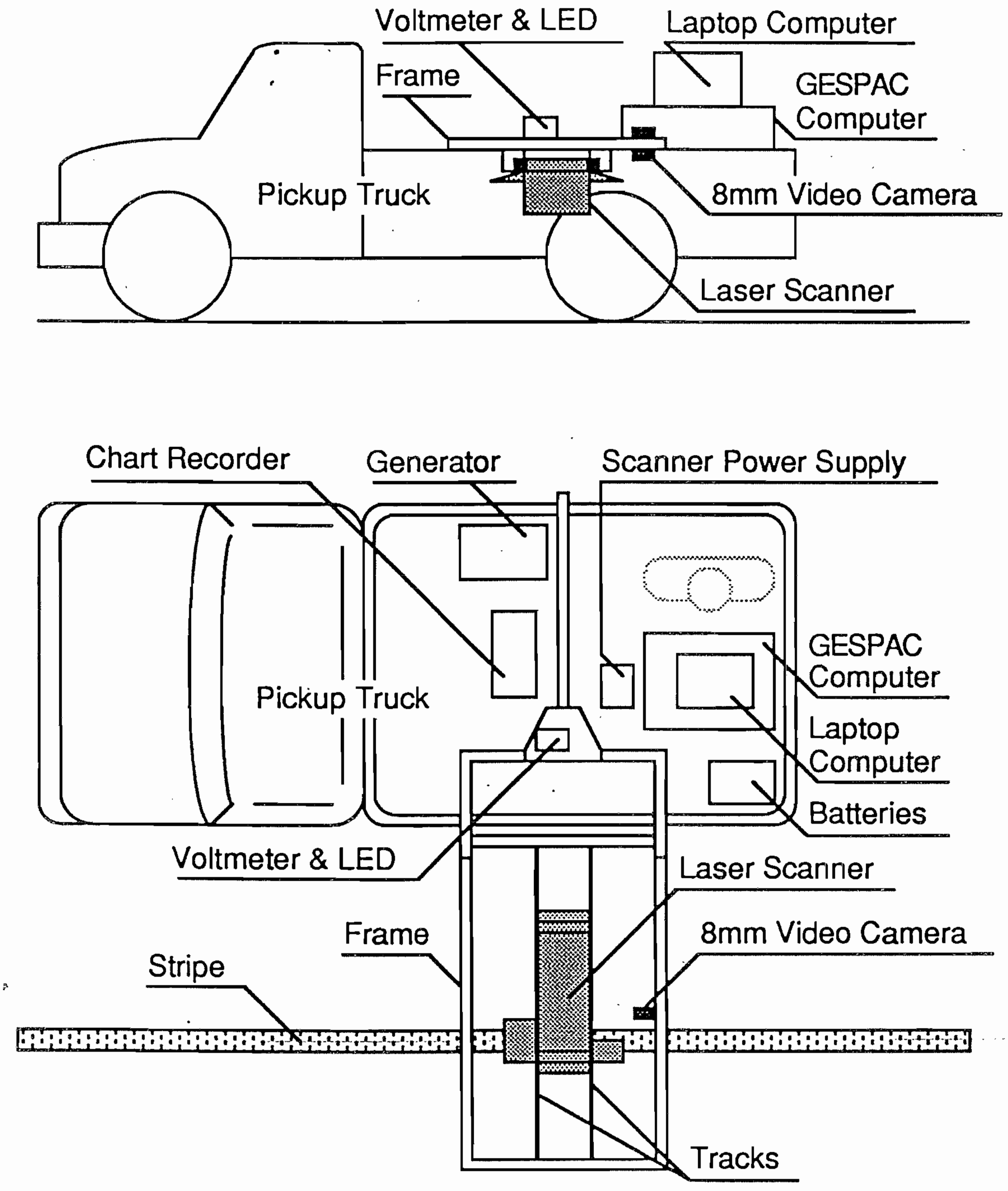


Figure 16 Field Test Apparatus on a Pickup Truck

shown in Figure 16). A small display box consisting of a bipolar DC voltmeter and a LED indicator was also place on the frame. The voltmeter is used to display the lateral position of the stripe and the LED indicates the paint gun on/off signal. In the main field test, an 8 mm video camera was attached to the frame just behind the laser scanner to monitor the lateral position of the stripe. A chart recorder was also applied in the main field test to record the lateral position output analog signal (voltage).

The electrical and electronic connections for the field test are shown in Figure 17. The odometer encoder signal, for convenience, was connected to the display box. There are three BNC connectors on the back of the display box for outputs of the lateral position analog signal, the paint gun on/off control signal and the odometer signal respectively. The GESPAC computer and the display box were connected by a 25 conductor shielded cable. The GESPAC computer and the IBM PC compatible laptop computer were connected through the RS-232 serial communication port. Since the GESPAC computer handles all the data acquisition process which is very sensitive to the environment noise, it was powered by a 110 VAC portable electric generator. The laptop computer was powered by the vehicle's 12VDC battery through the cigarette lighter plug. The laser scanner motor was driven by two 12VDC batteries via the scanner power supply.

The field tests were conducted on an unused two lane road near the campus of the University of California at Davis, California. The total length of the road is about 1000 feet. There are two different pavement markings in the center of the road. One is so called "one direction no-passing" marking, and the other is skip line. The test section used about 200 feet one direction no-passing marking and more than 400 feet skip line. The field test site is shown in Figure 18. The reflectivity of the pavement markings (stripes) on the field test site were between 40% - 60% of the new stripes. A big white cross symbol was found in the skip line. There was an old "STOP AHEAD" word warning on the one side of the road. Many white spots were found on the road and some of them were close to or even on stripes. There were also many Raised Pavement Makers (RPM) dotted between the skip lines. All the white spots, the RPMs and the white cross symbol made some noise for the guidance system. In the main test a piece of white reflective tapes was placed on the left side of the stripe every 100 feet to mark the distance for the data analysis.

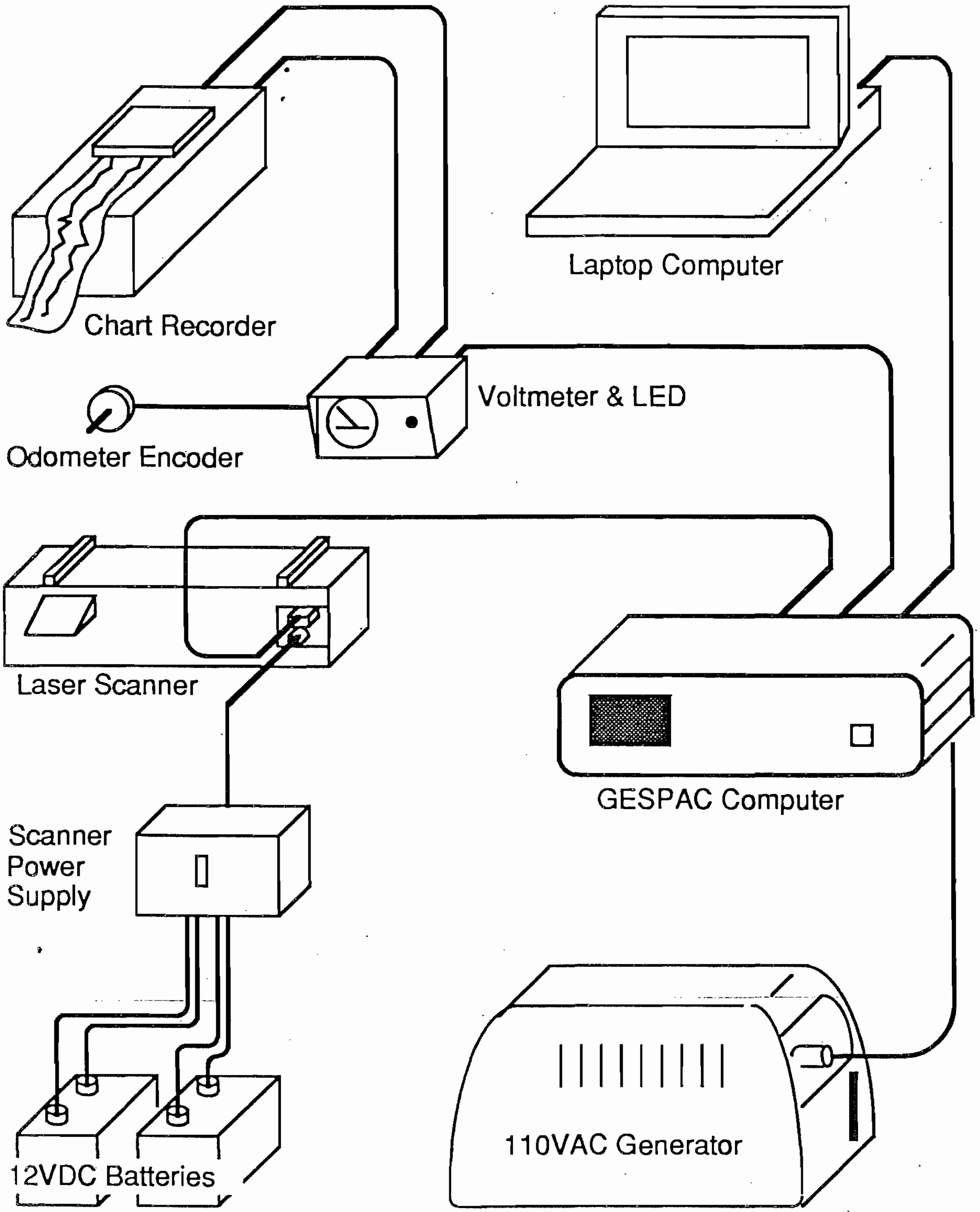


Figure 17 Field Test Apparatus Connections

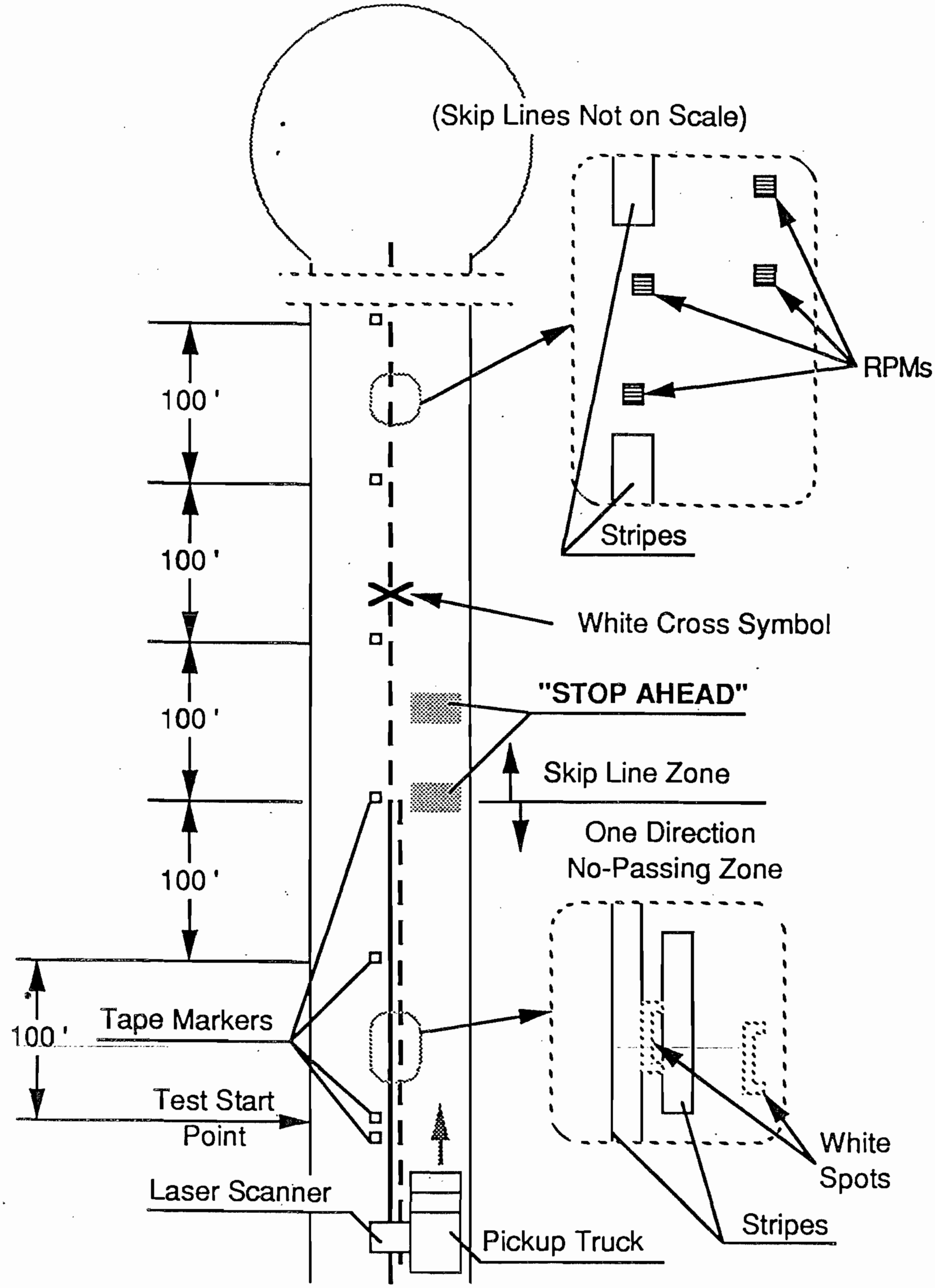


Figure 18 Field Test Site

The preliminary field test was conducted on September 27, 1991. The major purpose of the preliminary test was to test the basic concept of the principle and to find the correct method for the main field test. In the preliminary test, the video camera and the tape recorder were not used, only the voltmeter and the LED were used to display the system output. The preliminary test showed that the system was able to successfully detect the lateral and the longitudinal positions of the old stripe in the field conditions. Since no recording device was used in the preliminary test, no data can be illustrated in the report. After the preliminary test, the following changes were made in the system:

a) Since it was difficult for the operator to trace the lateral position of the stripe by reading the voltmeter, in the main field test the laser scanner would be fixed on the frame and the lateral position offset would be measured by other means such as the video camera.

b) A chart recorder would be used to record the lateral position, the paint gun on/off (longitudinal position) and the odometer signals. So that three BNC connectors were installed on the display box for the output signals of the lateral position, the paint gun on/off and the odometer pulses.

c) The GESPAC computer would collect the longitudinal position or the lateral position data during the continuous scan mode and transfer the data to the laptop computer when the continuous scan was finished. The laptop computer would store the data in the hard disk. The system would collect only one kind of data (either longitudinal or lateral) for each run because of the memory and the speed limitation. The longitudinal position data file would include the information of paint gun on/off signals and the corresponding odometer readings. The lateral position data file would include the information of the digital data of the lateral position (the variable value before the D/A converter) and the corresponding odometer readings.

d) When the system worked on more than one stripes, the operator could decide using either the left or the right stripe as the reference.

e) The laser beam to detect the longitudinal position would be changes from the 5 feet forward beam to the 8 feet forward beam.

f) An RPM differentiation method was developed for the longitudinal position detection. The basic concept of the method is that the RPM is about 1 inch wide in the longitudinal direction, if the vehicle is moving faster than 1Ø mph, a laser beam can scan over an RPM only once. So the system can tell the RPM if there is no consequence scans.

In the main field test a total number of 1Ø runs were made. Among these 1Ø runs, the computer recorded the longitudinal position data for the first run and the lateral position data for the others. The vehicle speed for these runs was between 25 - 4Ø mph. Because of the low gas level of the portable AC generator, runs 7 and 1Ø had too much voltage drop when the brake was used at the end of the run, the data files for these runs could not be created. In addition, run 5 did not finish because the chart recorder problem. All the other runs have both the computer data files and the chart recorder curves. To compare the data from the computer data file and the chart recorder plot, a part of run 2 computer data was plotted in Figure 19 and the corresponding curve plotted by the chart recorder during the test is shown in Figure 2Ø. Comparing the lateral position curve plotted by the computer data file to the corresponding curve plotted by the chart-recorder, it can be seen that the two curves are basically identical. The difference for the two curves is that the computer collected data was distance domain (i.e. the horizontal coordinate is distance), while the chart recorder data was time domain (i.e. the horizontal coordinate is time. Looking at the reference line on the chart recorder data, every pulse indicates Ø.1 second.) Since the data collected by the computer has digital values which can be easily evaluated or analyzed, the result analysis will basically use the computer collected data. The chart recorder data will be used as a reference to conform the computer data.

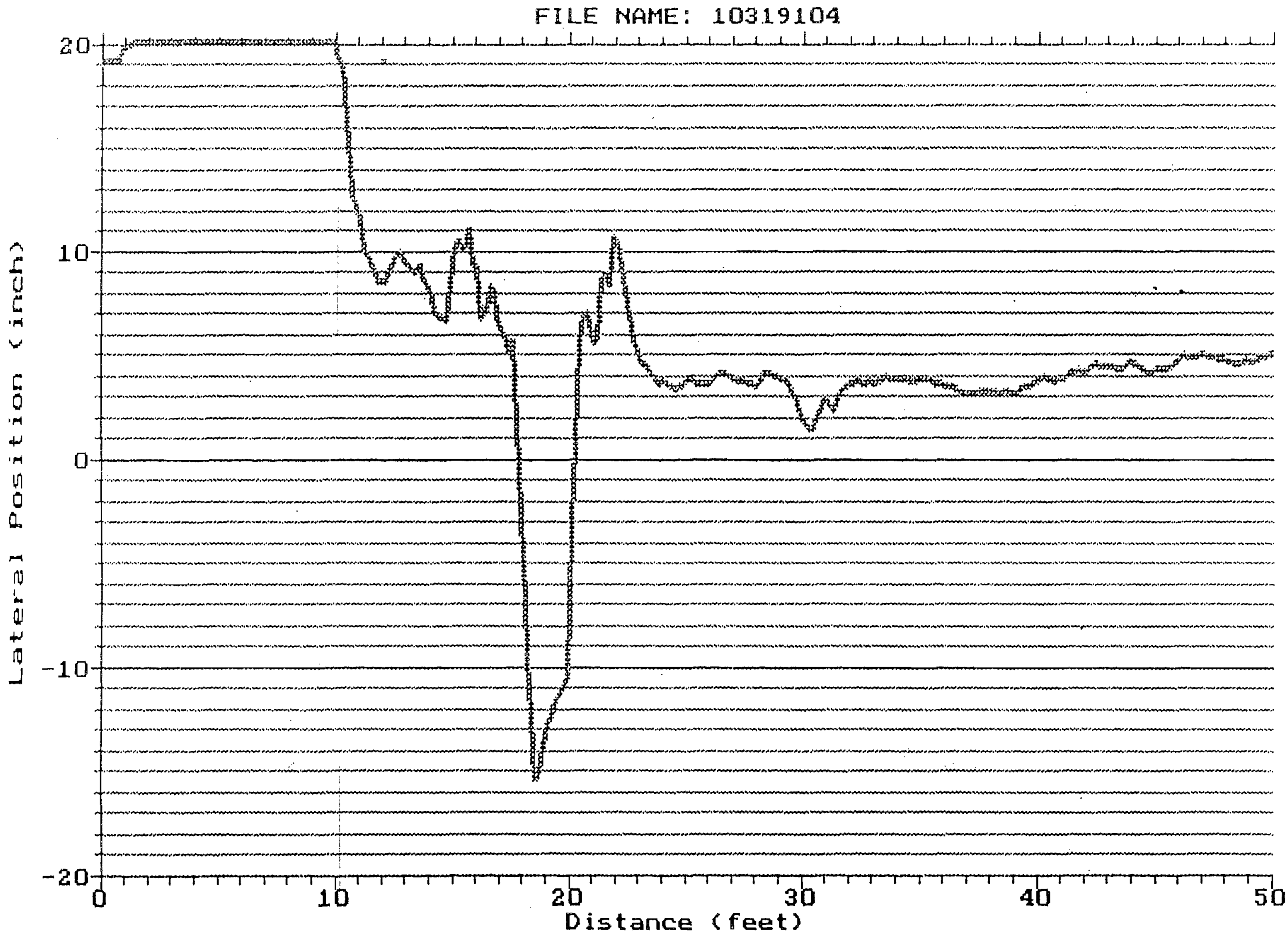


Figure 19 Lateral Position Data Curve Plotted From Computer Data File

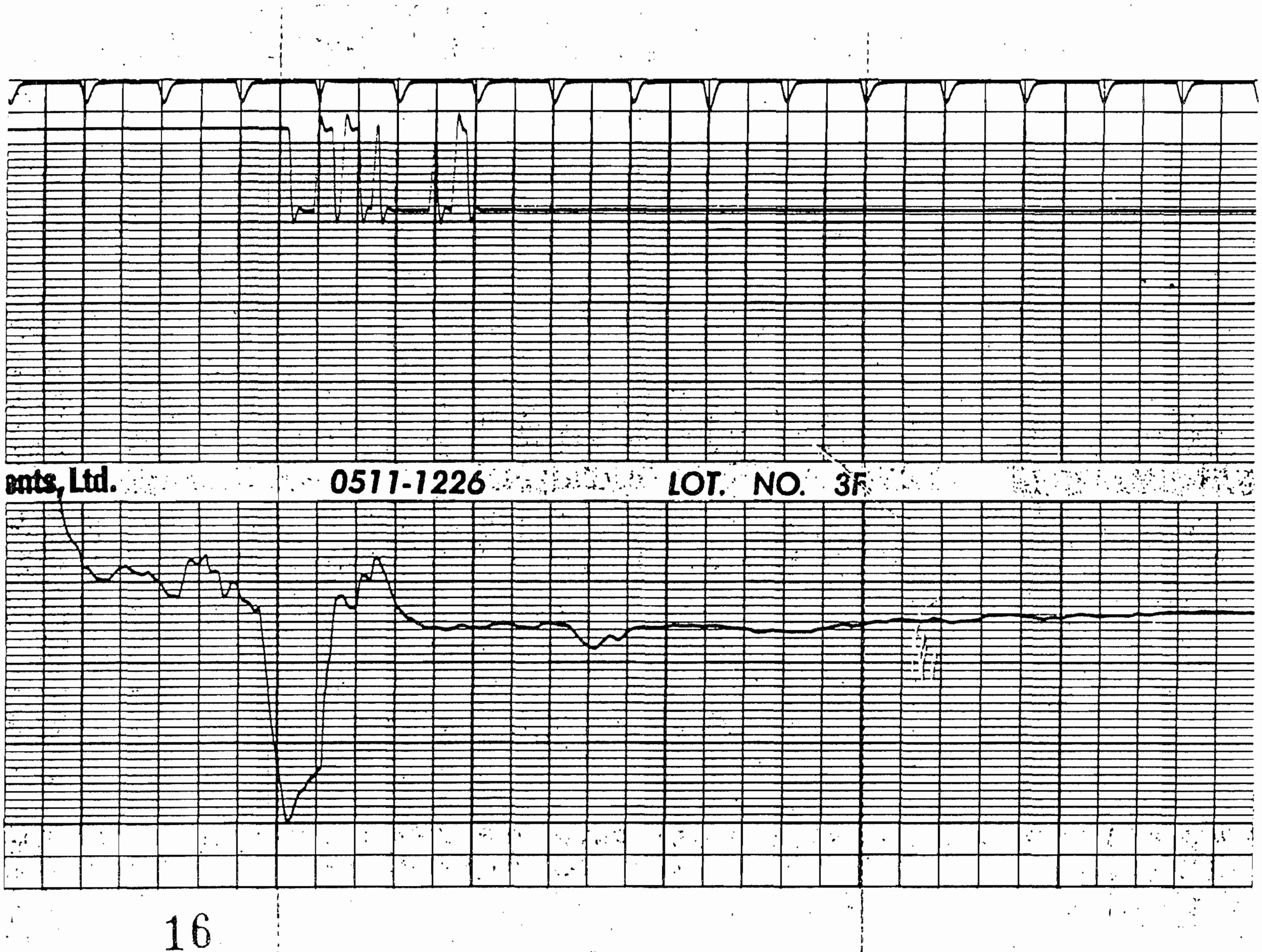


Figure 20 Lateral Position Data Curve Plotted by Chart Recorder

The real lateral position of the stripe was read from the video tape. Since the laser scanner output is the center position of the stripe, when reading the lateral position from the video tape, both edges of the stripe image were read and the center position of the stripe was determined by the average value of the two edges. Even though the widest viewing angle was used, the width of the video camera view on the pavement was only 24 inches. Considering the width of the stripe was about 5 inches, if the stripe was off more than 10 inches from the center, one of the edge might be out of the camera's view and the position of the stripe could not be determined. The video tape was read frame by frame. Because some of the runs were off too much, only a few runs could be used for the data analysis. In the resultant analysis, the first 400 feet of run 2 and the first 100 feet of the run 8 data file and the corresponding video tape have been analyzed.

Figures 21 to 28 are the comparisons of the lateral position data collected by the laser scanner computer and the lateral position values read from the video tape for the first 400 feet of run 2. Figures 29 and 30 are a similar comparison for the first 100 feet of run 8. On these figures, the computer collected data was plotted by the lines and the video tape readings were indicated by the cross (X) symbols. From Figures 21 to 30, it can be seen that the lateral position of the laser scanner output is very close to the lateral position values read from the video tape. Most small errors (noises) were caused by the worn out of the stripe edges and some big noises were caused by some obvious reasons. As mentioned before, to identify the distance or the longitudinal position, a piece of high reflective white tape was put on the left side of the stripe for every 100 feet (see Figure 18). These tapes would make some noise in lateral position outputs. The noises in run 2 (Figures 21 to 28) at positions of 7 - 10 feet, 93 - 99 feet, 107 - 111 feet, 193 - 212 feet, 293 - 304 feet, 307 - 314 feet and 392 - 400 feet were caused by those tapes. So were the noises in run 8 (Figures 29 and 30) at positions of 7 - 10 feet and 93 - 99 feet. The noises of run 2 at positions of 318 - 329 feet and 333 - 339 were caused by the big white cross symbol located between 320 - 330 feet from the starting position. In the skip line section of run 2, some of the noises were caused by the RPMs. In spite of the noises caused by the white tapes, the big cross symbol and RPMs, most small errors were less than 0.5 inches. The comparisons also shows that the laser scanner worked fine for both the solid line (the one

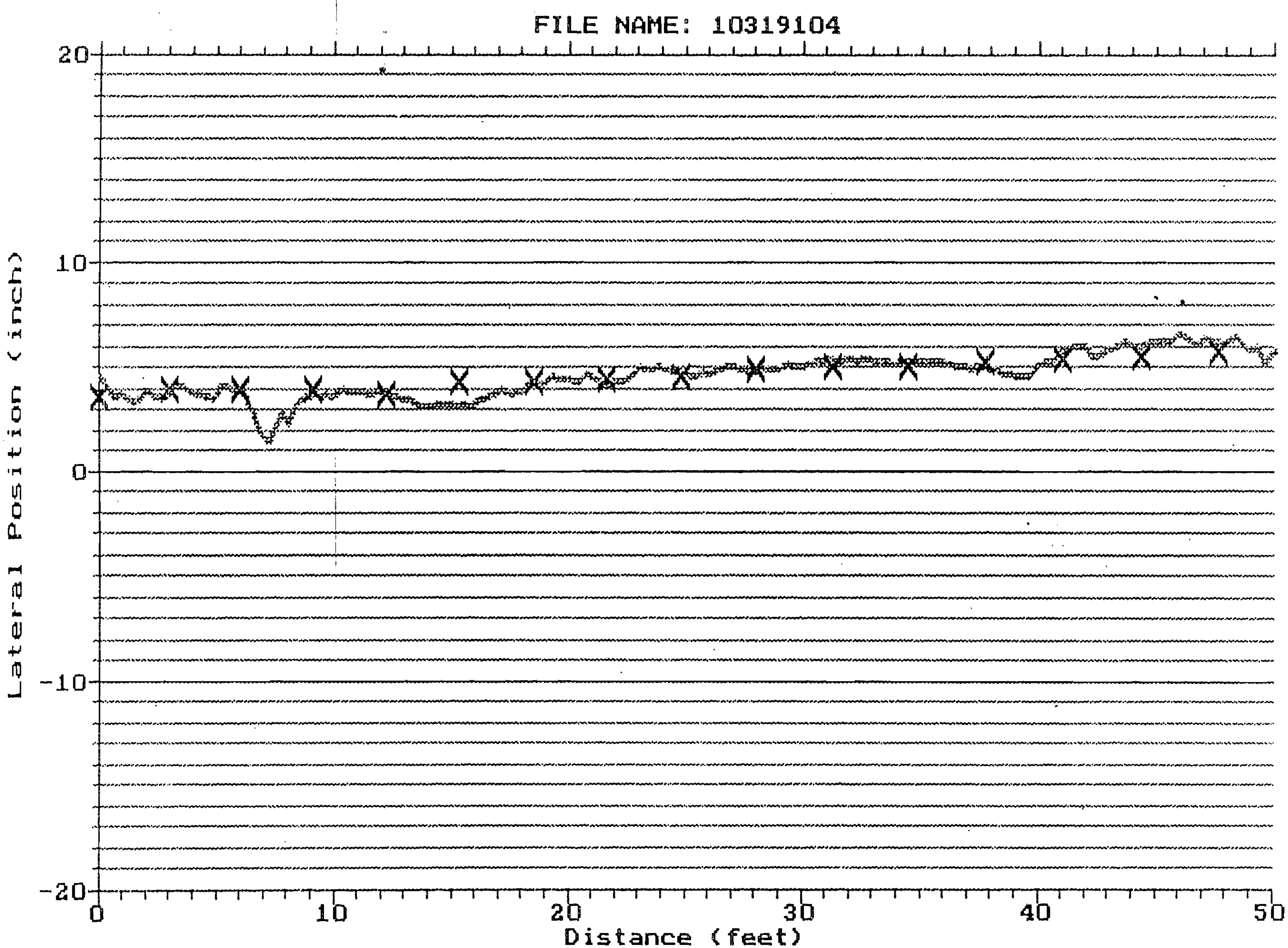


Figure 21 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 2
(0-50 feet, No-Passing Marking)

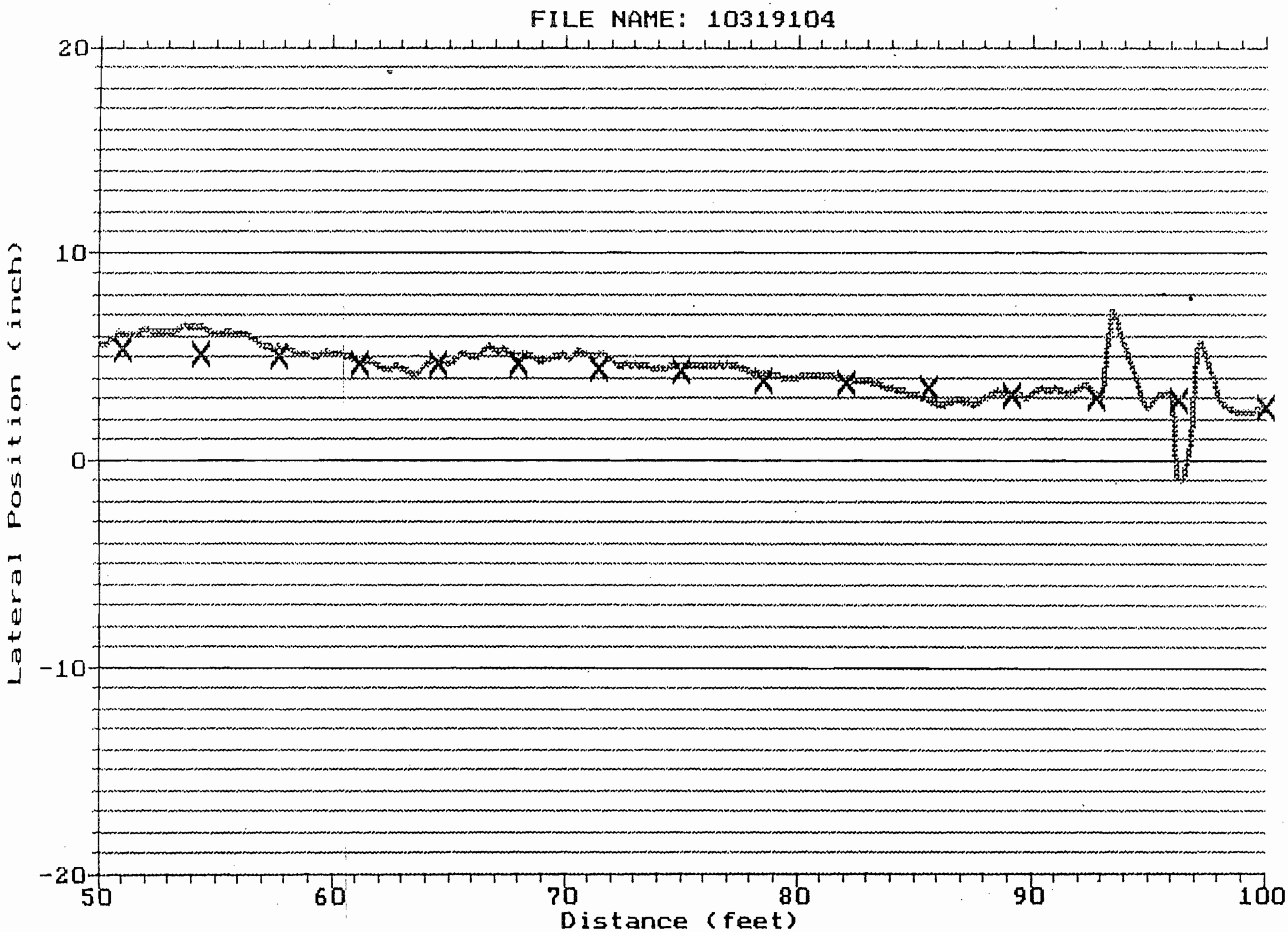


Figure 22 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 2
(50-100 feet, No-Passing Marking)

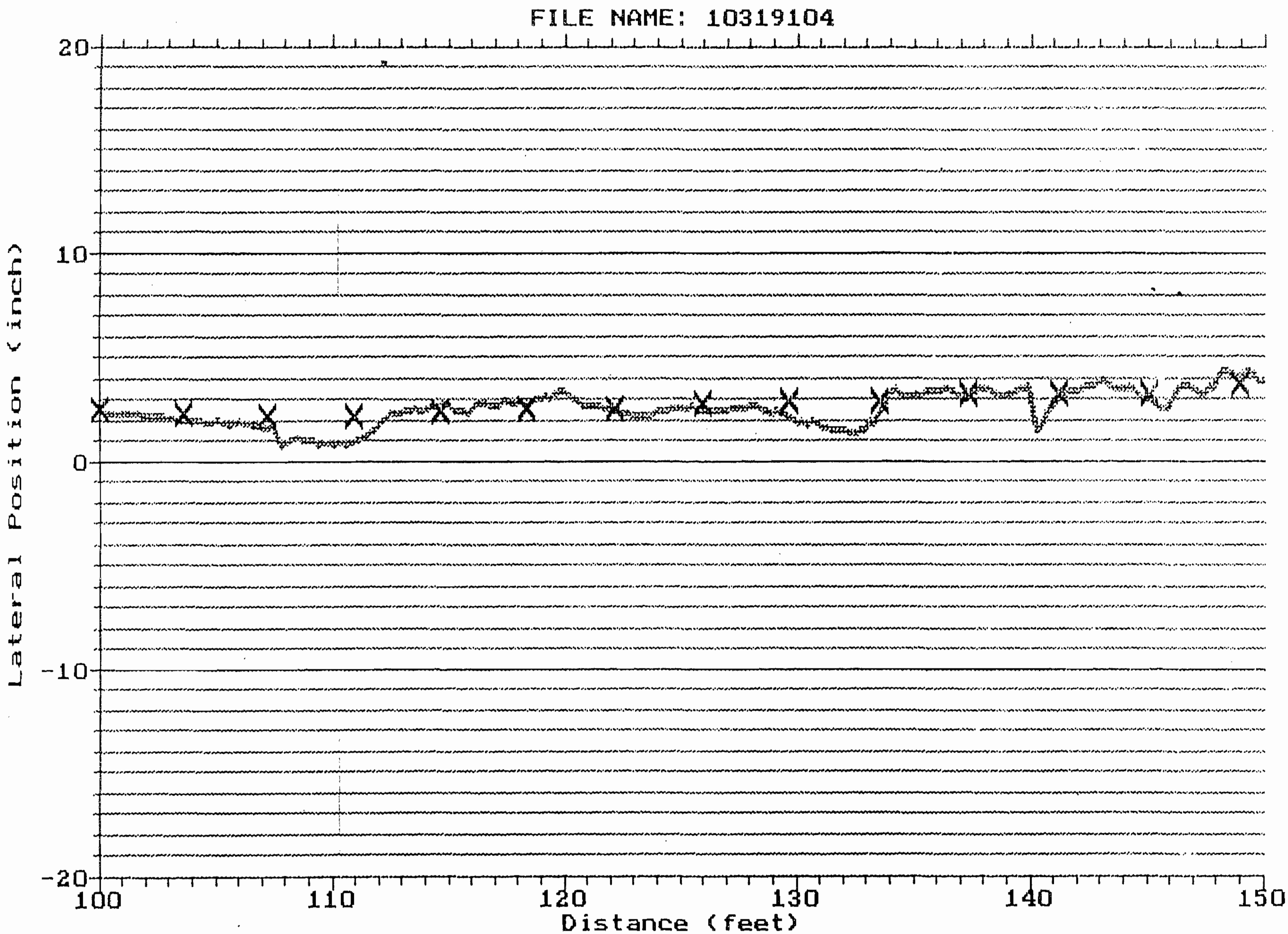


Figure 23 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 2 (100-150 feet, No-Passing Marking)

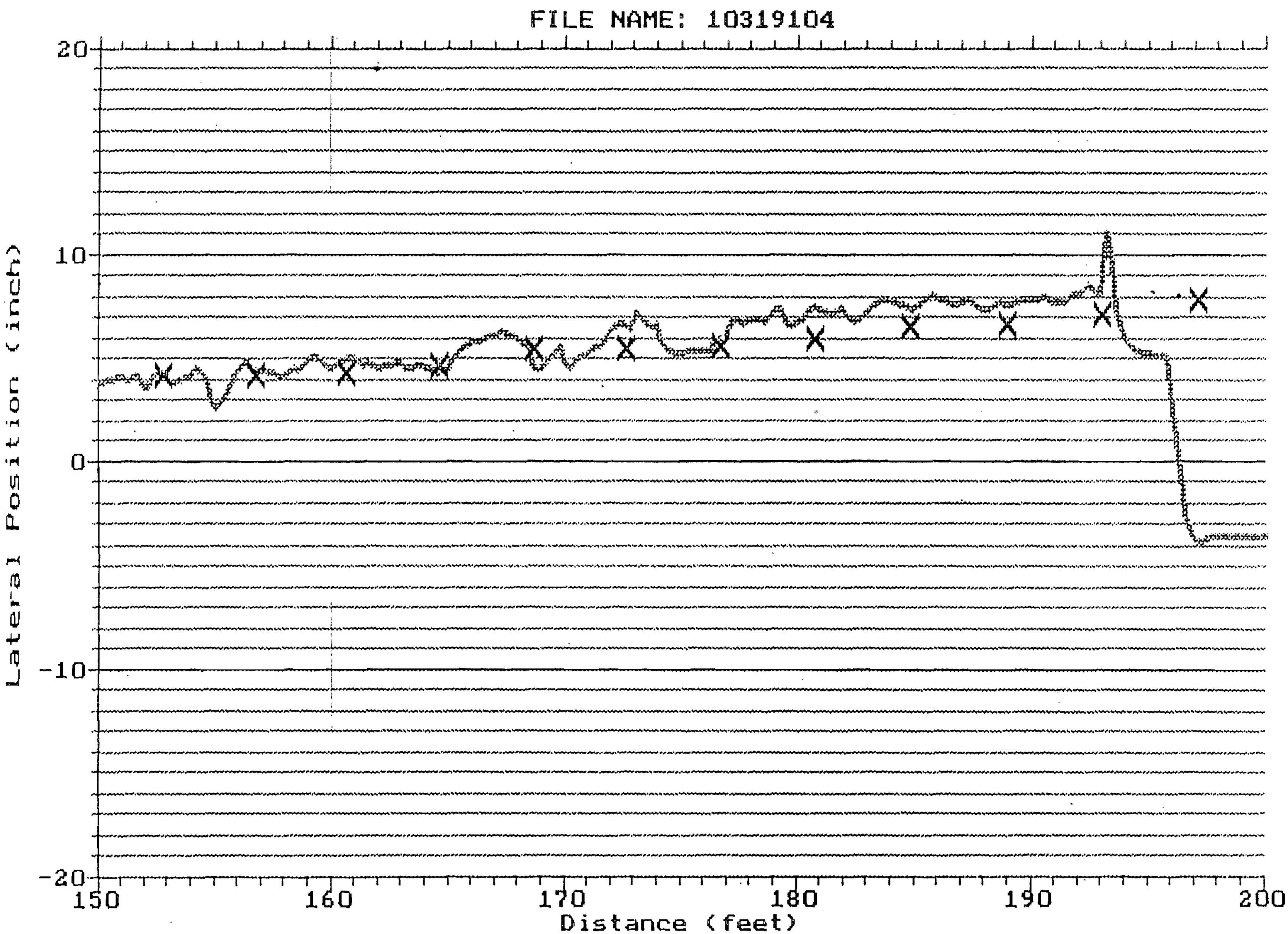


Figure 24 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 2
(150-200 feet, No-Passing Marking)

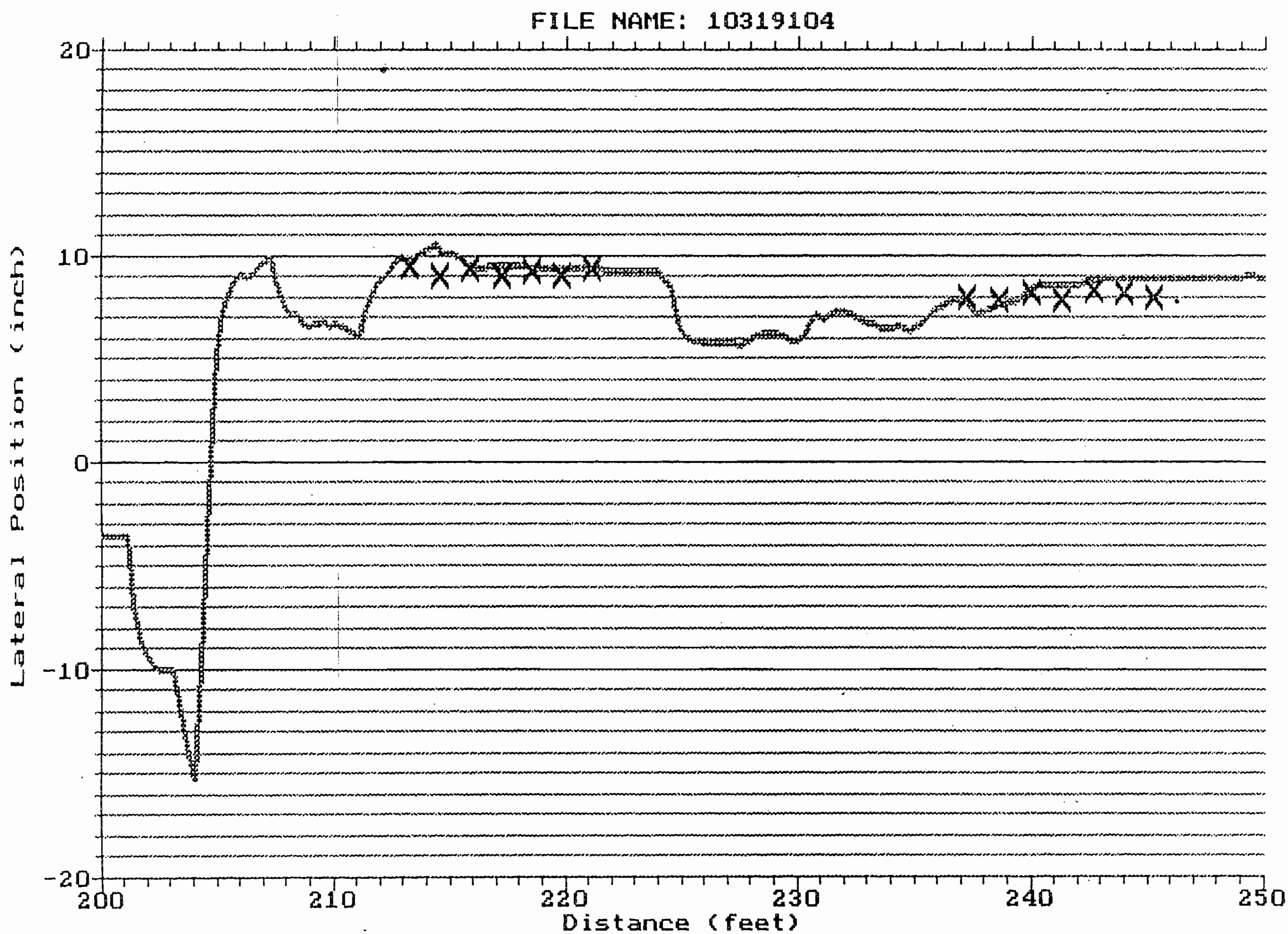


Figure 25 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 2
(200-250 feet, Skip Line)

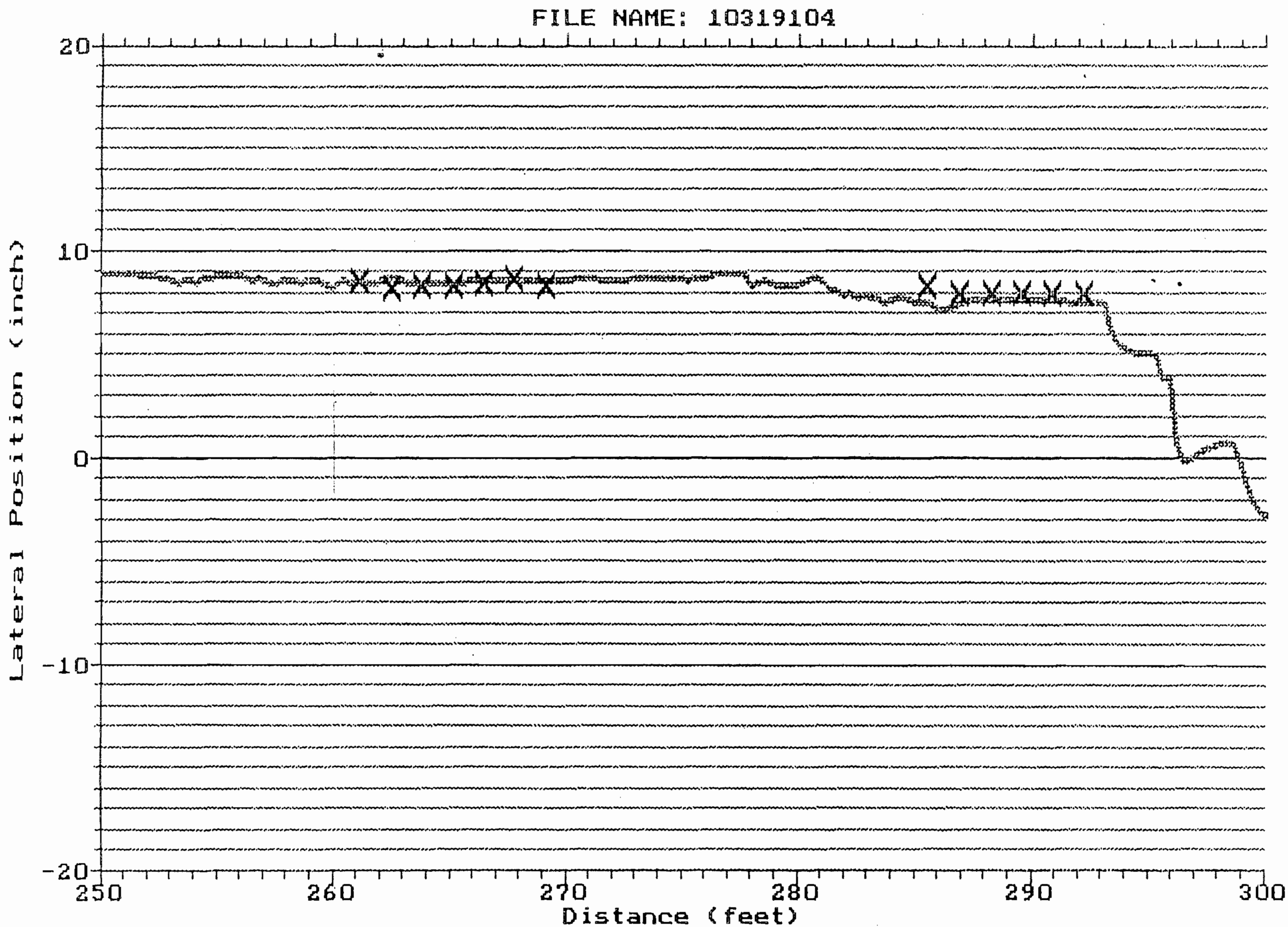


Figure 26 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 2
(25Ø-3ØØ feet, Skip Line)

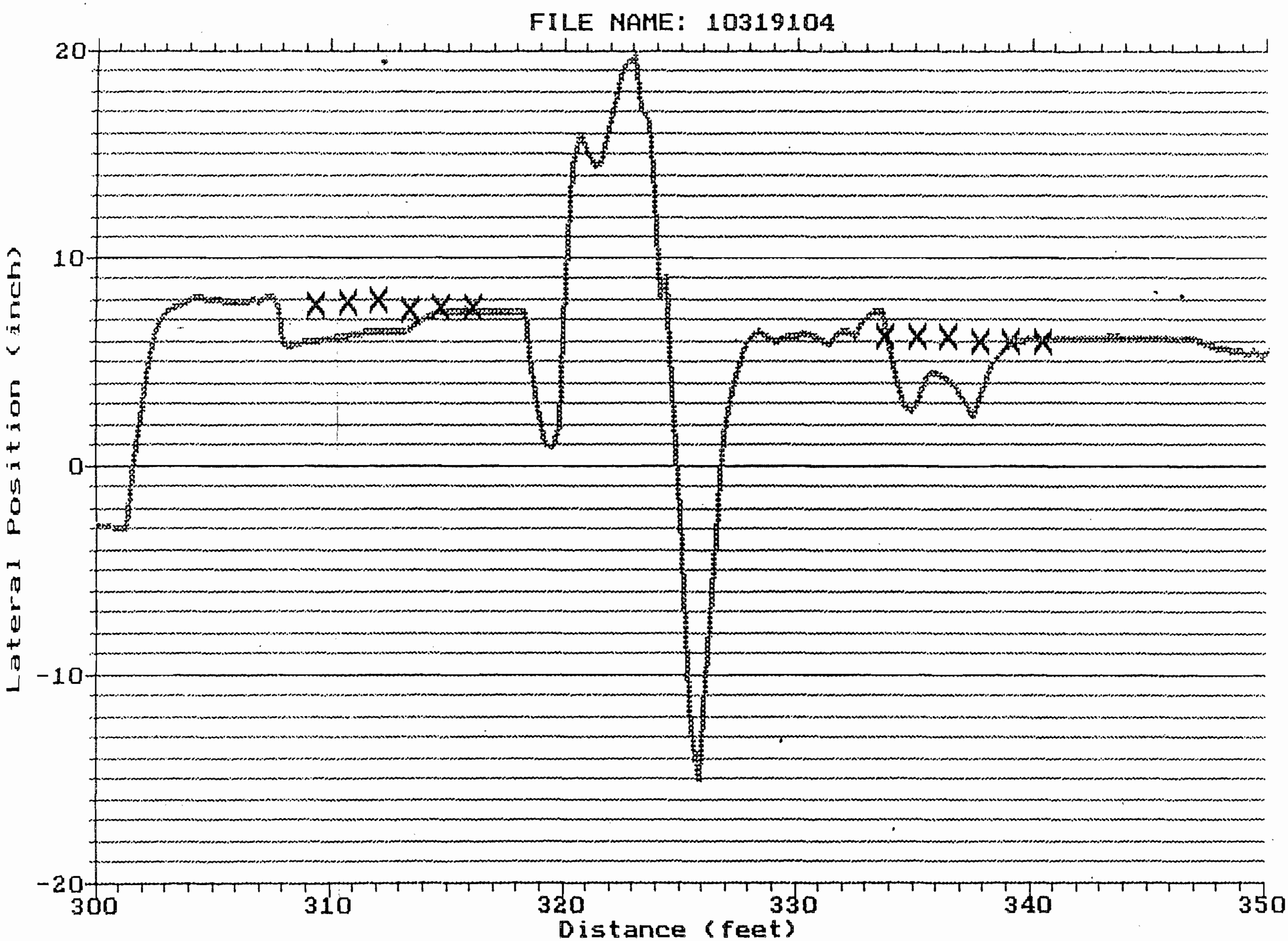


Figure 27 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 2
(300-350 feet, Skip Line)

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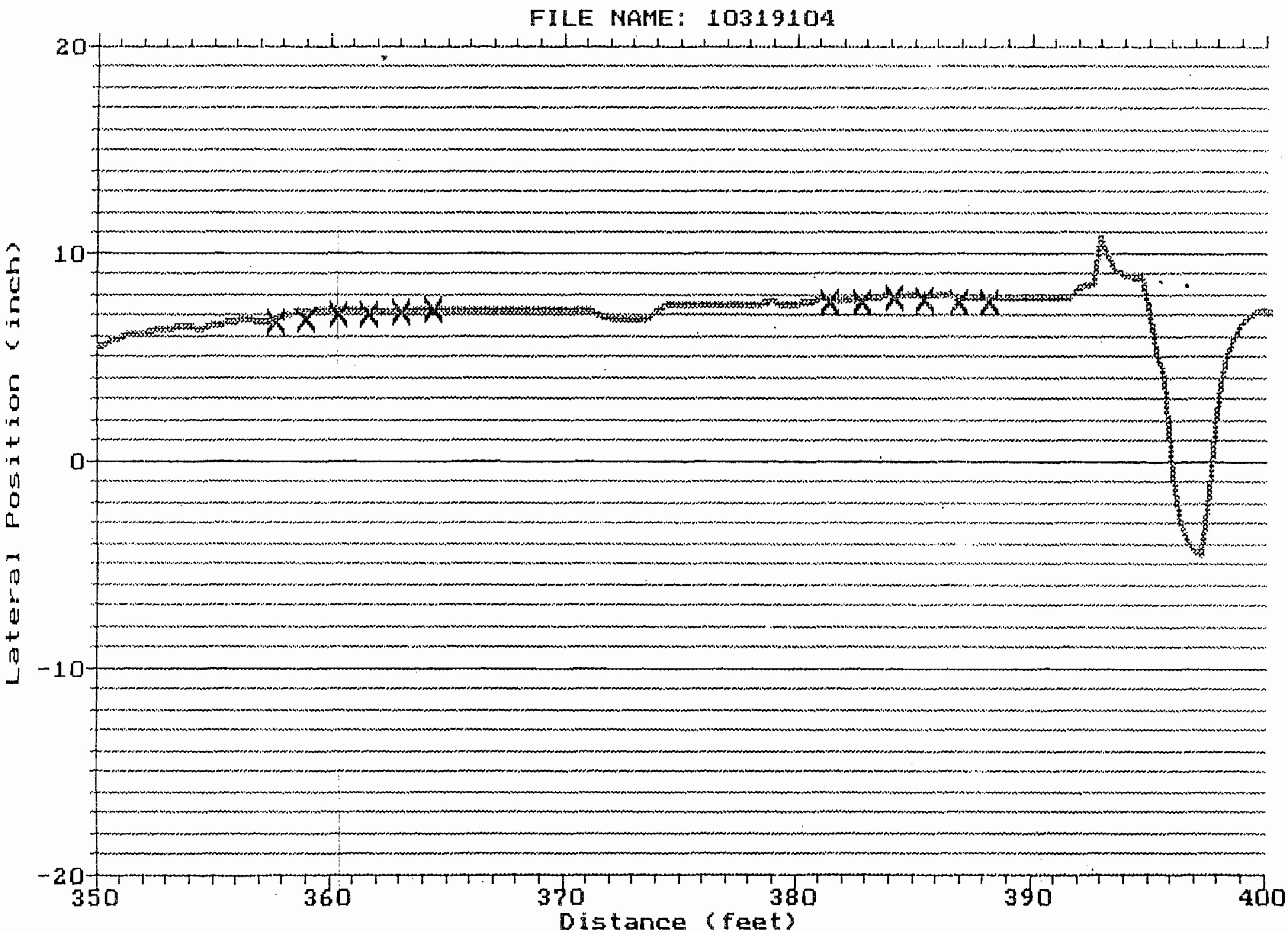

Figure 28 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 2
(350-400 feet, Skip Line)

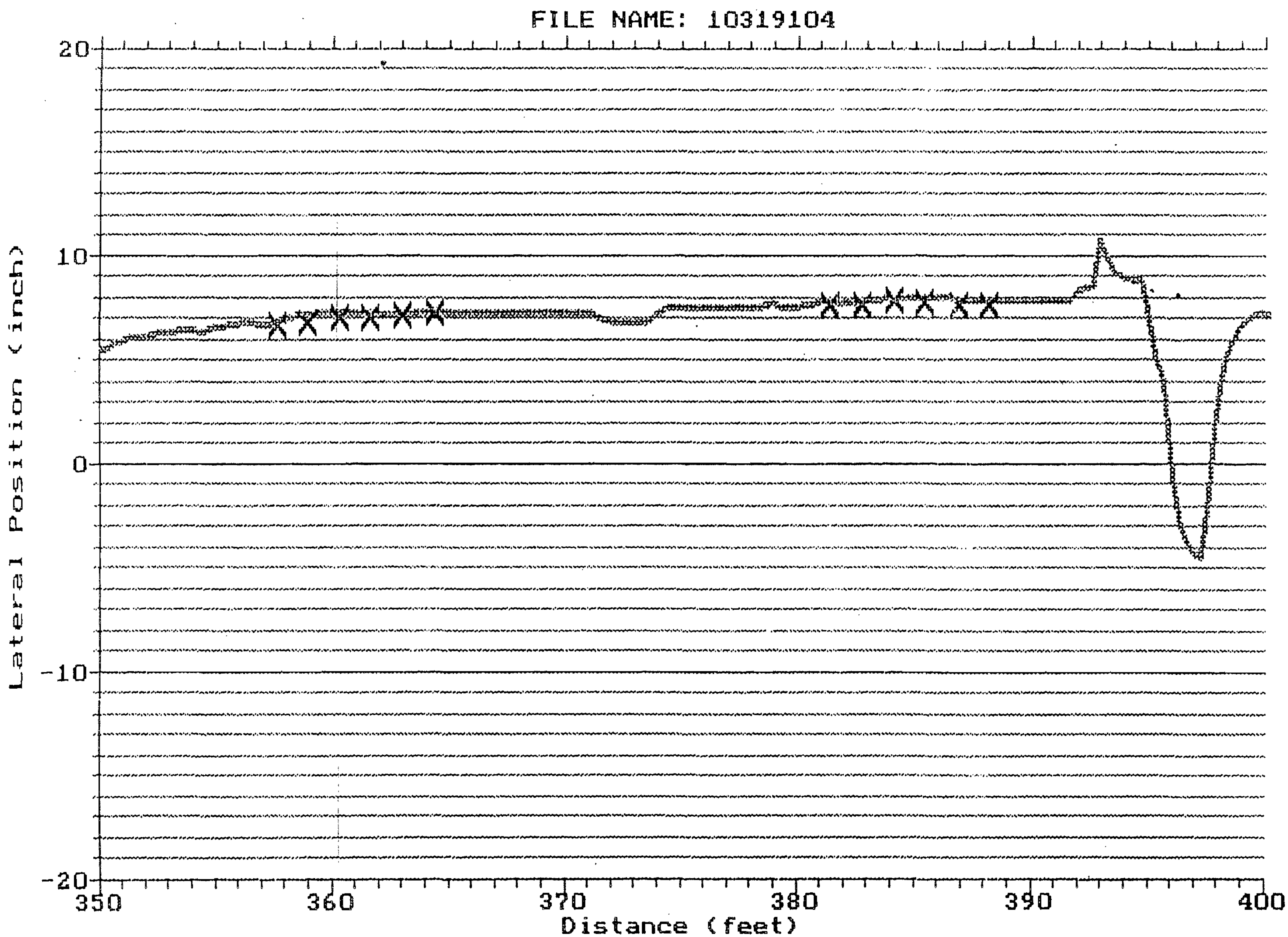

Figure 28 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 2
(350-400 feet, Skip Line)

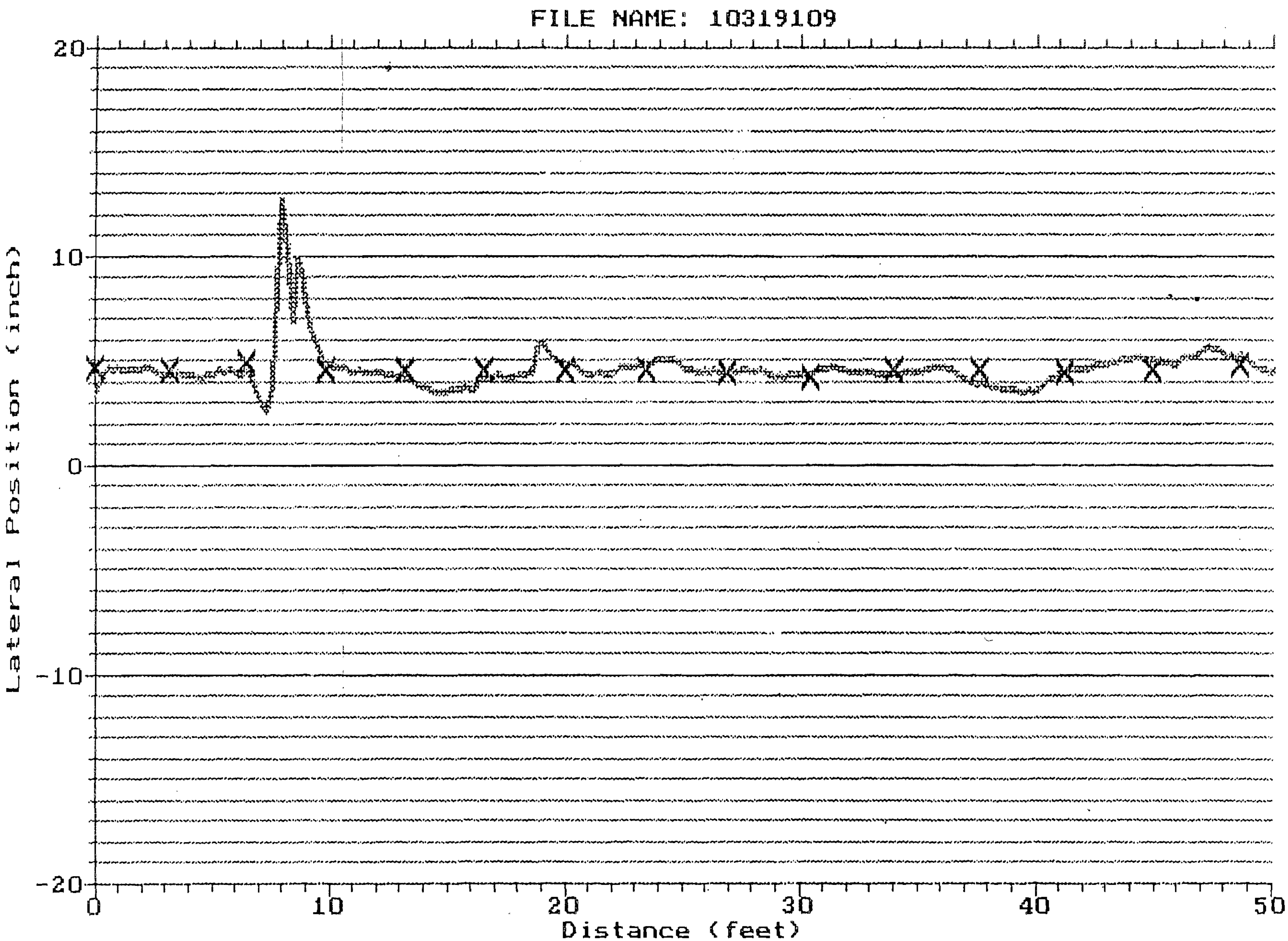

Figure 29 Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 8
(Ø-5Ø feet, No-Passing Marking)

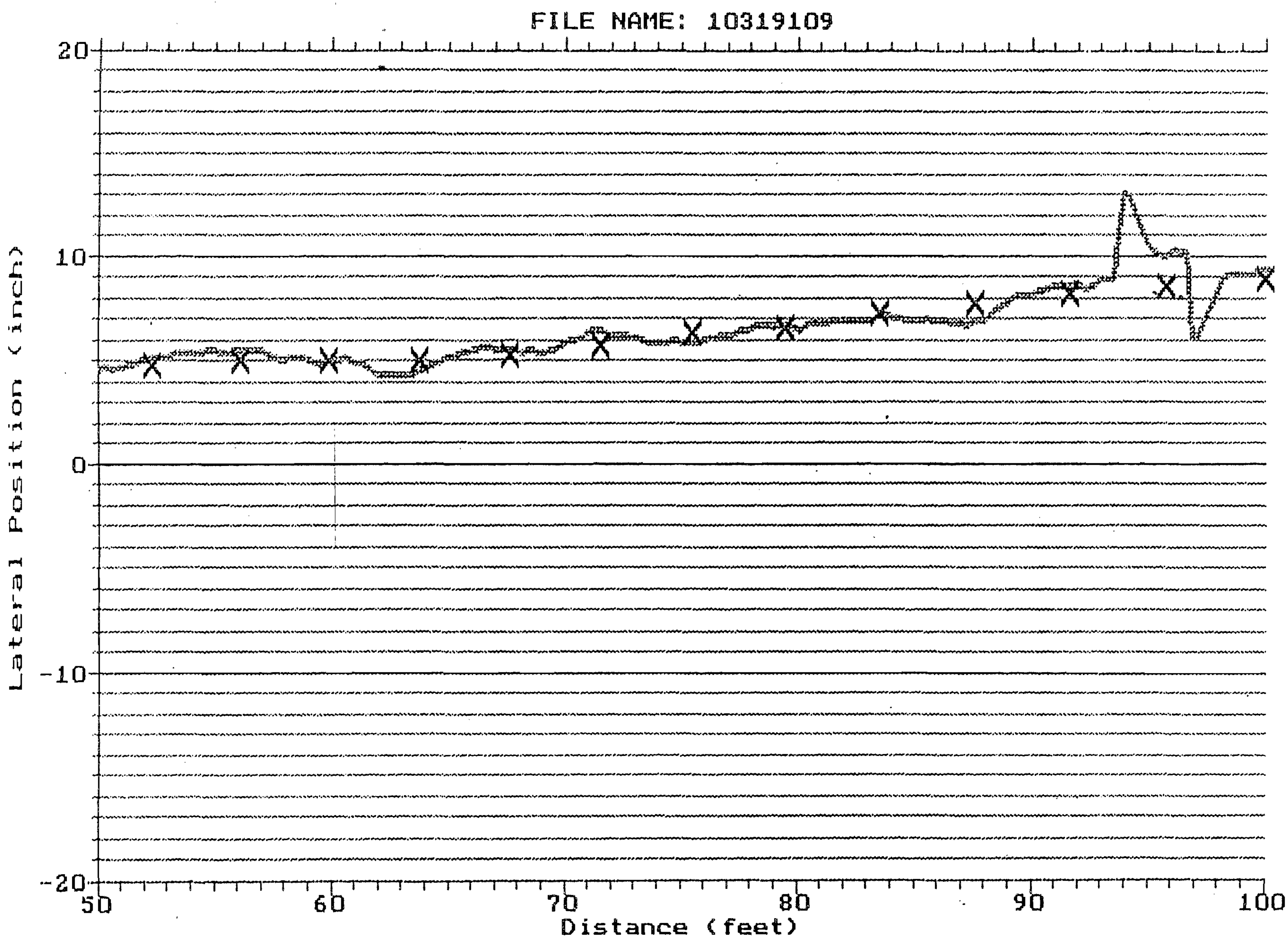

Figure 3Ø Comparison of Lateral Position Data of Laser Scanner and Video Tape for Run 8
(5Ø-1ØØ feet, No-Passing Marking)

direction on-passing section, Figures 21 to 24 and Figures 29 and 3Ø) and the skip line (Figures 25 to 28).

Most other small noises were caused by the uneven worn out of the stripe edges. As shown in Figure 31, because the edges of the old stripe were irregular in shape, when the laser beam scans the stripe at different positions, some errors would be generated. The noise caused by the worn out stripe edges usually can be reduced by a smoothing function. In the breadboard of the laser scanning/guidance system, a moving average smooth function with α = Ø.5 was applied. The results showed that in some case the noise caused by the worn out stripe edges was still a little bit high. To further reduce the noise, the smooth function might need to be improved. The improvement may be made by carefully selecting the α value or using different smooth functions, such as simple average, weighted average, etc. Figure 32 shows the comparison of the current data (α = Ø.5, thinner line) and the improved curve (thicker line) with an α value of Ø.9. The improved curve (α = Ø.9) looks much smoother than the current curve (α = Ø.5). The more smoothing is applied, however, the greater the delay in response. The delay may influence the sensitivity of the system control. More research work might be needed to optimize the smoothness and the delay of the output response in phase II project.

For the longitudinal positions, a data file was created by the first run of the main field test. The real longitudinal position was measured manually by a steel tape. The measurement was started from the beginning of the skip line. The comparison of the data collected by the computer and the measured ones are listed in Table 1. Besides the original distance data, Table 1 also lists the length of the stripes and the gaps. The differences of the distance between the laser scanner data and the measured one are shown in Figure 33. The differences of length (gap) are shown in Figure 34. From Table 1 and Figures 33 and 34 it can be seen that in spite of the noise caused by the big cross symbol, 24 out of 36 (67%) distance errors were within ±4 inches range, and 28 out of 34 (82%) length (gap) errors were within ±8 inches range. The distance errors usually include some cumulative errors in the measurement and the odometer calibrations. The skip line marking was measured by steel tape to the nearest one inch as the beginning and the end of the line was ill-defined. In addition several lines had old material underlining the newer paint and the starting earlier than the newest line. These old positions were ignored in the

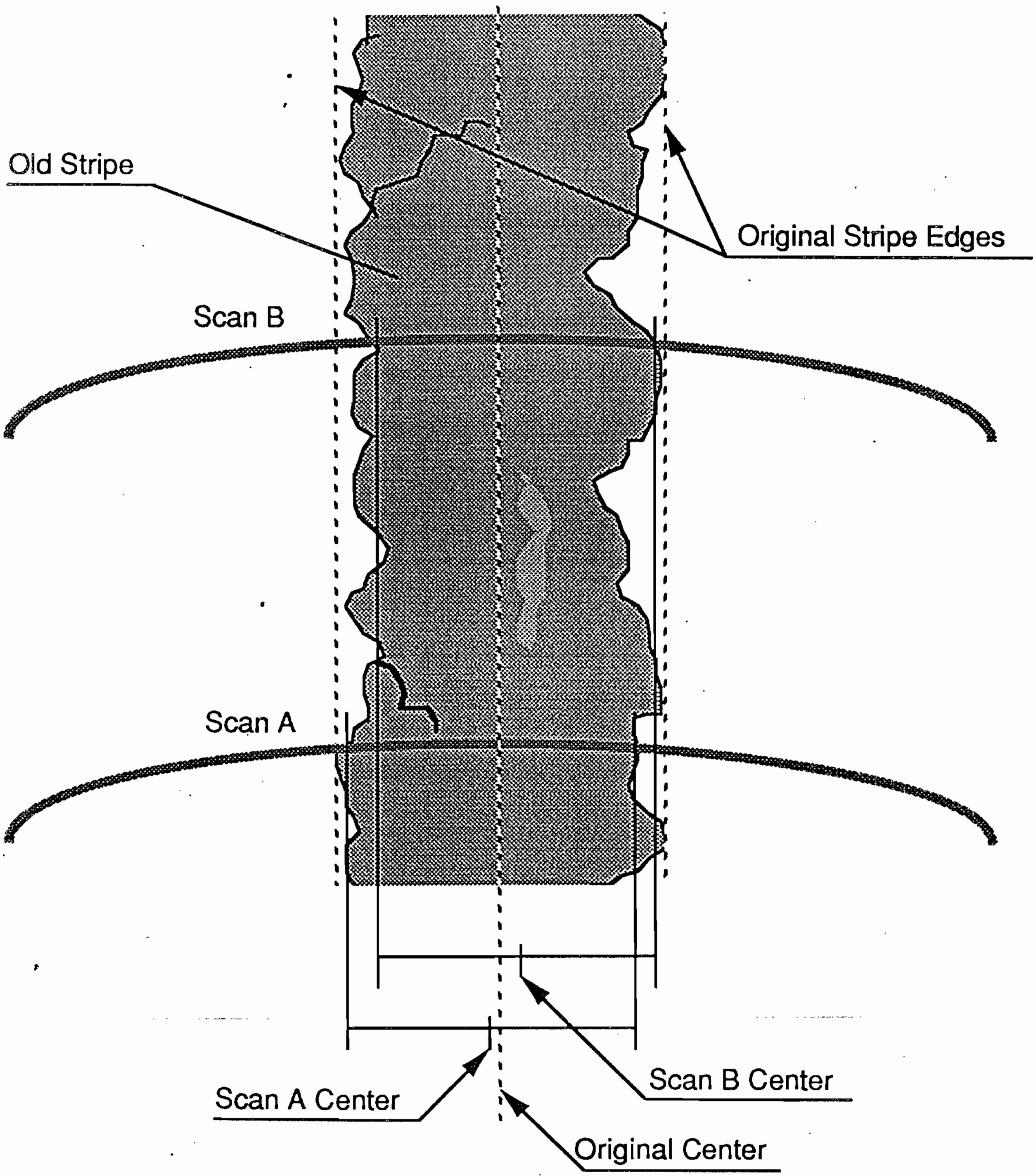

Figure 31 Typical Old Stripe and Scanning Error

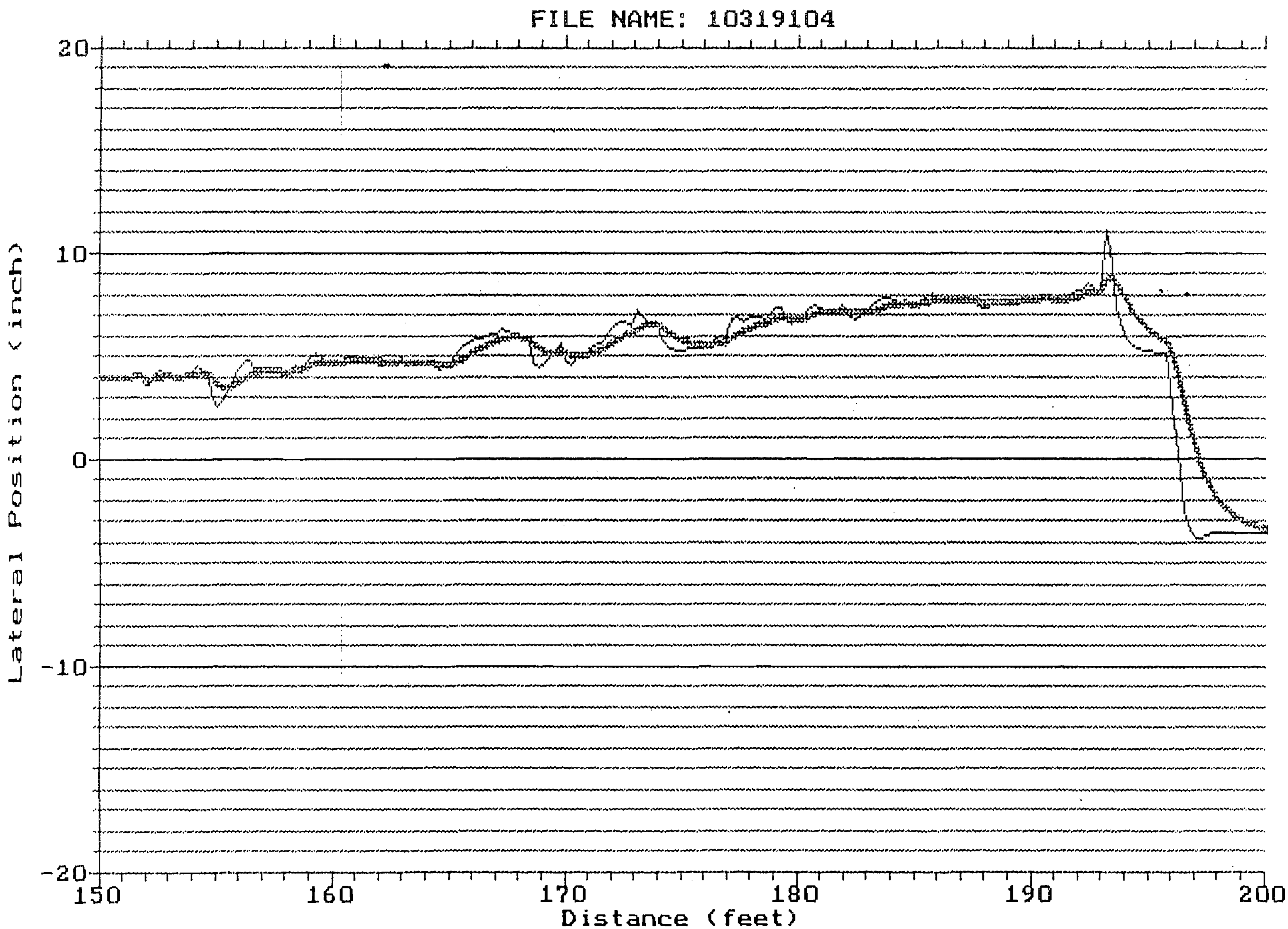

Figure 32 Comparison of Smooth Functions with α = Ø.5 (thinner) and α = Ø.9 (thicker).

Table 1 Longitudinal Field Test Data

Distance				Length			
Measured (feet)	Laser (feet)	Difference (feet)	Difference (inch)	Meas. (feet)	Laser (feet)	Difference (feet)	Difference (inch)
0	0	0	0				
12.67	12.54	0.13	1.56	12.67	12.54	0.13	1.56
21.83	21.49	0.34	4.08	9.16	8.95	0.21	2.52
36.67	36.67	0	0	14.84	15.18	-0.34	-4.08
46	45.97	0.03	0.36	9.33	9.3	0.03	0.36
60.5	60.98	-0.48	-5.76	14.5	15.01	-0.51	-6.12
69.83	69.68	0.15	1.8	9.33	8.7	0.63	7.56
84.25	84.61	-0.36	-4.32	14.42	14.93	-0.51	-6.12
93.67	93.56	0.11	1.32	9.42	8.95	0.47	5.64
108.08	108.14	-0.06	-0.72	14.41	14.58	-0.17	-2.04
117.5	117.27	0.23	2.76	9.42	9.13	0.29	3.48
132.5	128.96	3.54	42.48	15	11.69	3.31	39.72
141.92	141.75	0.17	2.04	9.42	12.79	-3.37	-40.44
156.33	156.42	-0.09	-1.08	14.41	14.67	-0.26	-3.12
165.75	165.54	0.21	2.52	9.42	9.12	0.3	3.6
180.08	180.56	-0.48	-5.76	14.33	15.02	-0.69	-8.28
189.58	189.43	0.15	1.8	9.5	8.87	0.63	7.56
203.83	204.43	-0.6	-7.2	14.25	15	-0.75	-9
213.33	213.48	-0.15	-1.8	9.5	9.05	0.45	5.4
227.67	227.98	-0.31	-3.72	14.34	14.5	-0.16	-1.92
237.08	237.1	-0.02	-0.24	9.41	9.12	0.29	3.48
251.5	251.17	0.33	3.96	14.42	14.07	0.35	4.2
260.92	260.81	0.11	1.32	9.42	9.64	-0.22	-2.64
275.25	275.65	-0.4	-4.8	14.33	14.84	-0.51	-6.12
284.75	284.52	0.23	2.76	9.5	8.87	0.63	7.56
299.08	299.36	-0.28	-3.36	14.33	14.84	-0.51	-6.12
308.5	308.91	-0.41	-4.92	9.42	9.55	-0.13	-1.56
324.58	324.44	0.14	1.68	16.08	15.53	0.55	6.6
334	333.65	0.35	4.2	9.42	9.21	0.21	2.52
348.33	348.66	-0.33	-3.96	14.33	15.01	-0.68	-8.16
357.75	357.53	0.22	2.64	9.42	8.87	0.55	6.6
372.17	372.45	-0.28	-3.36	14.42	14.92	-0.5	-6
381.58	381.15	0.43	5.16	9.41	8.7	0.71	8.52
395.92	396.07	-0.15	-1.8	14.34	14.92	-0.58	-6.96
405.33	404.77	0.56	6.72	9.41	8.7	0.71	8.52
419.75	419.87	-0.12	-1.44	14.42	15.1	-0.68	-8.16
429.17	428.83	0.34	4.08	9.42	8.96	0.46	5.52

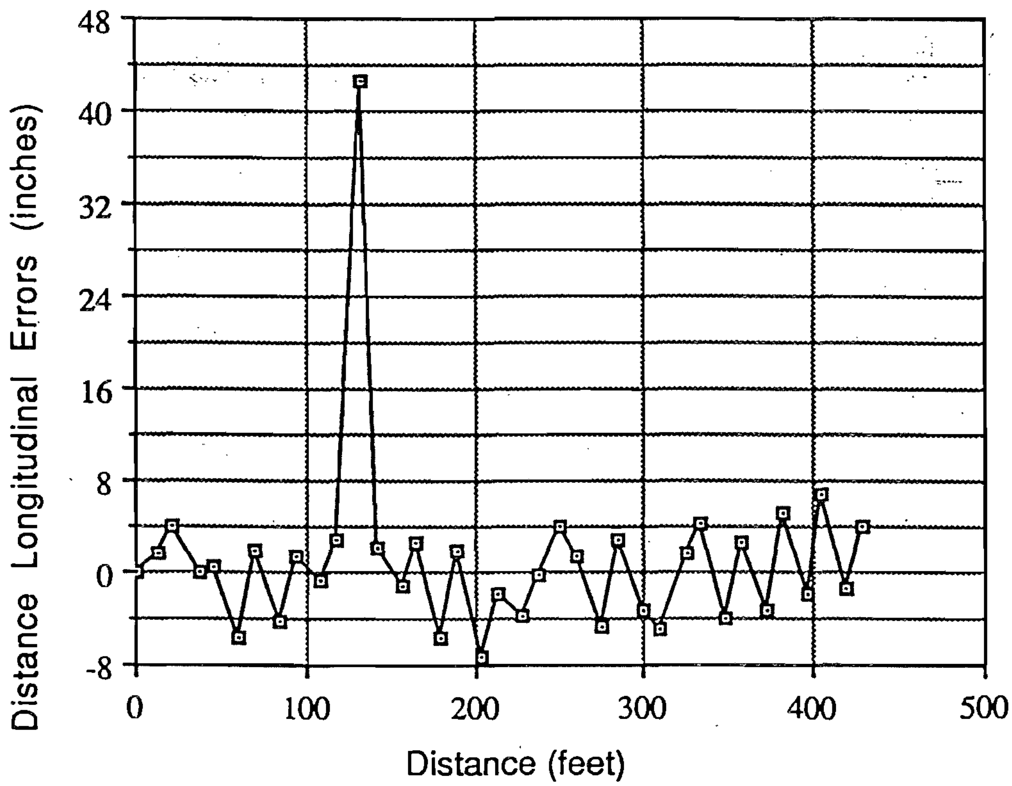

Figure 33 Distance Longitudinal Errors

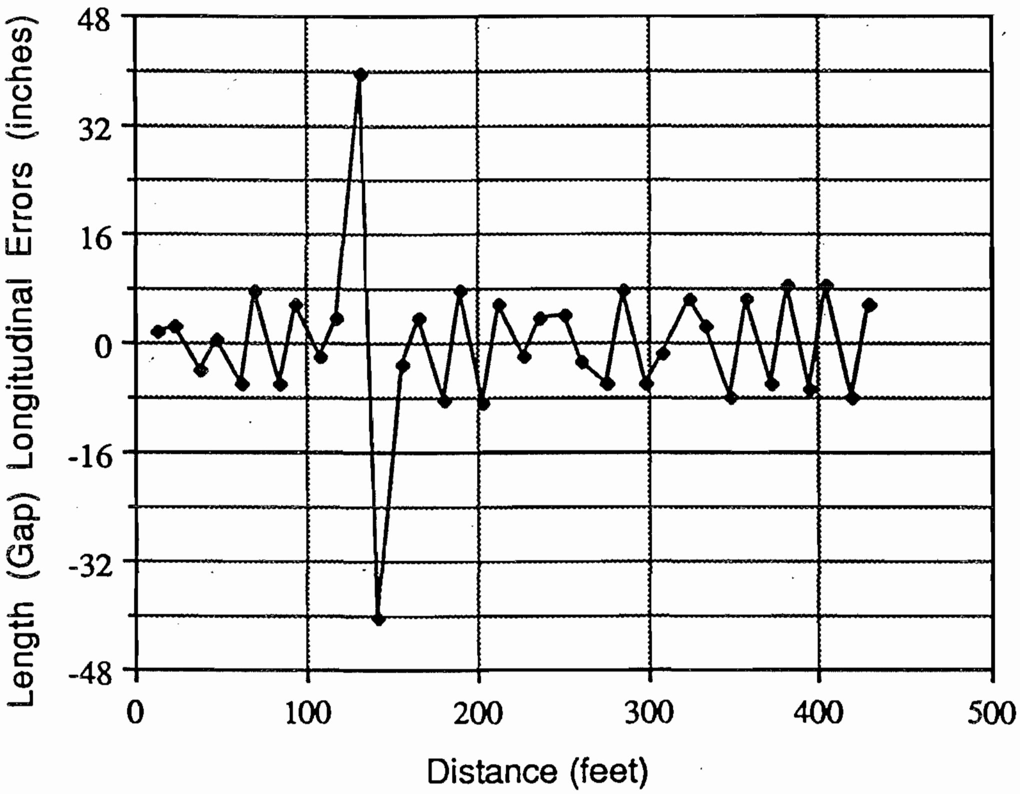

Figure 34 Length (Gap) Longitudinal Errors

steel tape measurements. It is found that most stripe lengths by the laser scanner were shorter than the measured ones. The possible reason is that the reflectivity of the both end of the stripe is lower than the threshold value of the laser system. This error could be corrected by adding a little length to each end of the stripe. For example, if a two inch length is added to each end of the stripe, the errors would be reduced dramatically. As shown in Figures 35 and 36, after the correction, 32 out of 36 (89%) distance errors are within ±4 inches range and 32 out of 34 (94%) length (gap) errors would be within ±8 inches range. The correction process could be developed in phase II project.

The RPMs in the skip line section made a lot of noises in the lateral position output especially when the distance was more than 400 feet. The longitudinal position detection, however, was not very sensitive to the RPMs since a RPM differentiation process was applied. Figure 37 is a part of the data sheet plotted by the chart recorder which shows both the lateral position and the paint gun on/off signals. Figure 37 shows that even there were a lot of noises (caused by RPMs) in the lateral position output, the paint gun on/off signal (longitudinal position output) was still clean. The concept of the RPM differentiation for the longitudinal position detection may not be applied in the lateral position detection process since the RPM and the stripe may appear in the same scan. The way to tell the RPM and the stripes may be found by evaluating their reflectivities because the RPM has a much higher retroreflectivity than the old stripes. The process of RPM differentiation for the lateral position detection would be developed in phase II project.

4.0 CONCLUSIONS AND RECOMMENDATIONS

A breadboard of the Laser Scanning/Guidance System has been successfully developed for an automated paint restriping recognition and guidance system as proposed in RFQ #90 D-A10580, 1990.

The laser scanning/guidance system uses laser beams as the light source which reduces the influence caused by the ambient luminance. The system can work properly in both the laboratory and the field conditions.

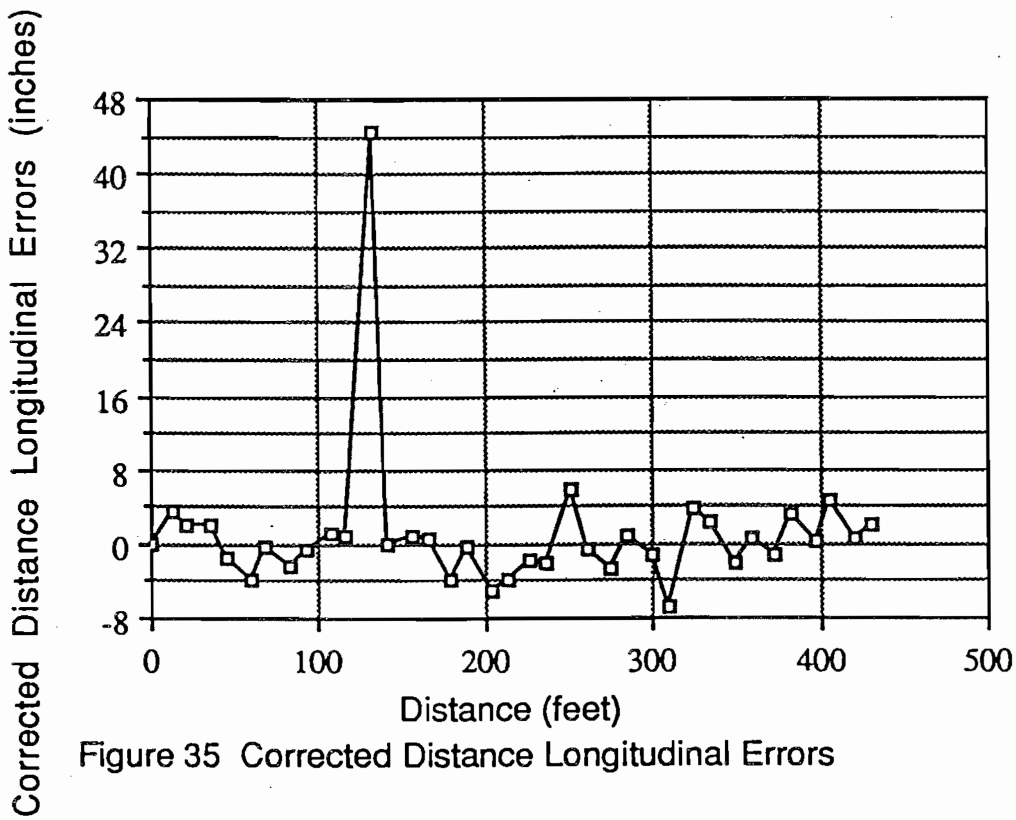

Figure 35 Corrected Distance Longitudinal Errors

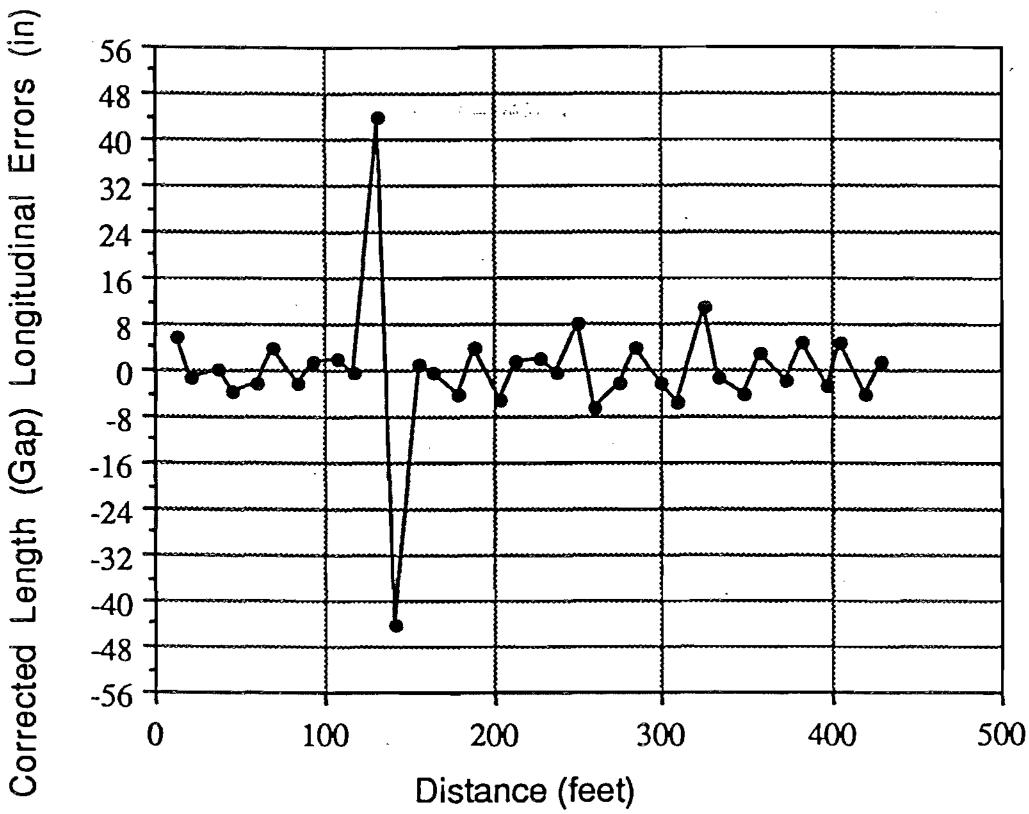

Figure 36 Corrected Length (Gap) Longitudinal Errors

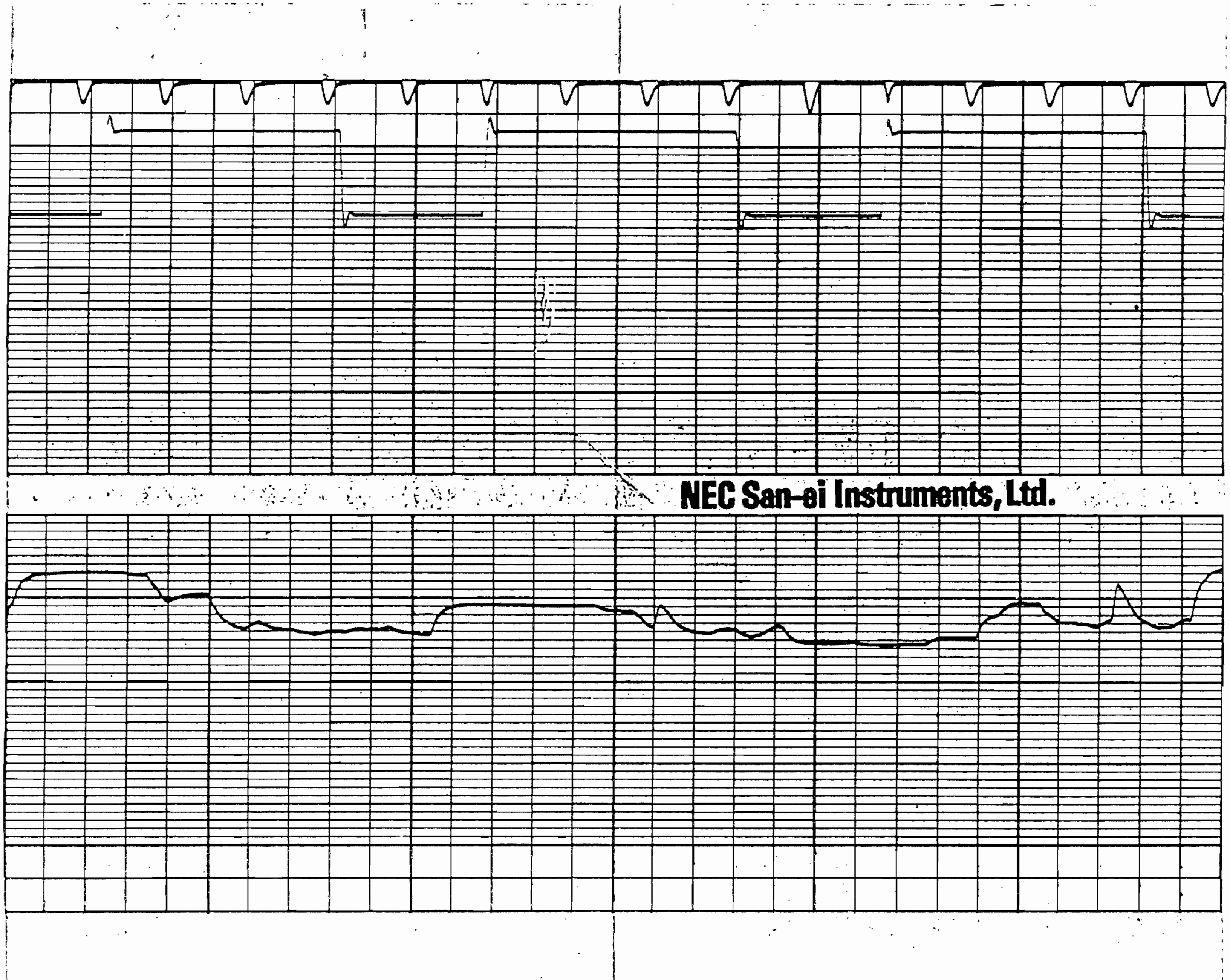

Figure 37 A part of Chart recorder data Shows the Noisy Lateral Signal Caused by RPMs and the Clean Longitudinal Signal.

The system utilizes retroreflection principle to increase the signal/noise ratio. The field test proved that the system worked fine with the old stripes which had only 40% - 60% of the reflectivity of the new stripe.

The three beam system can detect the lateral position of the stripe accurately. According to the results of the laboratory and the field tests, the system basically met the accuracy requirements of ±0.5 inches in the lateral position and ± 4 inches in the longitudinal position proposed in RFQ #90-DA1058, 1990.

Generally, the concepts of using a laser beam as the light source, scanning configuration, utilizing the retroreflection principle and using three beams are found to be a feasible combination for the restriping guidance system. The breadboard system showed a very good potential for further development.

To consummate the final system, the following improvements would be recommended:

a) The power of the laser unit might be increased from current 7 mW of the breadboard system to 10 mW to further increase the detection ability and the signal/noise ratio.

b) The optical system might be improved to make it easier to adjust, more compact and more efficient.

c) The photoreceptor amplifier and its electronics might be improved to reduce the electronic noise and increase the gain.

d) The GESPAC computer would be enclosed in the scanner's case to reduce the distance between the photoreceptor and the A/D converter.

e) The RPM differentiation process would be developed for the lateral position detection.

f) The laptop computer control might be combined to another IBM PC compatible industrial computer which also controls the outrigger hydraulic system. If so, the communication between the GESPAC computer and the IBM PC compatible computer can be changed to parallel.

g) A smoothing function to reduce the noise caused by the worn out edges of the stripe would be carefully selected.

h) If too much calculation are involved in the GESPAC computer, a more powerful CPU (e.g. 68Ø3Ø) would be considered.

i) An air condition system for the scanner would be installed to keep the system clean and temperature controlled.

j) The scanning width of the laser beam at 5 feet forward position would be expanded from the current 1.9 feet to 3 feet.

k) An automatic gain/threshold control process would be developed to increase the stability of the system and reduce the complexity of the operation.

APPENDIX A (SCANNER BLUEPRINT)

APPENDIX B (IBM-PC COMPATIBLE SOFTWARE MENUS)

```
  File    Controls    Scans    Parameters
                         LASER RETRO GUIDANCE SYSTEM

                                                  PARAMETERS
                                             Laser beam : ON
                                             Double line: using LEFT
                                             Odometer CF: 11.73 clks/ft
                                             Scan frequ.: 176 Hz
                                             Window size: 21.6° ≈ 3.0ft
                                             Points/scan: 142
                                             Stripe width 16pts ≈ 4.0in
                                             Threshold values:
                                               Beam #1:  1000
                                               Beam #2:  1000
                                               Beam #3:  1000

 Use arrow keys to move cursor and Enter key to select.
```

```
  File    Controls    Scans    Parameters
   Dos shell             LASER RETRO GUIDANCE SYSTEM
   Exit PC
   Quit all
                                                  PARAMETERS
                                             Laser beam : ON
                                             Double line: using LEFT
                                             Odometer CF: 11.73 clks/ft
                                             Scan frequ.: 176 Hz
                                             Window size: 21.6° ≈ 3.0ft
                                             Points/scan: 142
                                             Stripe width 16pts ≈ 4.0in
                                             Threshold values:
                                               Beam #1:  1000
                                               Beam #2:  1000
                                               Beam #3:  1000

 Use arrow keys to move cursor and Enter key to select.
```

```
File    Controls    Scans    Parameters
                                  LASER RETRO GUIDANCE SYSTEM
  Laser off
  Read odometer
  Set time
                                                   PARAMETERS
                                          Laser beam : ON
                                          Double line: using LEFT
                                          Odometer CF: 11.73 clks/ft
                                          Scan frequ.: 176 Hz
                                          Window size: 21.6° ≈ 3.0ft
                                          Points/scan: 142
                                          Stripe width 16pts ≈ 4.0in
                                          Threshold values:
                                            Beam #1:  1000
                                            Beam #2:  1000
                                            Beam #3:  1000

Use arrow keys to move cursor and Enter key to select.
```

```
File    Controls    Scans    Parameters
                                  LASER RETRO GUIDANCE SYSTEM
  Laser off
  Read odometer
  Set time
                                                   PARAMETERS
                                          Laser beam : ON
                                          Double line: using LEFT
     Odometer: 25733 clks   0.42 miles    Odometer CF: 11.73 clks/ft
                                          Scan frequ.: 176 Hz
                                          Window size: 21.6° ≈ 3.0ft
                                          Points/scan: 142
                                          Stripe width 16pts ≈ 4.0in
                                          Threshold values:
                                            Beam #1:  1000
                                            Beam #2:  1000
                                            Beam #3:  1000

Use arrow keys to move cursor and Enter key to select.
```

```
File    Controls    Scans    Parameters
                  ┌─────────────────────┐UIDANCE SYSTEM
                  │ Single scan         │
                  │ Continue scan       │
                  │ Threshold scans     │
                  └─────────────────────┘
                                         PARAMETERS
                                Laser beam : ON
                                Double line: using LEFT
                                Odometer CF: 11.73 clks/ft
                                Scan frequ.: 176 Hz
                                Window size: 21.6° ≈ 3.0ft
                                Points/scan: 142
                                Stripe width 16pts ≈ 4.0in
                                Threshold values:
                                  Beam #1:  1000
                                  Beam #2:  1000
                                  Beam #3:  1000

Use arrow keys to move cursor and Enter key to select.
```

```
File    Controls    Scans    Parameters
                  ┌─────────────────────┐UIDANCE SYSTEM
                  │ Single scan         │
                  │ Continue scan       │
                  │ Threshold scans     │
                  └─────────────────────┘
                                         PARAMETERS
                                Laser beam : ON
                                Double line: using LEFT
                                Odometer CF: 11.73 clks/ft
  Press 'Q' or 'Esc' to quit continue scan.
                                Scan frequ.: 176 Hz
                                Window size: 21.6° ≈ 3.0ft
                                Points/scan: 142
                                Stripe width 16pts ≈ 4.0in
                                Threshold values:
                                  Beam #1:  1000
                                  Beam #2:  1000
                                  Beam #3:  1000

Use arrow keys to move cursor and Enter key to select.
```

```
File    Controls    Scans    Parameters
                          LA              CE SYSTEM
   Left line
   Right line
   Odomter CF
   Window size
   Points/scan
   Stripe width

                PARAMETERS
   Laser beam : ON
   Double line: using LEFT
   Odometer CF: 11.73 clks/ft
   Scan frequ.: 176 Hz
   Window size: 21.6˚ ≈ 3.0ft
   Points/scan: 142
   Stripe width 16pts ≈ 4.0in
   Threshold values:
     Beam #1:  1000
     Beam #2:  1000
     Beam #3:  1000

Use arrow keys to move cursor and Enter key to select.
```

```
File    Controls    Scans    Parameters
                          LA              CE SYSTEM
   Left line
   Right line
   Odomter CF
   Window size

   HOW TO SET OR CALIBRATE THE ODOMETER

 1. Input the odometer calibration/setting
    distance (ft).
 2. Press Enter key when the vehicle is at
    the starting point of the distance.
 3. Press Enter key when the vehicle is at
    the ending point of the distance.

  Input Calibration Distance: 100

  Please press a key to start.
  Press a key when the distance travelled.

                PARAMETERS
   Laser beam : ON
   Double line: using LEFT
   Odometer CF: 11.73 clks/ft
   Scan frequ.: 176 Hz
   Window size: 21.6˚ ≈ 3.0ft
   Points/scan: 142
   Stripe width 16pts ≈ 4.0in
   Threshold values:
     Beam #1:  1000
     Beam #2:  1000
     Beam #3:  1000

Use arrow keys to move cursor and Enter key to select.
```

```
File    Controls    Scans    Parameters
                          LA            CE SYSTEM
                             Left line
                             Right line
                             Odomter CF
                             Window size
                             Points/scan
                             Stripe width

  The old window size is 21.60 degrees
  Please input new window size in degrees:

                                          PARAMETERS
                                     Laser beam : ON
                                     Double line: using LEFT
                                     Odometer CF: 11.73 clks/ft
                                     Scan frequ.: 176 Hz
                                     Window size: 21.6° ≈ 3.0ft
                                     Points/scan: 142
                                     Stripe width 16pts ≈ 4.0in
                                     Threshold values:
                                       Beam #1:  1000
                                       Beam #2:  1000
                                       Beam #3:  1000

Use arrow keys to move cursor and Enter key to select.
```

```
File    Controls    Scans    Parameters
                          LA            CE SYSTEM
                             Left line
                             Right line
                             Odomter CF
                             Window size
                             Points/scan
                             Stripe width

  The old points per scan is 142 pts
  Please input new points per scan in pts:

                                          PARAMETERS
                                     Laser beam : ON
                                     Double line: using LEFT
                                     Odometer CF: 11.73 clks/ft
                                     Scan frequ.: 176 Hz
                                     Window size: 21.6° ≈ 3.0ft
                                     Points/scan: 142
                                     Stripe width 16pts ≈ 4.0in
                                     Threshold values:
                                       Beam #1:  1000
                                       Beam #2:  1000
                                       Beam #3:  1000

Use arrow keys to move cursor and Enter key to select.
```

```
File    Controls    Scans    Parameters
                         LA                  CE SYSTEM
                              Left line
                              Right line
                              Odomter CF
                              Window size
                              Points/scan
                              Stripe width

 The old stripe width is  16 pts
 Please input new stripe width in pts:

                                          PARAMETERS
                                   Laser beam : ON
                                   Double line: using LEFT
                                   Odometer CF: 11.73 clks/ft
                                   Scan frequ.: 176 Hz
                                   Window size: 21.6° ≈ 3.0ft
                                   Points/scan: 142
                                   Stripe width 16pts ≈ 4.0in
                                   Threshold values:
                                     Beam #1:  1000
                                     Beam #2:  1000
                                     Beam #3:  1000

Use arrow keys to move cursor and Enter key to select.
```

APPENDIX C

LONGITUDINAL DATA FILE LIST

Data File Mane: 10179100.lrg

Gun	From(ft)	To(ft)	Length(ft)	Total Length(ft)
ON	34579.871	34585.244	5.373	5.373
OFF	34585.244	34588.059	2.814	8.188
ON	34588.059	34593.943	5.885	8.699
OFF	34593.943	34596.843	2.900	8.785
ON	34596.843	34602.216	5.373	8.273
OFF	34602.216	34605.031	2.814	8.188
ON	34605.031	34610.916	5.885	8.699
OFF	34610.916	34613.730	2.814	8.699
ON	34613.730	34619.615	5.885	8.699
OFF	34619.615	34622.515	2.900	8.785
ON	34622.515	34627.888	5.373	8.273
OFF	34627.888	34630.702	2.814	8.188
ON	34630.702	34636.587	5.885	8.699
OFF	34636.587	34639.487	2.900	8.785
ON	34639.487	34644.860	5.373	8.273
OFF	34644.860	34648.187	3.326	8.699
ON	34648.187	34653.560	5.373	8.699
OFF	34653.560	34656.374	2.814	8.188
ON	34656.374	34662.344	5.970	8.785
OFF	34662.344	34665.159	2.814	8.785
ON	34665.159	34670.532	5.373	8.188
OFF	34670.532	34673.346	2.814	8.188
ON	34673.346	34679.231	5.885	8.699
OFF	34679.231	34682.046	2.814	8.699
ON	34682.046	34687.504	5.458	8.273
OFF	34687.504	34690.745	3.241	8.699
ON	34690.745	34696.204	5.458	8.699
OFF	34696.204	34699.018	2.814	8.273
ON	34699.018	34704.903	5.885	8.699
OFF	34704.903	34707.803	2.900	8.785
ON	34707.803	34713.176	5.373	8.273
OFF	34713.176	34715.990	2.814	8.188
ON	34715.990	34721.875	5.885	8.699
OFF	34721.875	34724.690	2.814	8.699
ON	34724.690	34730.148	5.458	8.273
OFF	34730.148	34733.474	3.326	8.785
ON	34733.474	34738.847	5.373	8.699
OFF	34738.847	34741.662	2.814	8.188
ON	34741.662	34747.547	5.885	8.699
OFF	34747.547	34750.447	2.900	8.785
ON	34750.447	34755.820	5.373	8.273
OFF	34755.820	34758.634	2.814	8.188
ON	34758.634	34764.519	5.885	8.699
OFF	34764.519	34767.334	2.814	8.699
ON	34767.334	34772.792	5.458	8.273
OFF	34772.792	34776.033	3.241	8.699
ON	34776.033	34781.491	5.458	8.699
OFF	34781.491	34784.306	2.814	8.273
ON	34784.306	34790.191	5.885	8.699
OFF	34790.191	34793.005	2.814	8.699
ON	34793.005	34798.464	5.458	8.273
OFF	34798.464	34801.278	2.814	8.273
ON	34801.278	34807.163	5.885	8.699
OFF	34807.163	34809.978	2.814	8.699

Gun	From(ft)	To(ft)	Length(ft)	Total Length(ft)
ON	34809.978	34815.436	5.458	8.273
OFF	34815.436	34818.677	3.241	8.699
ON	34818.677	34824.135	5.458	8.699
OFF	34824.135	34826.950	2.814	8.273
ON	34826.950	34832.835	5.885	8.699
OFF	34832.835	34835.649	2.814	8.699
ON	34835.649	34841.108	5.458	8.273
OFF	34841.108	34843.922	2.814	8.273
ON	34843.922	34849.807	5.885	8.699
OFF	34849.807	34852.621	2.814	8.699
ON	34852.621	34858.080	5.458	8.273
OFF	34858.080	34861.321	3.241	8.699
ON	34861.321	34866.779	5.458	8.699
OFF	34866.779	34869.594	2.814	8.273
ON	34869.594	34875.479	5.885	8.699
OFF	34875.479	34878.293	2.814	8.699
ON	34878.293	34883.752	5.458	8.273
OFF	34883.752	34886.566	2.814	8.273
ON	34886.566	34892.451	5.885	8.699
OFF	34892.451	34895.265	2.814	8.699
ON	34895.265	34900.639	5.373	8.188
OFF	34900.639	34903.538	2.900	8.273
ON	34903.538	34909.423	5.885	8.785
OFF	34909.423	34912.238	2.814	8.699
ON	34912.238	34918.123	5.885	8.699
OFF	34918.123	34920.937	2.814	8.699
ON	34920.937	34926.395	5.458	8.273
OFF	34926.395	34929.210	2.814	8.273
ON	34929.210	34935.010	5.800	8.614
OFF	34935.010	34937.909	2.900	8.699
ON	34937.909	34943.282	5.373	8.273
OFF	34943.282	34946.609	3.326	8.699
ON	34946.609	34952.067	5.458	8.785
OFF	34952.067	34954.882	2.814	8.273
ON	34954.882	34960.766	5.885	8.699
OFF	34960.766	34963.581	2.814	8.699
ON	34963.581	34969.039	5.458	8.273
OFF	34969.039	34971.854	2.814	8.273
ON	34971.854	34977.739	5.885	8.699
OFF	34977.739	34980.553	2.814	8.699
ON	34980.553	34985.926	5.373	8.188
OFF	34985.926	34989.253	3.326	8.699
ON	34989.253	34994.626	5.373	8.699
OFF	34994.626	34997.526	2.900	8.273
ON	34997.526	35003.410	5.885	8.785
OFF	35003.410	35006.225	2.814	8.699
ON	35006.225	35011.598	5.373	8.188
OFF	35011.598	35014.498	2.900	8.273
ON	35014.498	35020.297	5.800	8.699
OFF	35020.297	35023.112	2.814	8.614
ON	35023.112	35028.570	5.458	8.273
OFF	35028.570	35031.897	3.326	8.785
ON	35031.897	35037.270	5.373	8.699
OFF	35037.270	35040.084	2.814	8.188
ON	35040.084	35046.054	5.970	8.785

Gun	From(ft)	To(ft)	Length(ft)	Total Length(ft)
OFF	35046.054	35048.869	2.814	8.785
ON	35048.869	35054.242	5.373	8.188
OFF	35054.242	35057.142	2.900	8.273
ON	35057.142	35062.941	5.800	8.699
OFF	35062.941	35065.841	2.900	8.699
ON	35065.841	35071.214	5.373	8.273
OFF	35071.214	35074.540	3.326	8.699
ON	35074.540	35079.914	5.373	8.699
OFF	35079.914	35082.728	2.814	8.188
ON	35082.728	35088.613	5.885	8.699
OFF	35088.613	35091.513	2.900	8.785
ON	35091.513	35096.886	5.373	8.273
OFF	35096.886	35099.700	2.814	8.188
ON	35099.700	35105.585	5.885	8.699
OFF	35105.585	35108.400	2.814	8.699
ON	35108.400	35113.858	5.458	8.273
OFF	35113.858	35117.184	3.326	8.785
ON	35117.184	35122.557	5.373	8.699
OFF	35122.557	35125.372	2.814	8.188
ON	35125.372	35131.257	5.885	8.699
OFF	35131.257	35134.157	2.900	8.785
ON	35134.157	35139.530	5.373	8.273
OFF	35139.530	35142.344	2.814	8.188
ON	35142.344	35148.229	5.885	8.699
OFF	35148.229	35151.044	2.814	8.699
ON	35151.044	35156.502	5.458	8.273
OFF	35156.502	35159.828	3.326	8.785
ON	35159.828	35165.201	5.373	8.699
OFF	35165.201	35168.016	2.814	8.188
ON	35168.016	35173.901	5.885	8.699
OFF	35173.901	35176.715	2.814	8.699
ON	35176.715	35182.174	5.458	8.273
OFF	35182.174	35184.988	2.814	8.273
ON	35184.988	35190.873	5.885	8.699
OFF	35190.873	35193.688	2.814	8.699
ON	35193.688	35199.146	5.458	8.273
OFF	35199.146	35202.472	3.326	8.785
ON	35202.472	35207.845	5.373	8.699