A PIEZOELECTRIC SENSOR FOR TESTING SEED METERS

BY

OUSSAMA EL GHARRAS

Ingénieur d'Application

Institut Agronomique et Vétérinaire

Hassan II Rabat, Morocco

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A PIEZOELECTRIC SENSOR FOR TESTING SEED METERS

Thesis Approved:

John B Solie

Thesis Adviser

Richard W. Whitney

Thomas C. Collins

Dean of the Graduate College

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LIST OF SYMBOLS AND ABBREVIATIONS

Chan.	Channel number
CV	Coefficient of variation
DT	Time interval between seeds (average instrumentation recorded data or data calculated from manually collected samples)
HE	Hall effect sensor
Instru.	Instrumentation recorded data
kPag	Kilo-Pascal gage pressure
Man.	Manually collected samples
MD	Median value from the instrumentation recorded data
ms	milli-seconds
N	Number of seeds dropped by the planter metering unit during one minute
OSU	Oklahoma State University
Peak	Peak value from the instrumentation recorded data (most recorded time spacing)
Pr	Pressure level setting
Rep.	Replication
RPM	Measured planter meter shaft revolutions per minute
S.C.	Seed drops code
SD	Instru. indicators significantly different from Man.
Sp.	Speed setting on the speed variator
STD	Standard deviation
Theo.	Theoretical number of seeds calculated from the RPM
TheoT.	Theoretical time spacing between seeds calculated from the RPM

CHAPTER I

INTRODUCTION

An important factor in the optimum germination and initial growth of plants is the proper placement of seeds in the soil during the planting operation. A planter is supposed to place seeds at a predetermined uniform spacing. But in practice, the actual placement of seeds deviates considerably from that desired.

Errors in seed spacing are of two types. First, error results from the occurrence of multiples or skips in seed metering where single seeds are desired at each placement position. This may be referred to as metering error. The second source of error is the result of deviation in actual seed placement position from the desired placement position. This error may be called seed placement error.

Several investigators have studied the effect of various factors on seed metering and/or seed placement error (Agness et al. (1975), Allam and Wiens (1982), Brandt et al. (1964), Joseph et al. (1985), Kemp et al. (1983), Moline (1973), Rohrbach et al. (1970), Roy and Buchele (1961), and Solie et al (1990)). These factors can be summarized as: variations in seed size and shape, planting speed, design of seed metering and dropping mechanisms, design of the seed hopper, seed level in the hopper, condition of the soil furrow where seeds are dropped, and some others specific to particular uses.

If the bouncing effect between the seeds and the soil is neglected, the accuracy of seed spacing depends upon the ability of the metering unit to singulate seeds from a large seed mass and to discharge them at a regular predetermined interval in relation to preceding and succeeding seeds.

Solie et al. (1990) showed that precision seeding for cereals increased the yield up to 14%. Therefore, a need to evaluate a vacuum metering unit that could potentially singulate cereal seeds is of great importance.

A part of this study involved development of instrumentation for automatic data acquisition of the seed distribution (or metering) pattern from a planter. In general, electronic seed sensors used in seed counters and planter monitors are based on optical principles (a light emitting diode and photo transistor). These instruments are inaccurate because they fail to count multiple seed drops, particularly at high speeds. They also lack the ability to distinguish between seeds and other interfering objects like seed coats. Therefore, a new instrumentation is needed to distinguish seeds from any other possible interfering object, in order to determine spacings between seeds.

CHAPTER II

OBJECTIVES

The overall objective of this study was to develop instrumentation to measure the seed spacing of a planter metering unit that may be used to plant wheat and other cereals at uniform spacings.

Specifically the objectives were as follows:

1- Design a sensor unit that may be located at the delivery point of a metering unit, which can measure seed spacing and can detect double seed drops.

2- Evaluate the effectiveness of the sensor for measuring seed spacing and determine the effect of temperature and vibration on the sensor.

3- Evaluate the performance of a John Deere Max Emerge 2 metering unit and use the sensor to measure intrarow spacing uniformity of hard red winter wheat.

CHAPTER III

LITERATURE REVIEW

The production of most food and fiber crops begins with the placement of seeds in or on the soil. This is accomplished either by hand or with a machine. Studies have shown that when precise methods of metering seeds are used, higher profits result. Precision planting, and optimization of spatial distribution of seeds, result in increasing the production.

Moline (1973) stated, in the concept of seed precision planting, that "the recognition of the need for precision planting, wherein seeds are placed at predetermined lateral spacings and soil depths, was first attempted by the Pharaohs of Egypt". Solie (1990) reported that "for at least 56 years, researchers have increased winter and spring wheat yields by reducing row spacing". Several other investigators have confirmed that precision planting and optimization of plant spacing should increase wheat yield by minimizing competition between plants for available resources of light, water, and nutrients (Frederick and Marshall (1985), Johnson et al. (1988), Joseph et al. (1985)). Optimizing spatial distribution and plant density to rapidly exploit resources can increase the competitiveness of wheat against the other winter grasses.

Holliday (1963) reviewed research and found that wheat yield increased up to 33% on average over three seeding rates when row spacing was decreased from 20 to 10 cm. Joseph et al. (1985) reported a 12 to 13% increase in yield of soft, red winter wheat by reducing row spacing from 20 to 10 cm. Similarly, an increase of soft red winter wheat yields between 6.0 and 13.2% by reducing row spacings from 18 to 13 cm, at six locations, was reported by Frederick and Marshall (1985). Typically, an increase in yields of 8% over approximately the same range of row spacing is the common result achieved by most investigators.

Research to investigate the effect of row spacing and related cultural practices on wheat grain yield and cheat seed yield, was initiated at Oklahoma State University in 1988 by Solie and his co-workers. Eighteen experiments were conducted during 1988-90 to determine the effect of wheat cultivar, seeding rate, banding of water or fertilizer, date of planting, and cheat density in conjunction with row spacing on wheat grain yield, and to develop mathematical models relating the potential yield increase to row spacing. Spatial distribution theory predicts that wheat yield should peak at a rectangularity ratio of 1 to 1 (the distance between rows divided by the average distance between plants in the same rows).

The agronomic explanation, is that yield increases are attributed to more efficient use of resources available in a given area and to a considerable decrease of weed competition when the density and arrangement of wheat seeds are uniformly spaced within the row coupled with the ultranarrow rows. The results from Solie's experiment showed that optimum yield for cereals occurred at row spacing of 68 to 80 mm which implies an optimum in-row-spacing between 65 and 75 mm.

Seeding Requirements Techniques

Precision planting is a term used often by researchers and equipment manufacturers. There are, however, several important aspects of the precision planting operation which, in themselves, must be defined. Brandt and Fabian (1964) reported the need to develop an accurate metering mechanism to separate and eject individual seeds. They summarized this objective in developing equipment to drill single seeds at a predetermined distance, and a hilldrop mechanism that could accurately deliver two or three seeds at predetermined intervals. Many researchers have used the term precision planting to refer to metering accuracy, depth control, longitudinal spacing accuracy, seed singulation and lateral seed placement accuracy. All these factors refer to the geometrical positioning of seeds and the operation of seed singulation.

Longitudinal plant spacings within the rows are of interest because of their relationship to productivity. The lateral seed placement or row spacing is a fixed variable due to the limiting physical characteristics of the equipment (width).

In general, seed-placement systems available to produce uniform in-the-row spacings are based on three physical processes:

1. Selection of a single seed from a large homogeneous seed population.
2. Movement of the seed to the point of discharge and releasing it.
3. Placement of the seed in the soil.

The problem as presented seems simple enough to solve for any kind or shape of seeds. However, there are economic limitations beyond which the problem becomes difficult to solve.

The precision planting systems exist with a high degree of control of spacing, singulation, and depth for most monogerm seeds and are very common at the farmer level. However, seeding systems developed up to now for wheat, in particular, and cereals, in general, are only volumetric metering units. Precision planting of wheat has not been developed earlier because the system is not economically justified (at least prior to the development of the ultranarrow row grain drill).

Planter Analysis

After reviewing literature of planters and seeders, Roy and Buchele (1961) studied the factors that affected the performance of the precision planters and established the following basic principles:

1. Low separating speeds must be used even at high tractor speeds, to prevent damage to the seed and secure better separation.
2. A solid fixed cut-off should not be used for removing excess seeds from the cells.
3. The seed must be ejected, at the release point, as close as possible to the ground surface, in a vertical direction, and with zero relative velocity with respect to ground.

All cereal seeders used until today have volumetric metering units which drop seeds into the tubes that convey the seeds close to the bottom of the furrow.

Seed separation systems are dependent on two factors, peripheral velocity of the seed metering unit (plate) and the resultant velocity of the seeds. Vector analysis shows that the resultant velocity is due to velocities caused by the acceleration of gravity, seed-to-plate friction and the impact of the seed on the edge or walls of the seed cells.

The percent of cells filled will be affected by the vertical velocity, but mainly by the plate velocity. The smaller the relative velocity of the plate to the seed the higher will be the percent fill.

Fixed cut-offs are used mainly in commercial planters. In most cases, this device is responsible for all the sheared seeds. The forces act on the seed like a couple and develop a torque on it. This torque will tend to roll the seed backwards and thus offer more area to the cut-off to shear it.

The conveying of seeds to the bottom of the furrow is accomplished mostly by a free fall through a guide tube. When the seeds leave the cell the velocity of the plate throws the seeds against the wall of the tube, bouncing them erratically. The place of landing will be determined by the velocity and direction of the seed when leaving the tube. The velocity of the seed is different at all times, therefore the relative velocity of seed to ground could not be predetermined, thus no accuracy could be expected of this system.

The landing of the seed on the soil is a subject that has not been studied enough. Roy and Buchele (1961) reported that the soil is not uniform in nature, especially when it has been mechanically sheared. The soil texture is formed by clods including some larger in size than the seed being planted. If the seed hits the surface in such a way that it is held between clods there will be no further movement, but if the seed hits a large clod, the bounce and final resting place of the seed can not be predetermined.

Physical Characteristics of Wheat Seeds

Studies of experimental planters showed that all of the planters were dependent on the physical characteristics of the seeds for good performance (Mohsenin, 1980). Therefore, it is important to have an accurate estimate of the shape, size, volume, specific gravity, surface area and other physical characteristics which may be considered as engineering parameters for the design of efficient equipment.

The physical characteristics of wheat seeds are irregular and vary depending on the crop variety and the soil and climatic conditions under which they were produced (stresses during the physiological cycle of the plants). However, an evaluation by measuring a set of specimens gives a range of dimensions for a designer to use. The physical dimensions (major diameter, minor diameter, and number of seeds per kilogram) for three varieties of wheat were measured and analyzed (Table I), and then compared with other reported in literature (Mohsenin, 1980). The results obtained were similar to those found in the literature.

TABLE I

PHYSICAL CHARACTERISTICS OF SOME WHEAT VARIETIES

Product	Major dia.(mm)	Minor dia.(mm)	Specific gravity	Seeds per kg
From Mohsenin				
Bast 46	7.3	2.8	1.41	21164
Onas 53	6.6	3	1.43	24030
Romona	6.9	3.5	1.43	19665
From our experiment				
Pioneer 2180	5.8	2.7	--	32573
Quantum 574	6.6	2.9	--	26316
Sioux land	5.6	2.5	--	34483
Average	6.5	2.9	1.42	26372

The shape of the cereal-grain seeds can be compared (approximated) to an elliptical or oblong shape but this characteristic varies considerably from one variety to another. This shape makes the singulation task difficult to perform.

Testing Procedures

Planter performance is ultimately important as it influences harvested yield. Engineers have developed methods for evaluating performance which include measurable variables other than yields.

The problem of precision planting of wheat consists of distributing seeds within the rows at equal spacings. Therefore, the objective is to minimize the variability within the rows to an acceptable value.

Allam et al. (1982) stated that the Prairie Agricultural Machinery Institute has accepted the following rating scale as its basis for rating uniformity of distribution between rows across seeders' width:

CV > 15%	Unacceptable
10 < CV < 15%	Acceptable
CV < 10%	Good.

Laboratory tests were conducted in 1989 at Oklahoma State University on different commercial metering units of grain drills to determine the within row (intrarow) coefficient of variation of seed spacing. The seeds were deposited on a continuous belt with attached adhesive strip and results are listed in Table II.

TABLE II

COEFFICIENT OF SEED SPACING VARIATION WITHIN-THE-ROWS FOR COMMERCIALLY AVAILABLE GRAIN DRILLS

Grain Drills	Meter Type	CV (%)
Great Plains 1/8 inches Gap	External Fluted Roll	96.8
Great plains 1/4 inches Gap	External Fluted Roll	137.1
Tye 1/8 inches Gap	Internal Fluted Roll	97.7
Tye 1/4 inches Gap	Internal Fluted Roll	154.5
John Deere 1/8 inches Gap	External Fluted Roll	126.6
John Deere 1/4 inches Gap	External Fluted Roll	125.2
Air seeder	Double Rubber Roll	117.0
Cone seeder		160.1

Unpublished data. Edmonson and Solie, agricultural engineering, OSU. 1989.

The variation reported in the above table is attributed to the overall metering errors (skips, multiple drops and landing variability) which introduce spacing errors. However, no standard for rating within-row variability was fixed by the above test. Moreover, the seed placement measurement procedure (using a belt system with an application of glue) followed during the tests may add variability in seed spacings due to the landing effect of the seeds. Also, and in addition to seed alteration, this testing procedure takes considerable time to prepare and run very short tests.

Data Acquisition System (Instrumentation)

An instrument is a measuring system incorporating one or more transducers that interpret the signal to provide a quantitative assessment of a principal characteristic of the substance being sensed. An instrument includes standardized procedures (Doeblin (1990)):

1- extracting information.
2- sensing the substance with the transducer.
3- interpretation of the signal and translating it.

1. The information to be extracted is the spacings between cereal seeds. Therefore, the extraction of this information is to be realized by a distribution unit of a planter.

2. The sensed object (substance) is essentially unaltered by the process of sensing; the natural state of the substance does not have to be significantly changed in order to effectively sense the substance. Then, the action of measuring and the required energy transfer does not significantly affect the end-use-suitability of the product being assessed.

The transducer must be able to extract information from the object and generate a signal that is unambiguously related to the principal characteristic (weight/force) being sensed. Therefore, the transducer is a specific device which utilizes a transducer principle to generate a signal, and it is the link between the sense level and measure level. The transducer (or impact detector) used in this study was a piezoelectric sensor.

Piezoelectricity is a phenomenon where an electric charge is generated by the application of a strain, and in reverse is strained by the application of a charge (voltage) (Doeblin (1990)). A piezoelectric element used for converting mechanical motion to electric signals thus may be thought of as a charge generator. Mechanical deformation generates a charge, which then results in a voltage appearing between the electrodes according to the usual law for capacitors;

$$E = Q/C .$$

Where: $Q = K * d$ and; K= proportionality constant
d= deformation

$d = K_e * e * C_r$ and; K_e=proportionality constant
e= kinetic energy
C_r=coefficient of restitution

The piezoelectric effect is direction-sensitive, in that the tension produces a definite voltage polarity while compression produces the opposite.

3. The interpretation involves reliability and standardization of procedures. But it also involves translating the information.

Doeblin (1990) defined traceability as the ability to trace the accuracy of a standard back to its ultimate source in the fundamental standards of the National Institute of Standards and Technology. In performing a calibration, the following steps are necessary:

a- Examine the construction of the instrument, and identify and list all the possible inputs (interfering and modifying).

b- Decide, as best you can, which of the inputs will be significant in the application for which the instrument is to be calibrated (vibration and temperature).

c- Procure apparatus that will allow you to vary all significant inputs over the ranges considered necessary.

d- By holding some inputs constant, varying others, and recording the desired static input-output relations (temperature tests and vibration tests).

Once the desired information (signal) is transmitted, the translation function (or data presentation) is carried out by a data storage or a playback element. During the development of an instrument, an oscilloscope is generally preferred as a playback element to analyze and present the temporary information. However, and for the common use, a data storage element (computer) is more efficient to analyze and store the translated information. This data storage element suppose also the development of a software that will assume the analyzes and presentation of the final information collected.

CHAPTER IV

METHODS AND APPROACHES

Sensor

Seed Detector

The initial design concept was a sound-level measurement system which uses a piezoelectric transducer. As mentioned in the literature review, piezoelectricity is the linear reversible coupling between mechanical and electrical energy due to displacement of charges bound in molecular structure. Pressure applied to a piezoelectric material produces a change in observed surface density of charge, and conversely, a charge applied over the surfaces produces internal stress and strain. Thus, the energy developed at the impact of seeds, on the sensor, could be related to the number of seeds dropped and produce a corresponding charge. Moreover, the initial design criteria was to detect seed drops at an average spacing time (DT) of 35 milliseconds with an output of high/low voltage.

Piezoelements are generally noise and temperature sensitive. Therefore, vibration and temperature were considered as possible interfering and/or modifying signals which could adversely affect the desired signal.

"NTK PIEZO BUZZER" (Appendix A, p:58) designed originally to produce electronic sounds for alarm systems and other uses requiring a buzzer. These piezoelectric audio tone transducers are available in a wide range of diameter sizes and resonance frequencies. The transducer chosen has a thin brass plate with a layer of piezoelectric ceramic (figure 1, Appendix A, p:61). The diameter of the brass plate was 50 mm with a 25 mm diameter and 0.46 mm thick piezoelectric element bonded to the top of the plate. Two electrodes were soldered on this transducer, one on the brass plate, and the other on the silvered plated surface over the piezoelectric ceramic element. A support frame was built from a 5 mm thick plexiglass sheet (figure 1, APPENDIX A, p:61). The transducer was glued, with a super glue, at the edges to the support, with brass plate facing up. A thin layer of plastic tape covered the entire assembly on the top. The tape helped to damp out part of the vibration caused by the elastic shock of seeds to the metallic plate of the transducer. Two small holes were drilled in the horizontal plane of the plexiglass support to accommodate lead placement.

The sensor interface includes amplification, a level detection for comparison of the signals, an inversion and a monolithic timer (figure 2, APPENDIX A, p:62). The power circuit for the electronic interface is shown in figure 3 (APPENDIX A, p:63). The amplification of the transducer signal is accomplished in two steps, in order to allow adequate bandwidth. The first amplifier is a high precision, high-speed operational amplifier (Op Amp) and has a gain of 4. The second stage was implemented with an internally compensated Norton operational amplifier with a gain of 6.

The level detectors were selected to distinguish between single and multiple seed drops. The threshold level (or reference) is adjusted for each comparator with a potentiometer based on seed weight (figure 4, APPENDIX A, p:63). Adjustment of reference level was very delicate because the threshold between a single seed drop and a multiple seed drop was very small (0.1 volt between the reference level of the first and second comparators). The design was based on double seed strikes producing higher amplitude than single seed strikes. Preliminary hand-drop tests consistently showed that the double seed strikes produced higher amplitude pulses than single seed strikes.

Further processing of the signal was done with a double inversion operation using two TTL nor-gates. Finally, the dual monostable vibrator (timer) was operated as a pair of "one shots" and produced output signals of constant amplitude and width for computer interfacing. The one shot duration was fixed after running many manual seed-drop tests to define the maximum time duration of the excitations (pulses) produced by the sensor. The circuit was intended to produce a pulse of 10 ms duration on the single seed line for a single seed strike or 10 ms pulses on both lines for a simultaneous strike by two or more seeds. Using this technique, the sensor charge was allowed to decay.

RPM Measurement

The rotational speed of the driving shaft was detected with a hall-effect sensor. A "SUNX" (Appendix A, p:58) proximity sensor was mounted on a frame adjacent to the meter shaft drive sprocket which allowed adjustment of clearance between the sprocket teeth and the sensor. The RPM interface circuit diagram is shown in figure 5 (APPENDIX A, p:64).

Signal Translation

An IBM AT compatible 80386 based micro-computer operating at 20 MHz was used to acquire and store the pulses from the instrumentation. Software was developed to read the pulses produced by the circuit through an RS232 port. The computer 60 s acquisition duration for the tests was set by a loop-counter in the software. Table III shows the timing calibration used. When the program was started, the program timed until the signal from the instrumentation went high then it determined the time spacing between the initialization of the pulse and the initialization of the next pulse and recorded it with a delay of less than 10 milli-seconds was added to the readings to accommodate the hardware reset time. The computer program then looped to measure the next time between seeds (DT) until the 60 seconds had expired.

TABLE III

TEST DURATION

Number	Time duration (in seconds)		
	Rep.1	Rep.2	Rep.3
50	21.80	21.70	21.90
100	35.10	35.10	35.10
150	48.40	48.40	48.40
175	54.80	54.80	54.80
185	57.50	57.70	57.50
190	58.80	58.85	58.80
195	60.20	60.25	60.30
194	60.00	60.00	59.90
200	61.50	61.50	61.50
225	68.10	68.10	68.10

Test Stand

The stand used during this study consisted of a metal frame supporting the seed metering unit. The metering unit was powered by a driving shaft supported on two pillow bearings, which was driven by a 12-tooth sprocket and a chain. The drive shaft was powered with an electric motor through a continuously variable transmission. Vacuum was supplied by a shop vacuum cleaner and regulated with a gate valve (Appendix A, p:58). A vacuum gage was used to measure the vacuum level at a point 250 mm between the valve and the planter metering unit (see figure 6).

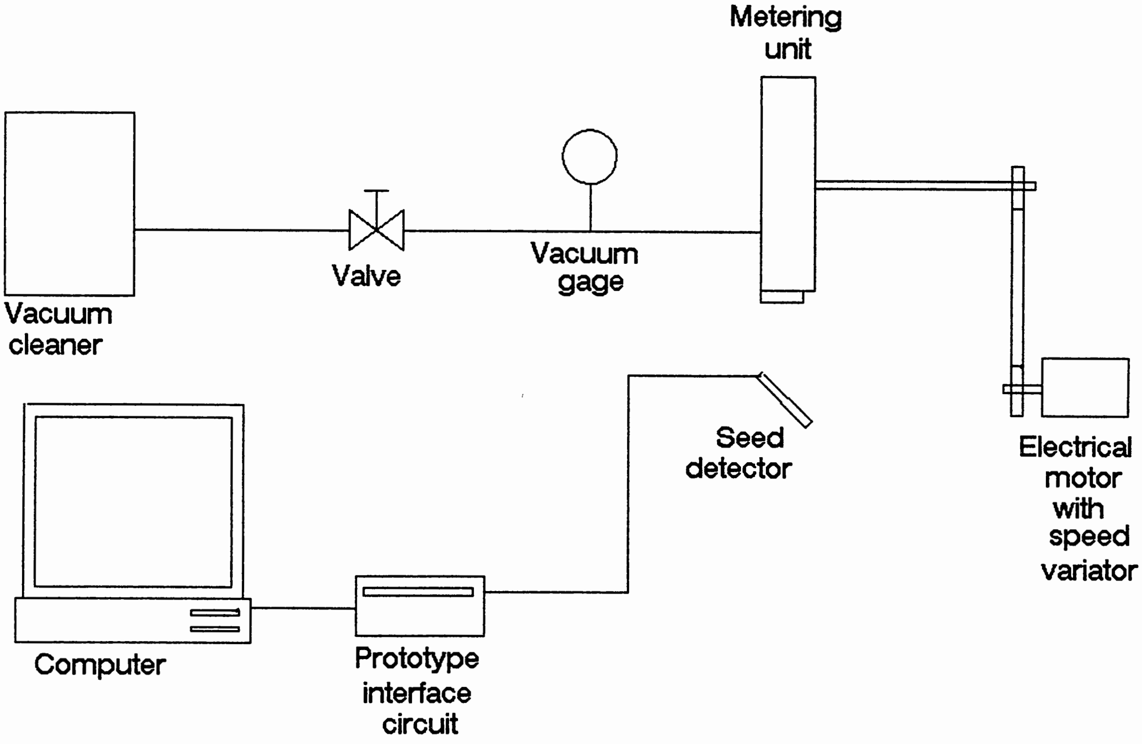
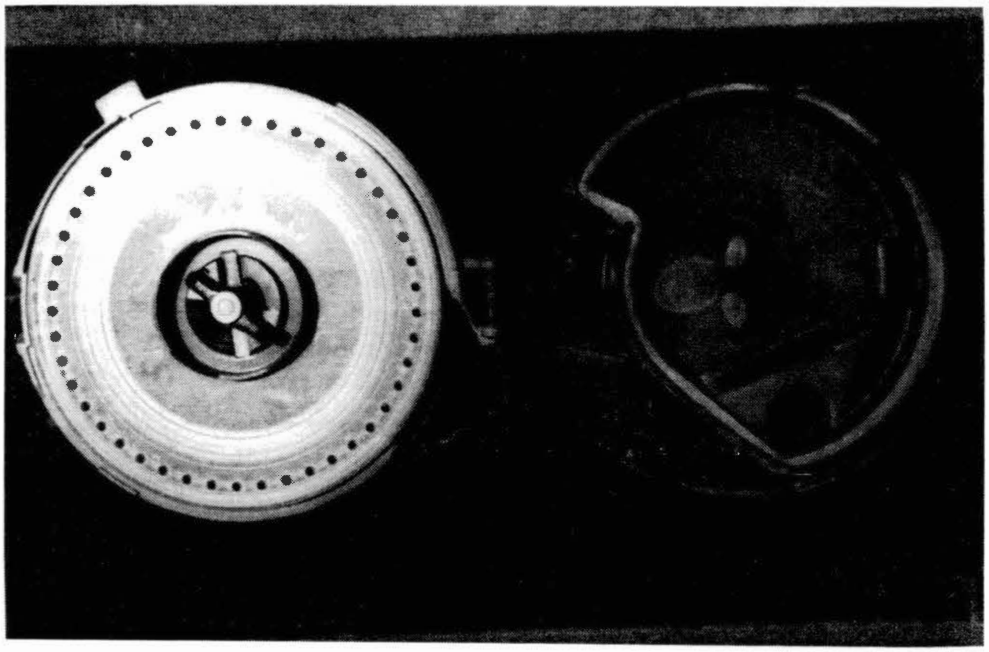


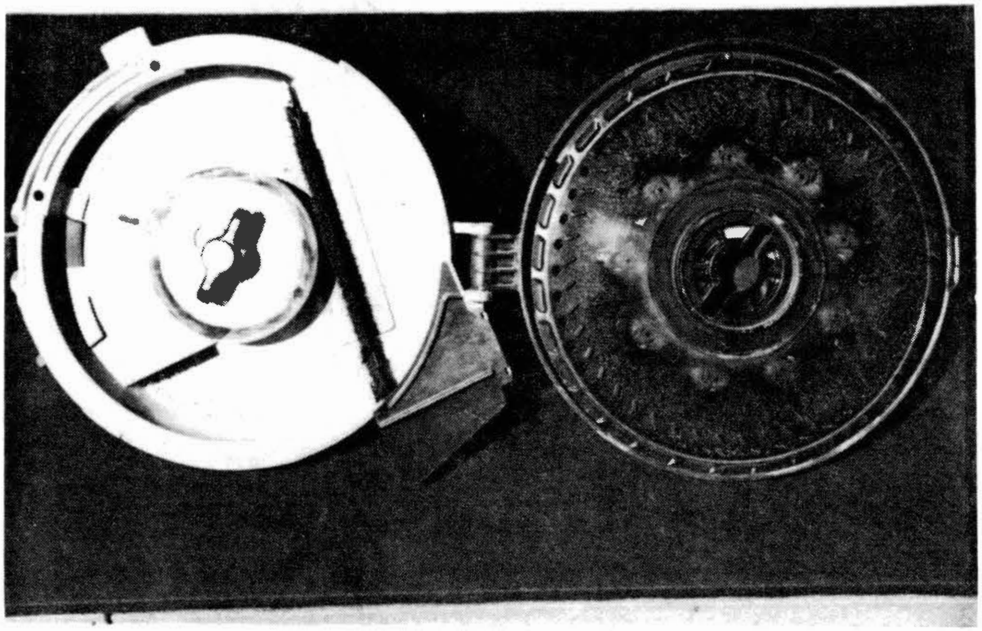
Figure 6. Schematic of The Experiment Layout

Planter Metering Unit

Laboratory tests were conducted to evaluate the seed spacing variability from a John Deere Max Emerge 2 metering unit for wheat. This metering unit was originally developed for sugarbeets (monogerm seeds) and recommended for small and medium size seeds (figures 7 a and b). The unit is based on a vacuum seed-pickup principle with a vertical plate distribution system. The principal components of the seed-metering unit are a housing, a plastic plate, and a



a. Vacuum Side and Back of Distribution Plate



b. Fill Side and Face of Distribution Plate

Figure 7. Max Emerge 2 John Deere Seed Metering Unit

seed ejector wheel. The plate rotates in the housing in a vertical plane. It has a hole at the center on which an adjustable compression spring is mounted to regulate friction between the plate and the housing. This plate also has 45 equally spaced conic holes, cells, of 1.5 mm end diameter. The seed mass is held in a circular container in a way that some seeds are always in contact with a segment of cells on the plate. When a vacuum is created in the housing, seeds attach to the cells and gradually move up with the turning of the plate. As the seed reaches near the delivery point, an ejector wheel acts from behind the plate and inside the housing to close the holes and release the seed. The interval between seeds dropped is varied by changing the speed of the shaft on which the plate is mounted.

CHAPTER V

TEST PROCEDURE

The seed variety used during the tests was "2158" wheat with an average 6.04 mm major diameter, 2.77 mm minor diameter, and 37.7 kernels per gram.

All the equipment listed in the following text are referenced in Appendix A, p:58 and figures 2, 3, and 5.

Sensor Test

The seed-detector sensor was mounted by a clamp to a laboratory ring stand at an angle of 45 degrees from the horizontal and 20 cm below the seed delivery (ejection) point of the planter metering unit (figure 8, appendix A, p:64). The sensor was adjusted in a way that all seeds falling from the planter struck upon it and bounced cleanly away from the sensor.

Tests were conducted on the instrumentation, at low driving shaft speed, for calibration to adjust the instrumentation thresholds for detecting singles and doubles after the computer interfacing.

After construction and completion of tests on the instrumentation, the author found that it was necessary to study the analog output signal of the piezoelectric sensor generated with the metering unit. Preliminary tests were conducted using the same sensor setting described above and a sound analyzer 8 bit A/D convertor card. The 8 bit card was used to collect wave forms generated by the piezoelectric sensor at a sampling rate of 11 kHz and with an appropriate low pass anti-alias filter. The A/D card was connected to the sensor electrodes ahead of the amplifiers. Wave forms were collected in three regions (low vacuum-low speed (-0.5 kPag and 5), low vacuum-high speed (-0.5 kPag and 25), and high vacuum-high speed (-4.5 kPag and 25)) where instrumentation behaviors were markedly different.

Instrumentation Test

Accuracy

The test procedure selected for evaluation of the instrumentation accuracy was based on double checking using the manual samples. The number of seeds collected manually allowed us to determine the different characteristics that could be compared with the ones obtained from the instrumentation for each test. A statistical analysis was run to find the best seed-spacing indicator, for each combination of disk speed and vacuum level (Sp-Pr). The independent variable was the method (instrumentation versus manually collected sample). The dependent variables were: number of dropped seeds (N), average seed time spacing (DT), peak value for the seed time spacing (peak), and the median value for the seed time spacing (MD).

Temperature

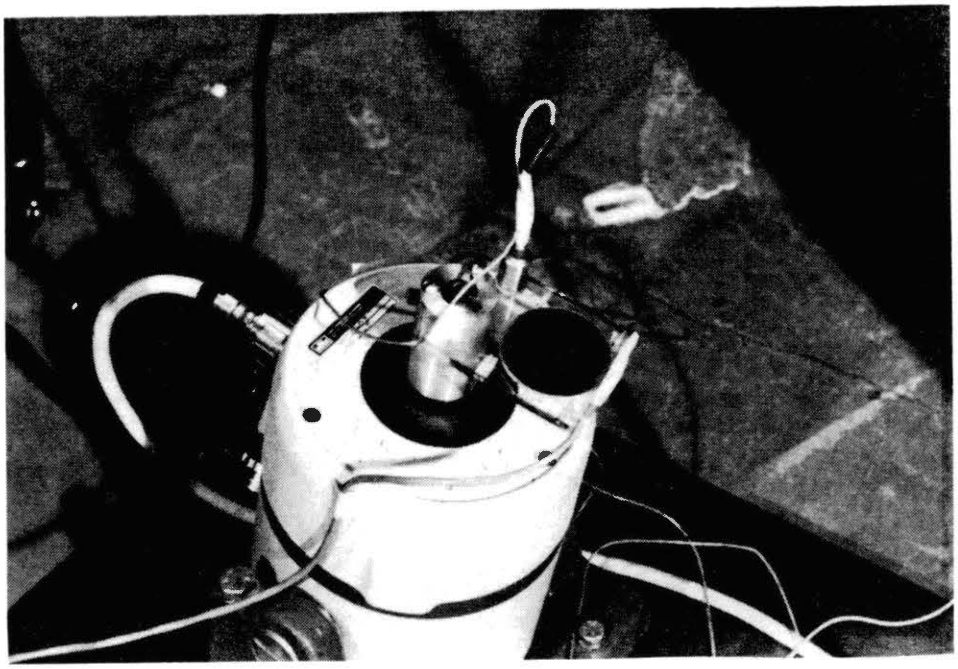
Piezoelectric elements are generally temperature sensitive. Therefore, a test was conducted to determine whether there were any temperature effects associated with the performance of the sensor. The procedure for the experiment was as follows. The pressure and speed were kept at constant levels. A copper constantan thermocouple (type T) was fixed on the plexiglass frame next to the piezoelement, in order to measure the temperature changes around this sensor. A thermocouple reader (Thermosense) was used to read and record the temperatures. An air-gun heater was used to blow hot air on the sensor from different distances in order to obtain a gradual change in temperatures. The temperature range covered was from 23.5 (ambient temperature) to 53.5 degrees centigrade. No specific increment in temperature change was selected because the equipments of the experiment did not allow it. The hot air was blown until the thermosense readings reached the steady state settings then the recording of data was started.

A linear regression analysis was run to identify the effect of the temperature on the recorded time spacings.

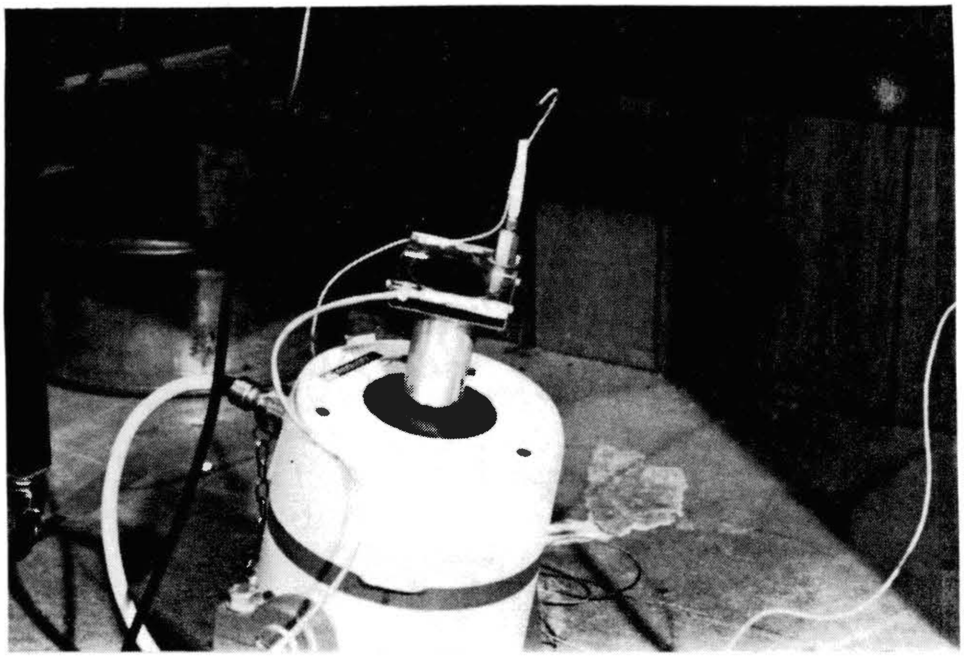
Noise (vibration)

The piezoelectric elements are generally very sensitive to vibrations. During the design of the instrumentation, minimizing the effect of vibration by using some mechanical isolation (plexiglass support and tape) and adjustments of the threshold of the level detector in the electronic circuit was considered. However, the need to define the limitations of this sensor was important for further development. Therefore, a vibration test was conducted to find the spectrum of false signal detections of our sensor mounted in two different ways (cantilever and bridge mountings) (figures 9, a and b). A false signal was a pulse that generated an output similar to the signal of a seed dropped on the sensor.

The vibration experiment set up was as follows (figure 10). A shaker (vibrator) was used to generate vibrations and was controlled by a power amplifier which allowed the frequency to be varied from 10 to 5000 Hz. As the frequency was increased, the amplitude decreased. No fixed control of the amplitude was possible. The sensor was mounted on the head of the shaker in the two different ways as shown in figures 9. An accelerometer was mounted on the plexiglass frame of the sensor on the part just above the shaker's head, to measure the frequencies and amplitudes of the excitations. The system was excited and the observations were displayed on the two channel digital recording oscilloscope. As soon as false pulses appeared or disappeared on the oscilloscope screen, the readings of the excitation frequency and amplitude related to the accelerometer were recorded on the second channel of the oscilloscope. Three tests were conducted, for each mounting



a. Cantilever Mounting



b. Bridge Mounting

Figure 9. Mounting Methods of The Seed Detector For Vibration Tests

Figure 10. Vibration Experiment Setup

method.

Planter Metering Unit Testing

The prototype metering unit was mounted on the test stand described earlier (figure 6 or 8). The variable speed drive was stepped from 5 to 25 on the drive speed indicator scale in five equal steps. This way, the planter shaft speed was also intended to be varied in five steps from 4 to 60 Revolutions Per Minute (RPM). However, the actual speed was measured to detect any influence of the vacuum pressure. The speed proximity sensor was mounted on the 12 tooth sprocket of the driving shaft. The information from this sensor allowed us to determine the actual RPM from which we could calculate the theoretical spacing between seeds and count expected from each test.

The vacuum level was varied from -0.23 to -4.5 kPag using the valve mounted on the vacuum tube. The pressures were selected based on the observed seed metering performance. The levels of vacuum used during the tests were; -0.23, -0.5, -0.75, -1.0, -2.0, -3.0, -3.5, -4.0, and -4.5 kPag. Smaller intervals were selected near the lower and upper vacuum limits to define as nearly as possible the limits for the range of the best performance of the planter metering unit. At each vacuum level the five speed levels were tested, thus 45 combinations (tests) were conducted. During each test, three one-minute samples were collected by the instrumentation intercalated by three 30-seconds samples taken manually. The instrumentation samples were stored and analyzed by the computer. The manually collected samples were counted using a seed counter, and damaged seeds were counted.

Six random 2158 wheat seed samples from the same bag of seeds used during the tests, were taken. The number of damaged seeds were compared with the manually collected samples in order to evaluate the effect of the metering unit on the seed quality (breaks). The number of completely broken seeds was determined and reported. A T-test was run to identify any effect of the planter metering unit on seed breakage.

CHAPTER VI

RESULTS AND DISCUSSIONS

SENSOR

The sensor design was constructed at the Agricultural Engineering laboratory of OSU. The detection of seed drops and distinction between a single seed drop and more than one seed drop was achieved during the calibration of the instrumentation. At low speeds and vacuum combinations (speed setting 5 and less, and up to -0.7 kPag) the sensor appeared to effectively distinguish double seed drops because they were rare and the seed drops were widely spaced.

Table I (APPENDIX B.1) shows one of the test results during the calibration of the instrumentation at vacuum level -0.7 kPag and speed setting 4 which correspond to 1.63 RPM. The total number of seeds dropped during the first replication was 73 single seeds and 1 double seeds (a total of 75 seeds). The second replication had 71 single seed and 2 double seed drops (a total of 75 seeds). The last replication had 73 single seed and no double seed drops (a total of 73 seeds). The average seed spacing of the three replication was 811.7 ms and the calculated spacing and number of seeds from the measured meter shaft speed (theoretical spacing and theoretical counts) were 818.5 ms and 72.67 seeds respectively. The manually collected samples counted 70, 72, and 76 seeds, respectively, from the three replications which gave an average seed spacing of 825.7 ms.

The instrumentation failed to distinguish between single and double seed drops when the speed setting was increased above level 5, because the seed sensor (piezoelectric) did not have enough time to damp out the transient signal from a single seed strike. This problem was not detected during the development stages of the sensor, because the metering unit was not available and calibration was performed by manually dropping the seeds. The manual dropping process was not fast enough to generate the problem. The simple corrections that I tried in order to solve this problem at later stages, did not remedy the problem (figure 11, appendix A.2.5). Therefore, the instrumentation threshold was calibrated to detect all seed drops as doubles to have a uniform recording device for all the combination tests (Sp-Pr). The assumption made at that time was that most seeds would not strike the sensor at intervals of less than 10 ms (hardware dead-time). Thus, the effective doubling, if it happened, would be detected as small time intervals (less than 50% of the average seed spacings).

Figure 12 showed some typical analog output signals from the seed detector sensor generated with the metering unit. In general, the generated wave forms showed a common pattern

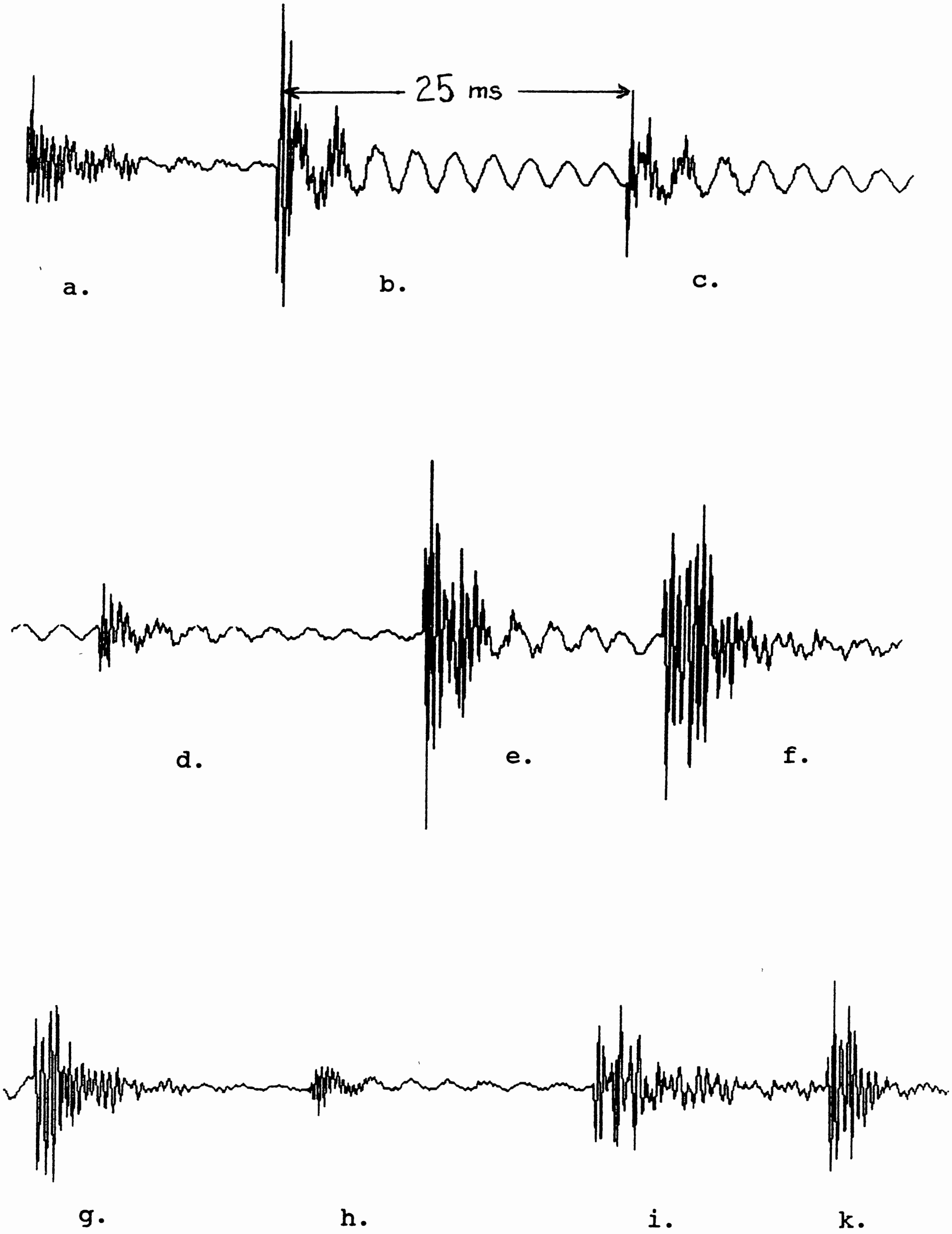


Figure 12. Typical Analog Output Signals From The Piezoelectric Sensor With John Deere Seed Meter Operating at Settings (-4.5 kPag, 25 Speed Setting)

of signal characterized by a high amplitude-frequency pulse(s) followed by some lower amplitude-frequency waves. The high frequency waves were the result of the seed-sensor shock. The low frequency waves were the results of the natural frequency of the system (sensor = piezoelectric element, electrode wires, frame, and tape).

Figure 12.(a, b, c, d, e, and h) could be results of single strikes even if the amplitudes and forms (number of peaks) were not similar.

Figure 12.(f, g, and i) could be results of double (or multiple) seed strikes because the amplitudes did not decay as fast as expected or remained constant for a relatively long time. Some of those wave shapes could also be generated with a single seed strike. Thus the seed could have struck the sensor on its vertical axis (head) and then rolled to produce a larger shock.

Figure 12.h was a signal in which the variation of the frequency was obvious but no amplitude variation was observable. This signal could have been generated either with a single seed strike or only a high frequency noise generated from a shock on the sensor stand.

Instrumentation

Accuracy

A first error, which we supposed could have a random effect on the instrumentation recorded data, was induced by the sensor inclination. The seed detector was mounted at an angle of 45° from the horizontal plane and the seeds were falling from a distance of 0.20 m (mean distance from delivery point in the seed meter to the sensor). Assuming a random seed distribution on the sensor the maximum error in height should be:

$$\frac{0.05 * \sin 45}{2} = 0.0175 \text{ m} \quad \text{(height of the inclined sensor)}$$

Consequently, the maximum error in time should be:

$$t_1 = \sqrt{\frac{2 * 0.2}{9.81}} = 0.202 \text{ s}$$

$$\Delta t = \pm 0.009 \text{ s}$$

$$t_2 = \sqrt{\frac{2 * 0.2175}{9.81}} = 0.211 \text{ s}$$

However, a better measure of error for the instrumentation is the average error which is the mean deviation from the centerline. This is the centroid for one half of a circle or 0.0106 m from the center. Then, the average absolute error is to be calculated as follows:

$$\text{Semi-circle centroid} = \frac{4 * r}{3 * \pi} = 0.0106 \text{ m}$$

$$de = 0.016 * \sin 45 = 0.0075 \text{ m} \quad \text{(height from the center to centroid)}$$

The time equation:

$$t = \frac{-v \pm \sqrt{v^2 + 2*g*d}}{g}$$

The velocity equation:

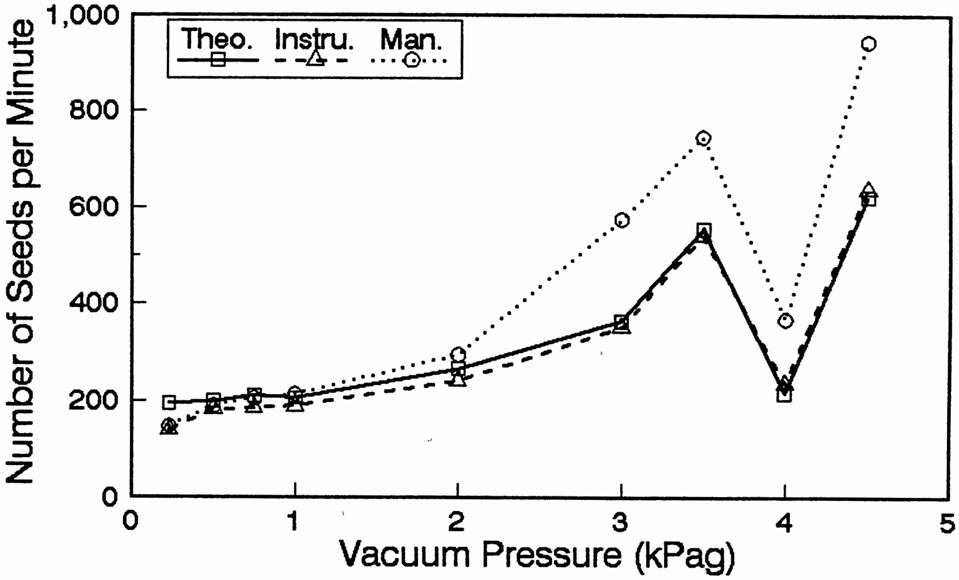
$$v = \sqrt{2*g*d}$$

Then,

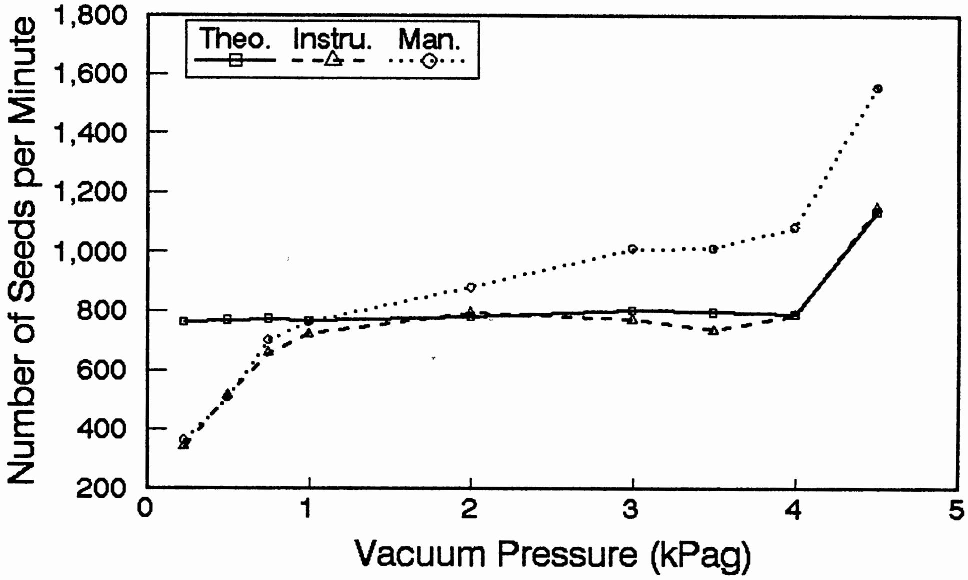
$$t = \frac{-1.98 \pm \sqrt{(1.98)^2 + 2\ (9.81*0.0075)}}{9.81}$$

Average error at 45° $\Delta t = \pm 0.0038$ s

Figure 13.(a, b, c, d, and e) showed that the instrument always under-estimated seed counts compared with the manually collected samples. This problem (under-counting)

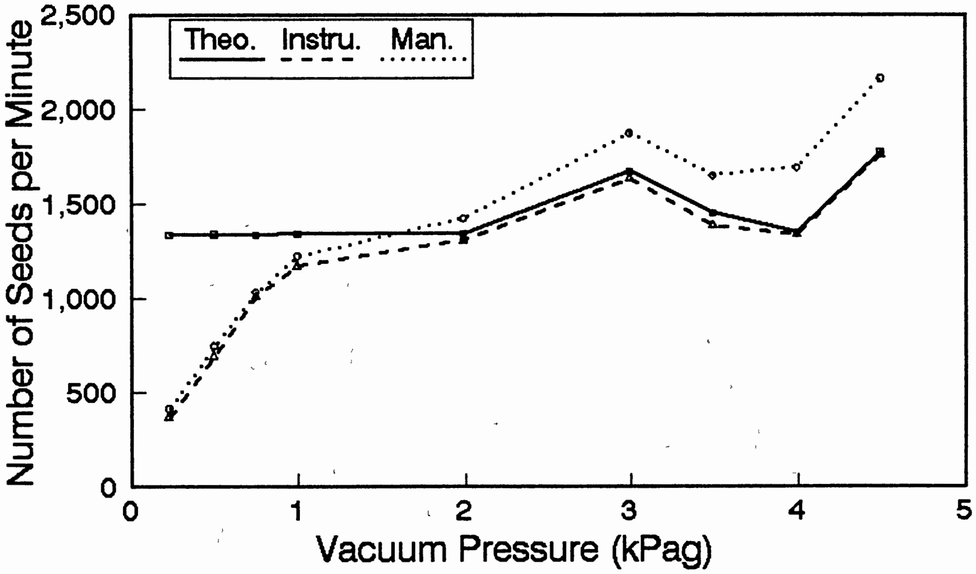


a. At Speed Setting 5

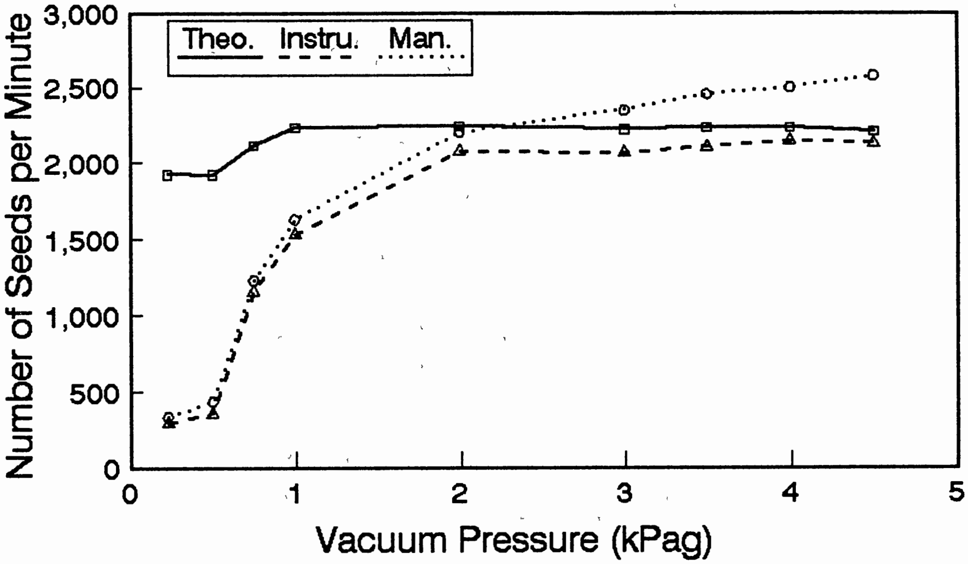


b. At Speed Setting 10

Figure 13. Effect of Vacuum Pressure on Seed Delivery of a John Deere Max Emerge 2 Vacuum Metering Unit



c. At Speed Setting 15



d. At Speed Setting 20

Figure 13. Effect of Vacuum Pressure on Seed Delivery of a John Deere Max Emerge 2 Vacuum Metering Unit

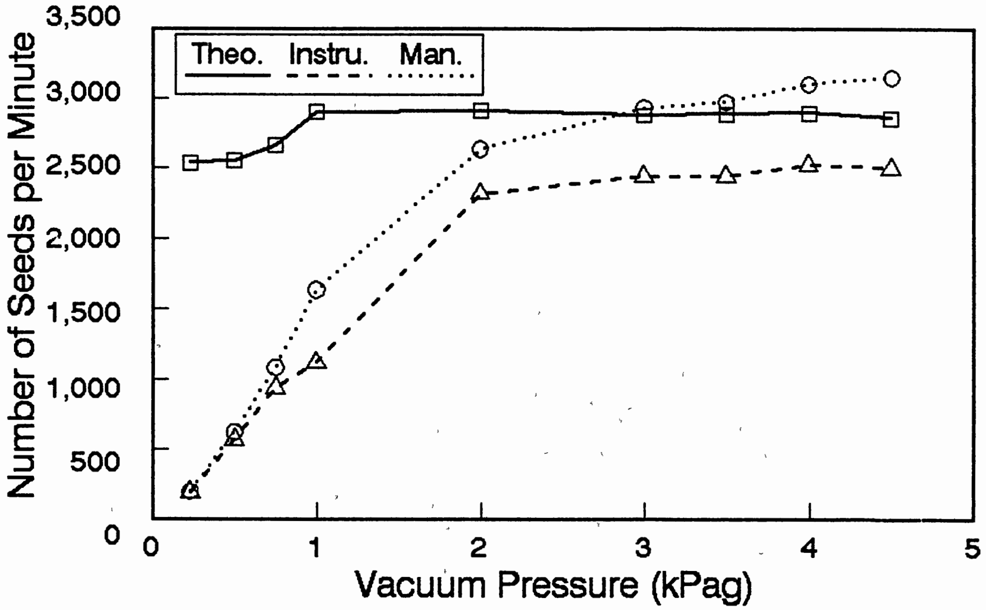
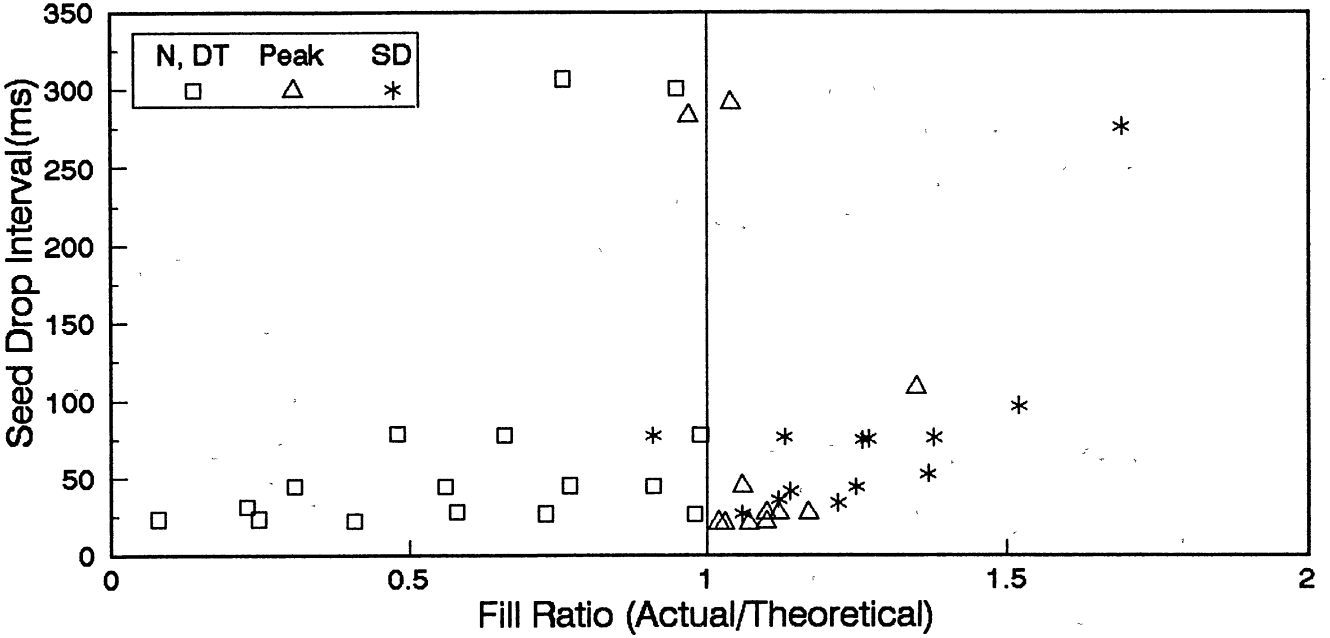


Figure 13. Effect of Vacuum Pressure on Seed Delivery of a John Deere Max Emerge 2 Vacuum Metering Unit e. At Speed Setting 25

was intensified as the vacuum pressure increased over all the speed settings and became more serious at higher speed settings, reaching the point where the instrumentation was grossly under-estimating compared to the theoretical seed counts (as if skips were occurring). However, some statistical parameters (N: number of seed dropped, DT: average seed time spacings, peak: highest recorded frequency of the time interval between seeds, and MD: fiftieth recorded value) were investigated in order to see if they could be used to predict either the counts or average spacing of the manually collected samples.

Table V (APPENDIX B.1.4) showed the results of the distribution indicators selected from the SAS (univariate and frequency) analysis in order to explain the seed variation pattern. The null hypothesis tested, was "H_o: instrumentation recorded indicators are significantly different from manually collected sample spacing indicators". Two regions were identified in Table V from SAS analysis of variance results. A first region where different distribution indicators could be used (either N, DT, Peak, or MD) to predict seed pattern and a second region were where all the indicators were significantly different from the manually collected samples.

Figure 14 showed a summary of the results from Table V and allowed us to distinguish the two zones. The parameters chosen for this figure were the fill ratio (actual/Theoretical) and the expected (theoretical) time interval between seeds. The two regions were clearly separated at the fill ratio one. When the average fill ratio was less than one, the instrumentation was capable of predicting the time intervals (spacings) and the number of dropped seeds. But, when the average fill ratio was higher than one, the instrumentation was not capable of predicting the time intervals nor the number of dropped seeds. However, the peak (most recorded time spacing value from the instrumentation), at small time intervals and when the fill ratio was close but greater than one (and less than 1.2 in general), was some times a good distribution pattern indicator. However, in this region (fill ratio higher than 1), the instrumentation was in general not capable of



* N, DT: number of seeds and time interval between seeds
Peak: most recorded time interval from instrumentation
SD: instrum. significantly different from Man

Figure 14. Operating Conditions Where The Sensor Performance is Within 95%

accurately predicting the time spacing between seeds. This was because the seeds were falling in mass and at a high rate (3 to 5 seeds per cell) (figure 15).

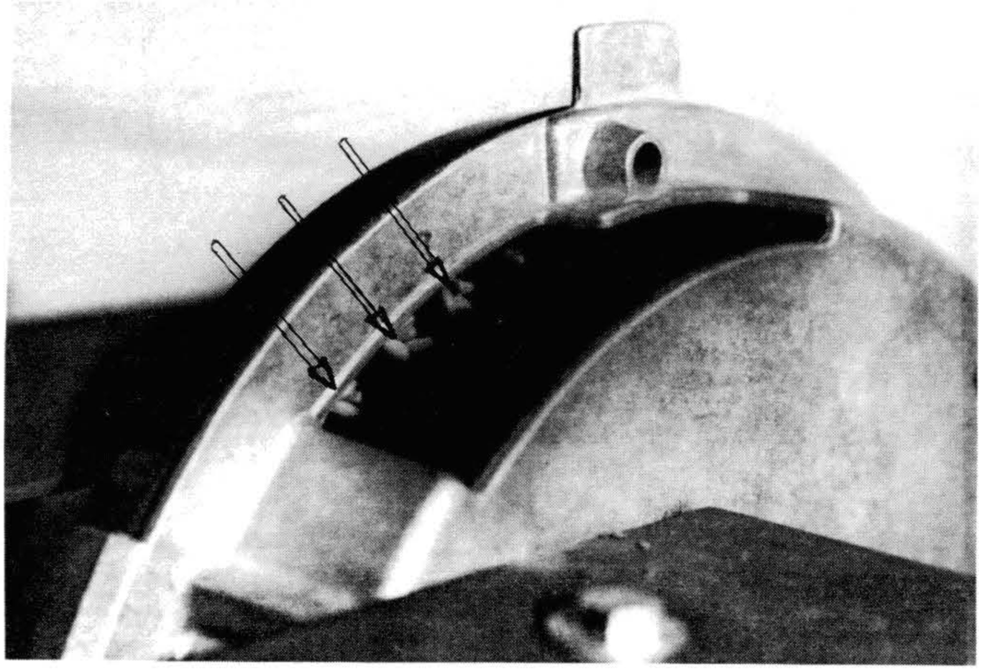


Figure 15. Clustering of Wheat Seeds Around The Seed Cells of a John Deere Max Emerge 2 Vacuum Metering Unit

Temperature

The results from the temperature tests were summarized in Table VI (APPENDIX B.1.1). The SAS regression analysis showed that the model (p>F=0.05) did not significantly explain the variability. Parameter estimates showed that the intercept was significantly different from zero and that the slope was not significantly different from zero. Figure

16 showed that the regression line was horizontal which explained the low correlation coefficient (R^2=0.0001) and also why the linear model was not significant. Therefore, there was no significant effect of temperature on the time spacings (DT) and, consequently, on the sensor within the tested range.

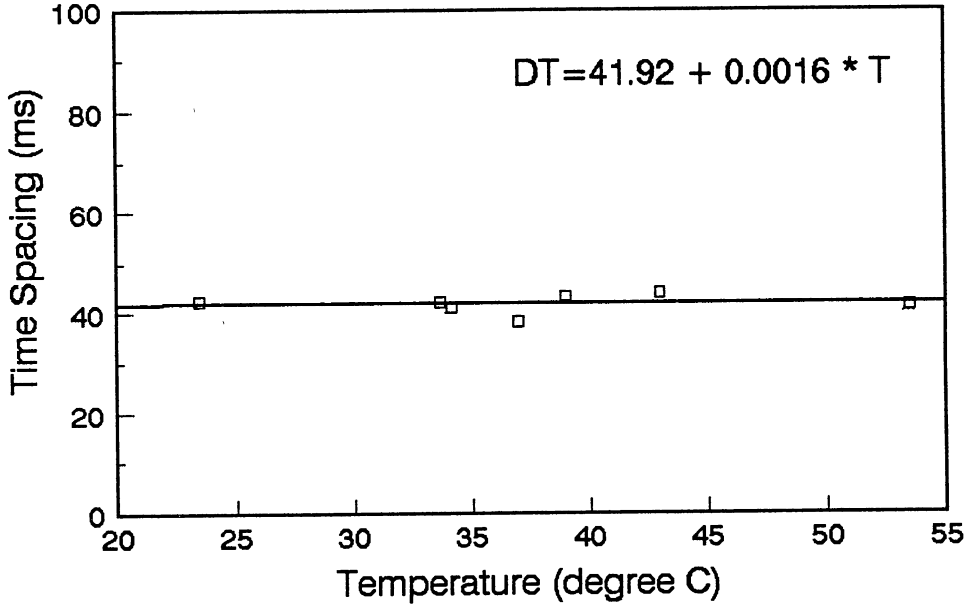


Figure 16. Regression of Temperature Effect on The Piezoelectric Sensor Response

Vibration

Figure 17.(a and b) showed results from the three replications of the vibration test for each mounting method. A spectrum of false pulses was plotted on a semi-logarithmic graph. The curves showed that for both mounting methods (cantilever and bridge) the false signals appeared at lower

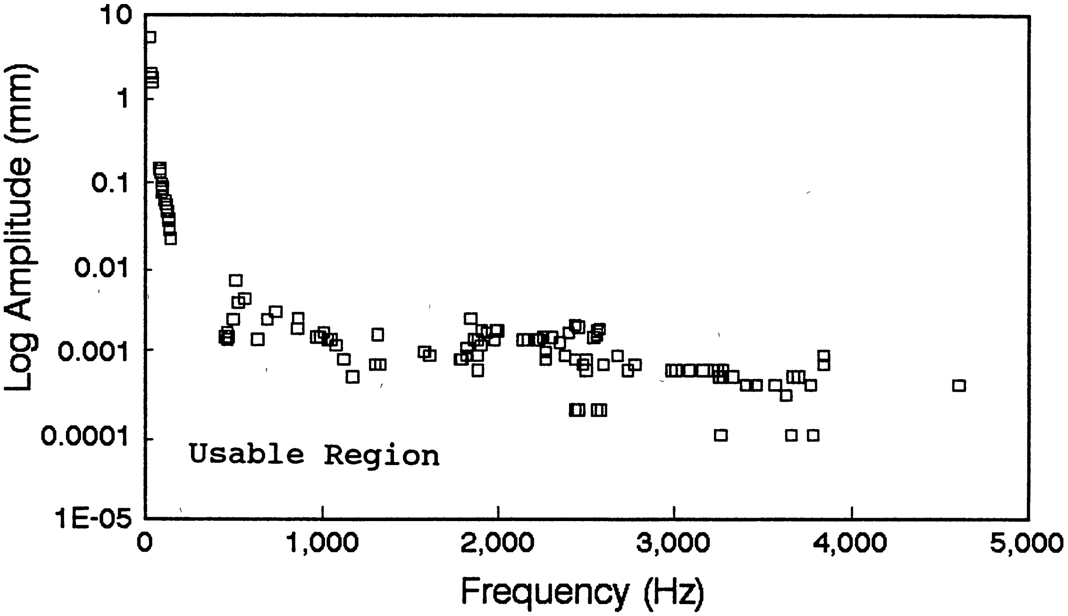
amplitudes as the frequency increased. The threshold of the detected false signals was the same as the threshold for seed detection.

The usable region for the piezoelectric seed detector sensor was below the curves. This test showed also that the cantilever mounting was less sensitive to the amplitude effect than the bridge mounting (for the same frequency the amplitude for the cantilever was higher than the bridge mounting). This could be explained by the fact that the bridge mounting was less flexible and the transmittance ratio was higher for bridge than cantilever mounting.

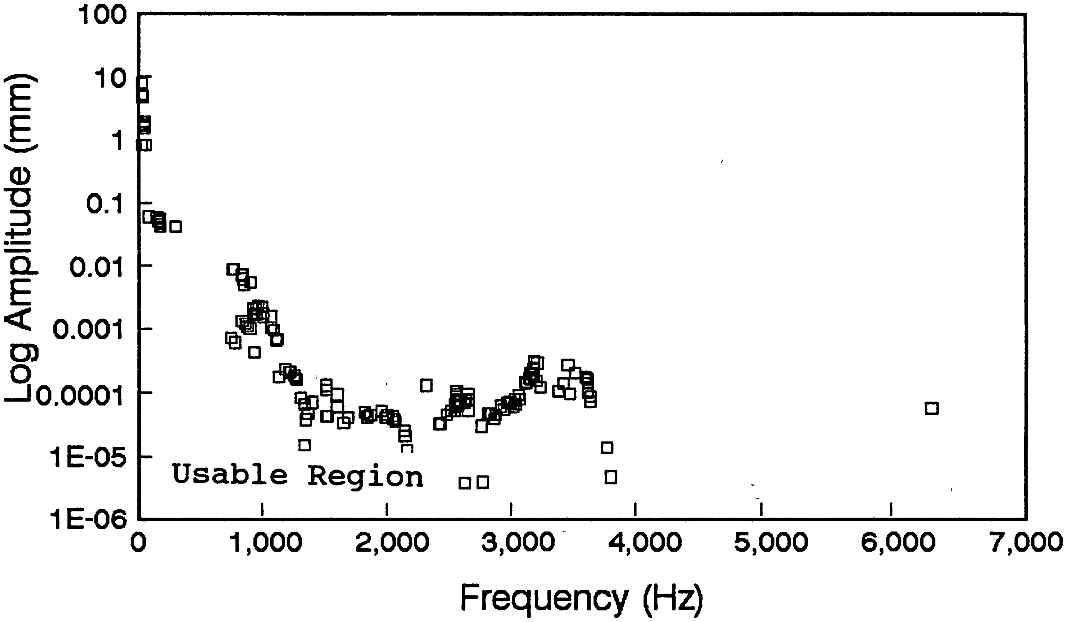
Planter Metering Unit

Results of the planter metering unit tests were based on the instrumentation recorded data, the manually collected samples and also some visual observations (using a stroboscope) during the test runs.

Figure 18 showed that the increasing vacuum pressure influenced (increased) the driving shaft speed of the metering unit. Table VII below the graph showed the regression parameters and the correlation coefficient at every speed setting. The speed variation was greater at lower (5 and 10) than higher speed settings. This phenomenon (speed variation) is the result of the vacuum pressure pulling the vertical seed distribution plate away from the housing of the metering unit and thus reducing the plate friction. Figure 19 showed how the vacuum pressure



a. Cantilever Mounting



b. Bridge Mounting

Figure 17. Spectrum of False Signals Detection of The Piezoelectric Seed Sensor

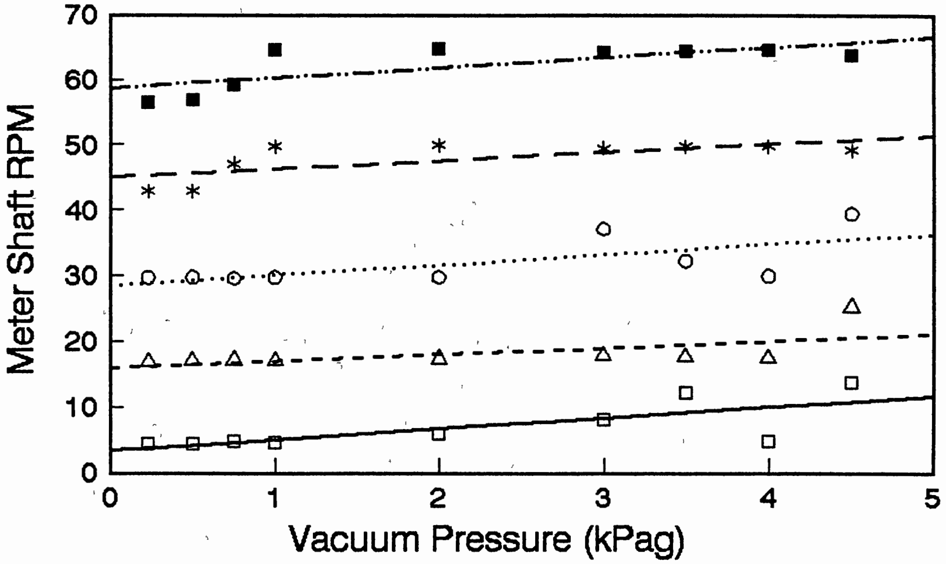


Figure 18. Effect of Vacuum Pressure on The Driving Shaft Speed of a John Deere Max Emerge 2 Metering Unit

TABLE VII

REGRESSION EQUATIONS RELATING VACUUM PRESSURE TO METER SHAFT SPEED AT 5 VARIATOR SPEED SETTINGS

Speed Setting	b	a	R^2
5	1.67	3.38	0.56
10	1.01	16.06	0.38
15	1.55	28.63	0.46
20	1.26	45.12	0.49
25	1.55	58.76	0.52

affected the theoretical seed spacing. The effect of the vacuum pressure was highly significant at the lowest speed setting 5 and was not significant at high speed settings. Figure 13.a showed that the planter meter behaved erratically at the low speed setting. The speed variation within this range was not uniform. At the vacuum level -4 kPag, the measured RPM (4.82) was lower than the predicted (10.06) (figure 18 and Table VII). This could be attributed to a grabbing phenomenon (and/or resonance) that was observed during the test runs. The manually collected sample seed-count was higher than the predicted (theo.) at higher vacuum level settings (above -1.00 kPag). The high seed-count was caused by more than one seed clustered in a seed-cell (figure 15). These clumps of seeds were probably caused by the shape of the seed-cells which was not originally designed for wheat seeds. The spherical shape of sugarbeet seeds closely conformed to the conic shaped seed cell of the distribution plate, but the oblong (elliptical) shape of cereal seeds did not effectively fit in the cell.

Figure 13.b showed that theoretical seed count (RPM*45) was not affected by vacuum until very high levels (over -4.0 kPag). The calculated number of dropped seeds (Theo.) showed that the seed spacing (count/time) was stable until the effect of the vacuum level (-4.50 kPag) started to be significant. At low vacuum levels (-0.23 to -1.00 kPag) the planter delivered fewer seeds (both manual and instrumentation counts) than predicted (Theo.). This was

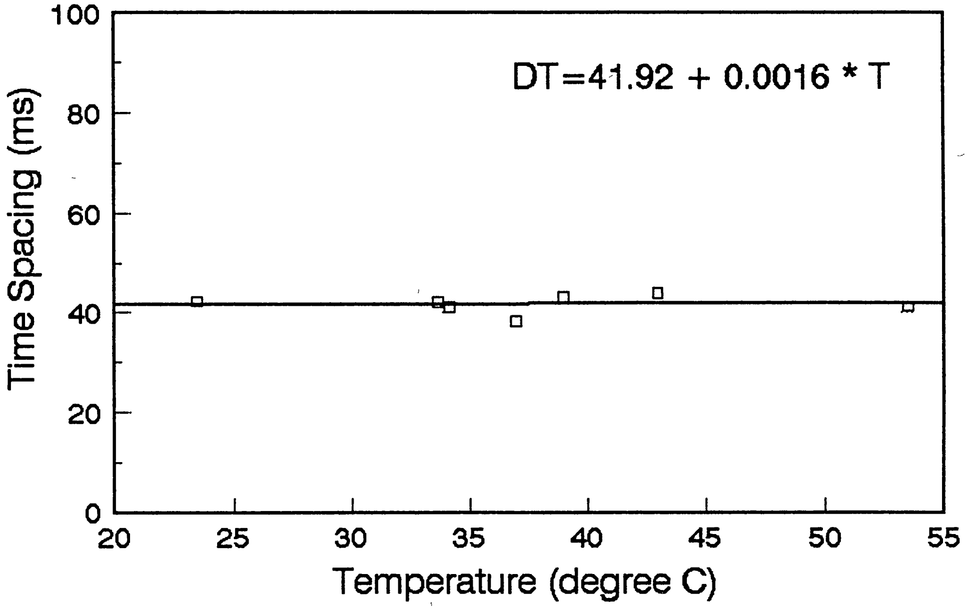


Figure 19. Effect of Vacuum Pressure on Theoretical Seed Spacing {(Spacing Calculated From Measured Meter Shaft Speed) of a John Deere Max Emerge 2 Vacuum Metering Unit}

TABLE VIII

REGRESSION EQUATIONS RELATING VACUUM PRESSURE TO THEORETICAL SPACING (SPACING CALCULATED FROM METER SHAFT SPEED)

Speed Setting	b	a	R^2
5	-40.30	315.35	0.61
10	-3.26	81.16	0.43
15	-1.82	46.10	0.47
20	-0.79	29.67	0.49
25	-0.56	22.75	0.53

caused by distribution skips (cells not filled) at low vacuum levels. At higher vacuum levels (over -1.00 kPag) the manual sample counts showed that the metering unit was over delivering seeds (giving doubles, triples and more). The vacuum effect at -4.5 kPag was a highly significant factor affecting the seed distribution (more seeds were dropped).

Figures 13. c, d, and e also showed that theoretical seed distribution was not affected by the vacuum. The calculated number of dropped seeds was uniform and constant at all the tested vacuum levels. However, the distribution skips were observed at higher vacuum levels (-1.5, -2.0, and-2.75 kPag respectively) through the test runs at different speed settings. In this region, the multiple seed drops occurred in fewer numbers. This could be due to the fact that the high speed was not allowing any more seeds to clump round the distribution cells.

Table XI (APPENDIX B, p:83) showed the CV's results from the instrumentation recorded data. Those CV's were calculated based on the standard deviations and average time spacings from the test replications. The over all results showed that the CV's consistently increased with increasing speed setting. At low vacuum levels (-0.23 to -1.00 kPag), the variation of the CV's was linear and highly significant. At higher vacuum pressure levels (-1.00 to -4.00 kPag), the CV's tended to have a quadratic (parabola) fit curves with the speed setting 15 as the minimum (vertex). At -4.50 kPag vacuum, the CV's were not consistent in their variations. This was due to the poor performances of the instrumentation (seed detector sensor), the metering unit which was not effectively singulating seeds, and the high vacuum pressure which pulled the disk away from the housing allowing seeds to leak out.

The seed damage results showed that there were no significant difference between the percentages of damaged seeds from the manually collected samples and the random seed samples taken from the unmetered seeds during our tests. The average percentages of damaged seeds from the manually collected samples and the random samples were 0.43 and 0.46 respectively. Therefore, no significant seed damage was caused by the tested seed metering unit.

CHAPTER VII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

A piezoelectric seed sensor was designed at the agricultural engineering laboratory of OSU. This sensor was designed to distinguish between single seed and double seed drops on the basis of signal amplitude. Results showed that the sensor detected all seeds at low seeding rates (less than 100 seeds per minute) and when there was little or no doubling but failed to do so at higher seeding rates.

A frequency analysis was run, on the instrumentation recorded data, in order to define where the sensor failed to work. The statistical parameters (N, DT, Peak, and MD) defined from this analysis were chosen as potential indicators of the seed distribution pattern of the planter metering unit. T-tests were performed comparing these indicators with those determined from manual sampling to determine if they could be used to accurately predict average seed spacings.

Tests were run to define temperature and vibration limitations on this sensor. Results showed that no temperature effect was registered within the tested range (23 to 54 °C). The vibration tests defined the ranges where the sensor should be used under two different mounting methods tested (cantilever and bridge).

A John Deere Max Emerge 2 vacuum metering unit was evaluated for its ability to singulate wheat seeds and also to test the performances of the instrumentation. Test results showed that the metering unit did not effectively singulate wheat seeds. At low vacuum levels (-0.23 and -0.50 kPag), the metering unit produced skips. However, at medium and high vacuum levels the meter dropped doubles, triples, and quadruples, and on occasion up to six seeds were observed in seed cells.

Conclusions

A piezoelectric sensor, with capability of detecting seed doubles, was designed and constructed in order to measure seed spacing at a seed meter outlet. Sensor performance was evaluated and the sensor was used to measure the ability of the John Deere Max Emerge 2 to precisely meter wheat seeds. Based on a series of experiments the following conclusions were made:

Sensor Performance

1. The sensor design was only a partial success. This, because the seed detector did effectively detect multiple seed drops.
2. The sensor did effectively measure the seed spacing.
    a. Provided the time interval between seeds was much

greater than 10 ms. The statistical analysis of the recorded data showed that distribution indicators divided the tested range into two regions.

b. The temperature did not affect the performance of the piezoelectric sensor within the tested range.

c. The region in which the sensor was immune to external vibration was defined and two different mounting methods. Those regions gave a good working range for our sensor.

John Deere Max Emerge 2 Seed Meter Performance

3. The performance of the Max Emerge 2 John Deere metering unit, for wheat seed singulation, was not satisfactory. This was principally due to seed cell shape which was not designed for cereal seeds. Thus, the intrarow spacing was not as good as expected. The CV's were as high as the ones from the conventional seed drills. However, no seed damage was observed.

Recommendations

A study of the analog output signal of the piezoelectric sensor should be realized more carefully using a metering unit for seed dropping. Based on the results of this study, the electronic interface circuit should be redesigned. A shorter dead-time (around 1 ms) is imperative for the success of seed counter instrumentation.

Digital signal processing may be a solution to study the capabilities of this piezoelectric sensor. The analog output signals showed that the use of this method was promising. The problem of the error in measuring time interval arising from the inclination of the sensor can be minimized by reducing the angle of inclination, and repositioning the sensor. Vibration sources which adversely affect the response of the sensor should be identified and eliminated. However, if the piezoelectric sensor is not able to detect more than two seeds striking at the same time, a different kind of sensor should be used.

The John Deere Max Emerge 2 vacuum metering unit should be redesigned for wheat precision seeding. The vacuum significantly affected the wheat seed distribution.

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APPENDIXES

APPENDIX A

LIST OF EQUIPMENT USED IN RESEARCH AND ILLUSTRATIVE FIGURES

TABLE IX

LIST OF EQUIPMENT USED IN THIS RESEARCH

Brand	**Make**	**Description**	**Model Nº**	**Serial Nº**
Planter				
John Deer	Max Emerge 2 integral planters	For sugarbeets (Monegerm) recommended for small and medium size seeds.	H 136445	
Driving Unit				
Doerr	Electric corporation	A.C motor Type K 1/8 Hp 1725 RPM	M 164E793	A833
Graham	Transmissions Inc.	Conic variator	20EMW20	78649
Vacuum				
Pullman		Ball bearing motor	JB 252	8389
Speedometer				
Sunx sensor system		Hall effect sensor	GX-12M	OGH U
Piezoelectric sensor				
NTK	Technical ceramics	Ceramic Buzzer	EC-R250H^2-50BA	
Seed counter				
The Old Mill Company		Electronic seed counter	850-2	47

TABLE IX (Continued)

Brand	Make	Description	Model Nº	Serial Nº
TEMPERATURE TEST				
Type T Thermocouple		Copper - constantan		
Digi-sense	Thermosense	Thermocouple reader	8528-20	639970
Alpha		Air heat gun	HG-2	581
VIBRATION TEST				
Kistler Instrument Corporation	Accelerometer	Quartz accelerometer	8002	C9514
Oscillator (Shaker)				
Ling dynamic systems	LDS	Power amplifier	PA100	489
Ling dynamic systems	LDS	Shaker	V408	245
Charge Amplifier				
Kistler Instrument Corporation	Kistler	Dual mode amplifier	5004	185413

TABLE IX (Continued)

Brand	Make	Description	Model Nº	Serial Nº
Oscilloscope				
Nicolet Instrument Corporation		Digital oscilloscope	2090	813552
ELECTRONIC PARTS				
OPAMPs	Motorola	Semiconductor	LM 318	
	Motorola	Semiconductor	MC3401	
TTL NorGate	Motorola	Semiconductor	74LS04	
DUAL TIMER	Signetics	Semiconductor	556	
Potentiometers		0 to 50 kOhms		
Capacitors				
Resistors				

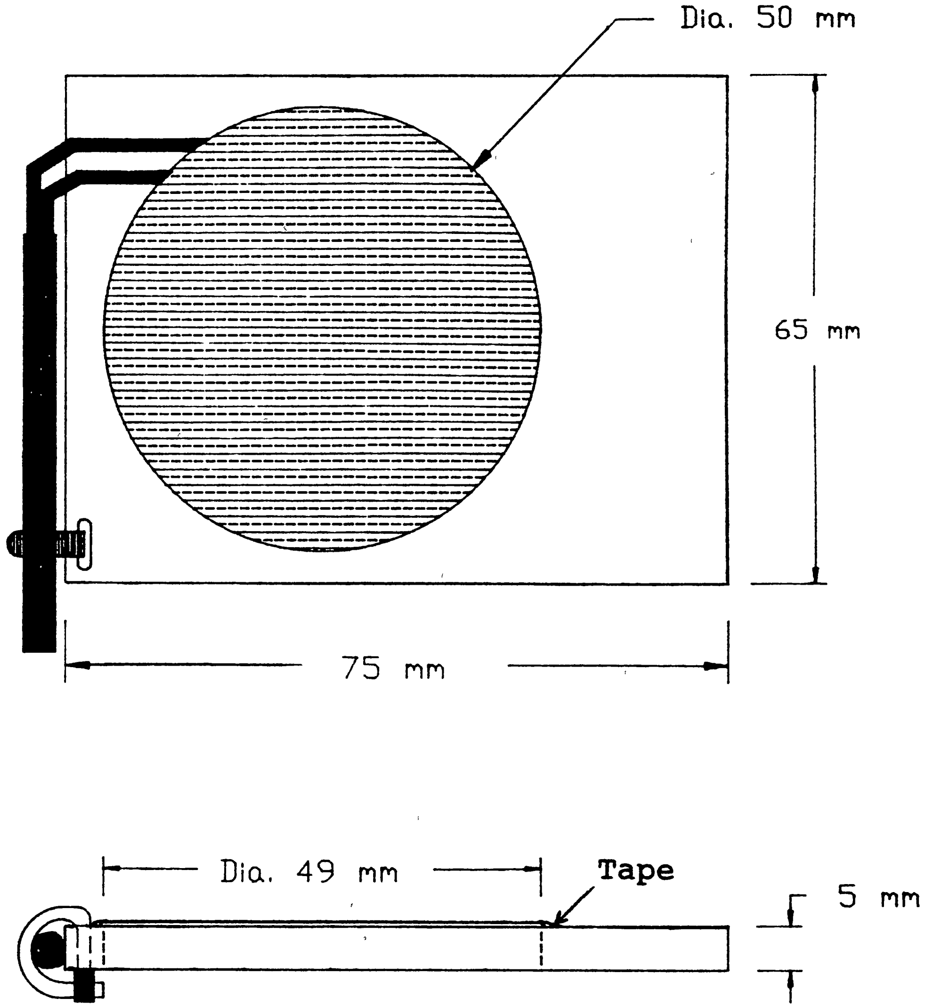

Figure 1. Seed Sensor Support Frame

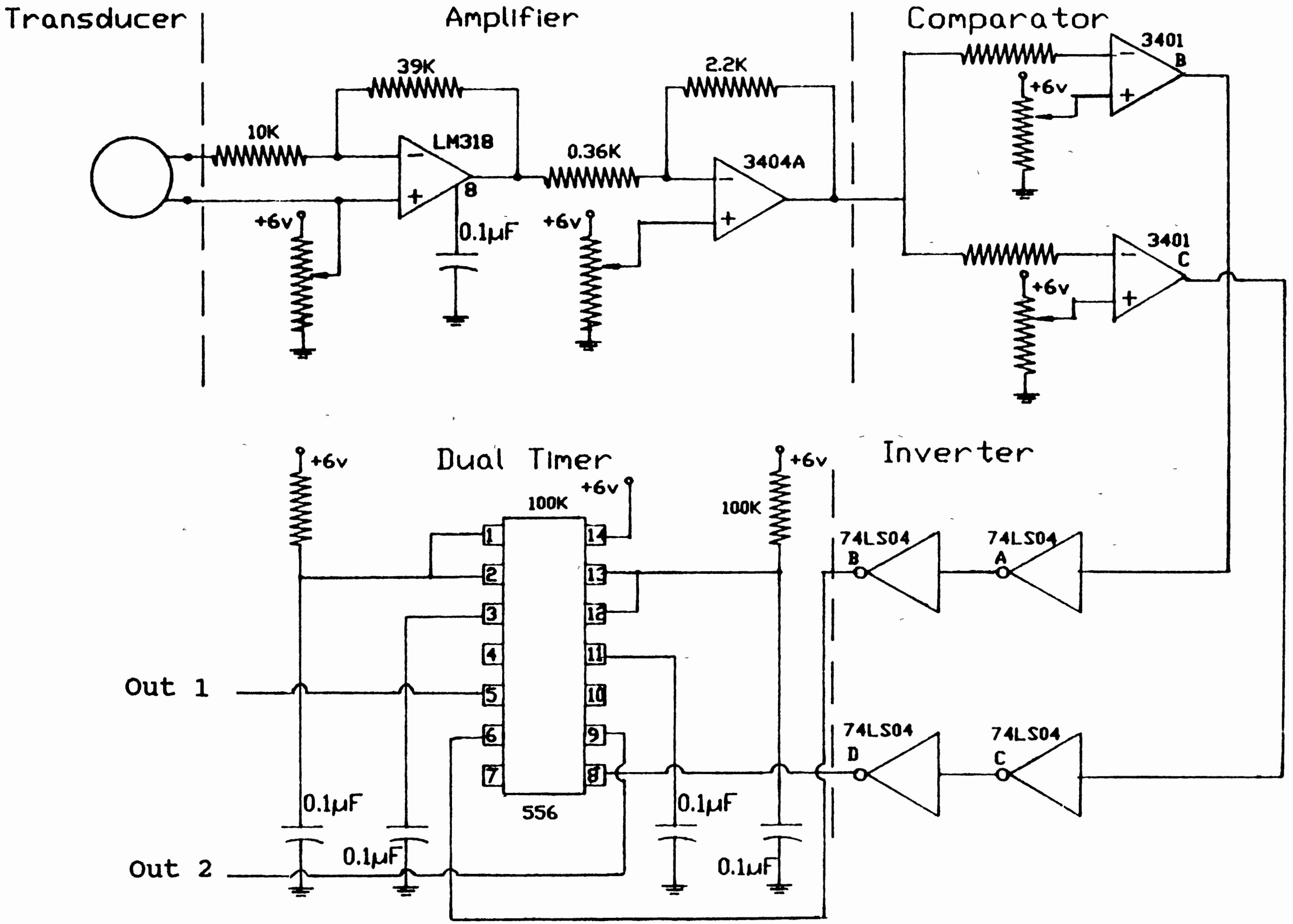

Figure 2. Electronic Interface Circuit Diagram

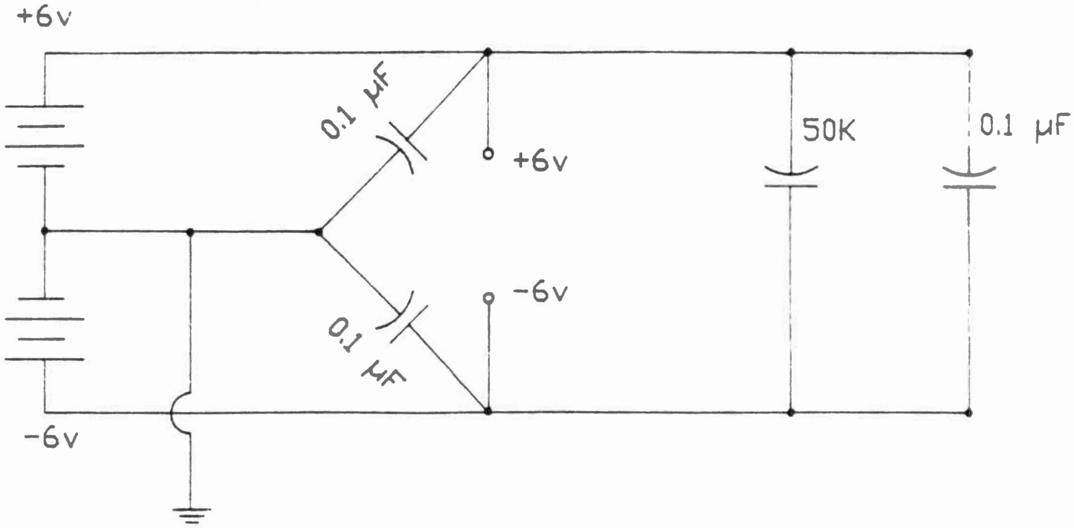

Figure 3. Power Circuit Diagram

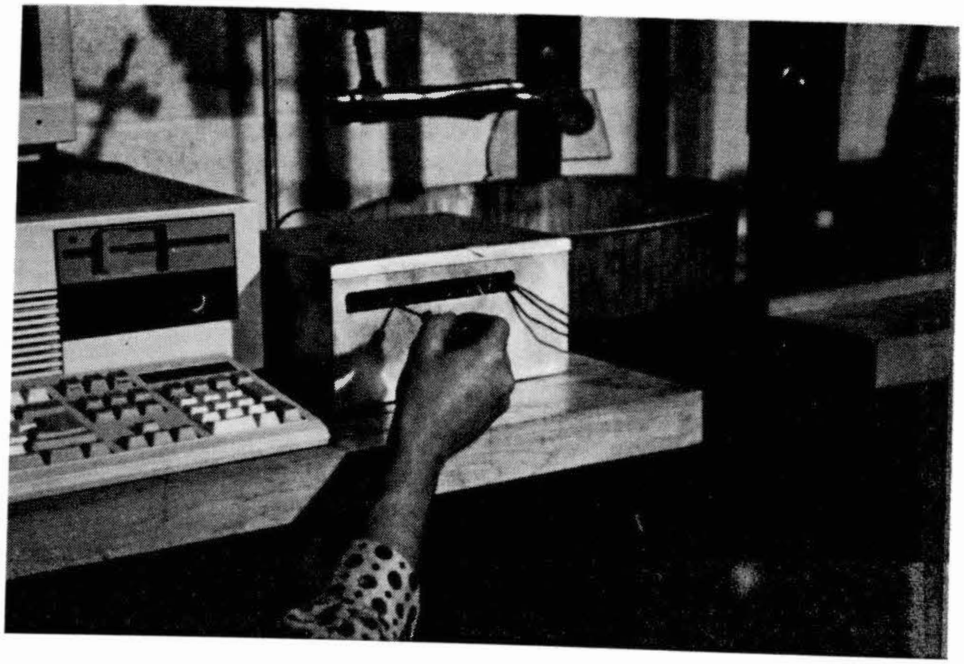

Figure 4. Metallic Sensor Box (Adjustment of The Threshold by The Potentiometers)

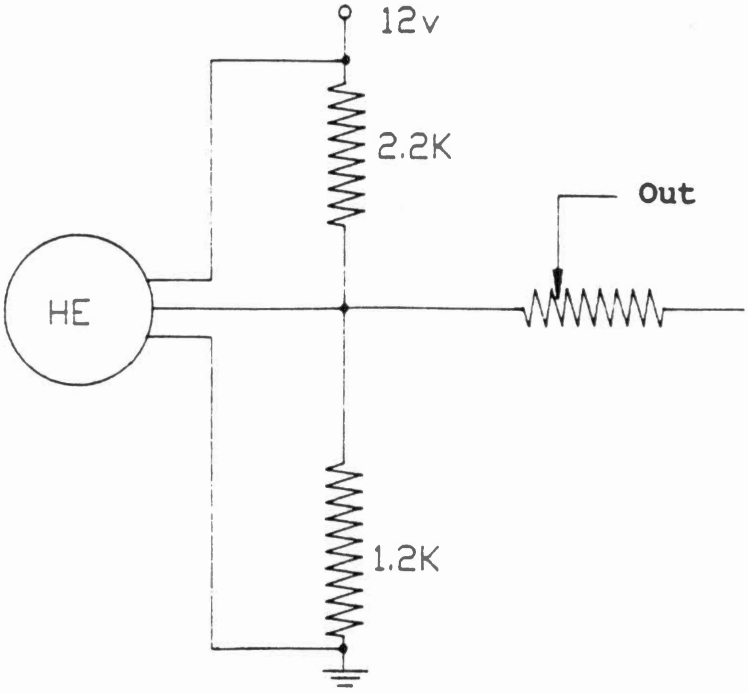

Figure 5. RPM Hall Effect Sensor Interface Circuit Diagram

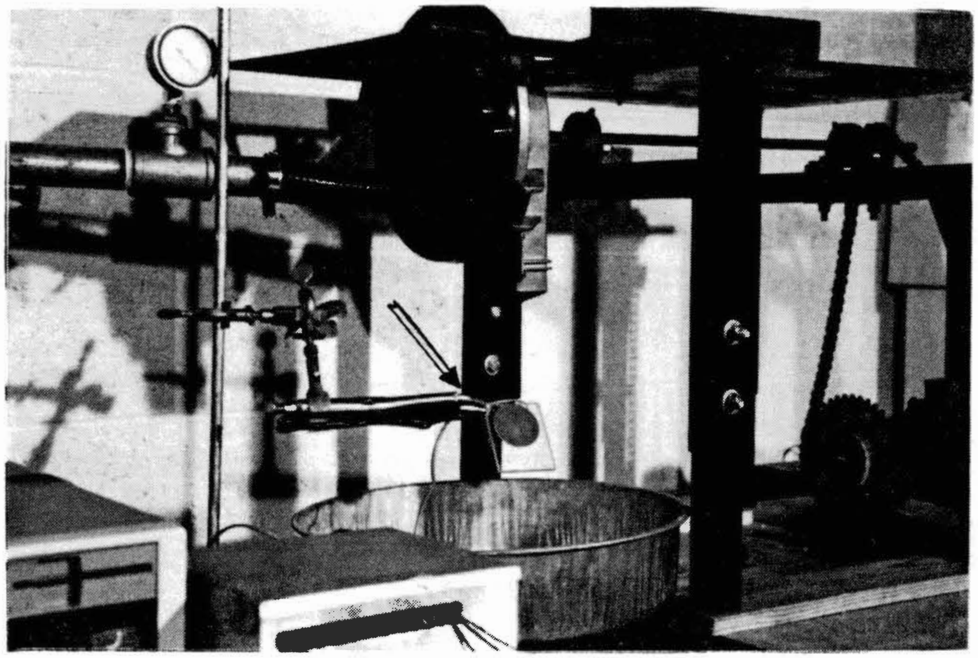

Figure 8. Mounting Method of The Seed Detector

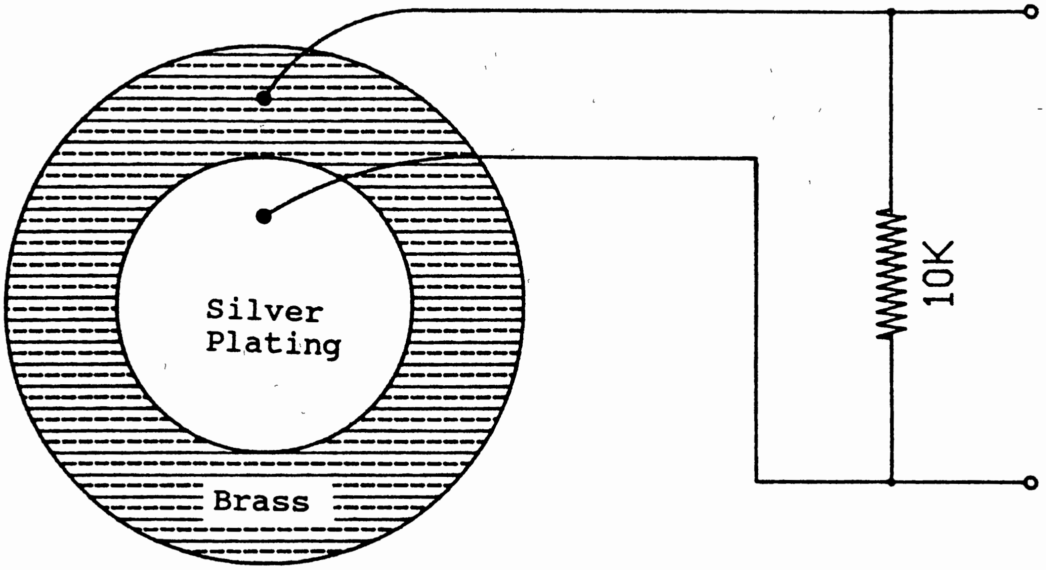

Figure 11. Charge Damper Circuit Diagram For The Piezoelectric Seed Detector

APPENDIX B

TABLES OF RESULTS

TABLE IV

TEST RESULTS FROM THE INSTRUMENTATION RECORDED DATA DURING CALIBRATION AT VACUUM PRESSURE LEVEL -0.7 kPag AND SPEED SETTING 4

Chan.	S.C.	DT (ms)	Chan.	S.C.	DT (ms)	Chan.	S.C.	DT (ms)
5	1	943	5	1	805	5	1	846
5	1	916	5	1	809	5	1	1
5	1	785	5	1	782	5	1	780
5	1	821	5	1	5	5	1	749
5	1	773	5	1	877	5	1	735
5	1	791	5	1	847	5	1	582
5	1	777	5	1	853	5	1	249
5	1	843	5	1	894	5	1	864
5	1	831	5	1	911	5	1	826
5	1	739	5	1	787	5	1	869
5	1	1	5	1	802	5	1	903
5	1	756	5	1	808	5	1	836
5	1	765	5	1	809	5	1	779
5	1	919	5	1	799	5	1	833
5	1	794	5	1	300	5	1	875
5	1	859	5	1	545	5	1	769
5	1	1	5	1	688	5	1	816
5	1	918	5	1	800	5	1	1
5	1	857	5	0	725	5	1	889
5	1	769	5	1	781	5	1	850
5	1	826	5	1	825	5	1	839
5	1	856	5	1	854	5	1	738
5	1	828	5	1	844	5	1	868
5	1	835	5	1	891	5	1	789
5	1	898	5	1	883	5	1	750
5	1	876	5	1	789	5	1	844
5	1	799	5	1	777	5	1	810
5	1	786	5	1	864	5	1	780
5	1	902	5	1	829	5	1	771
5	1	863	5	1	841	5	1	833
5	1	820	5	1	768	5	1	843
5	1	847	5	1	900	5	1	796
5	1	6	5	1	822	5	1	804
5	1	885	5	1	789	5	1	941
5	1	800	5	1	791	5	1	800

TABLE IV (Continued)

Chan.	S.C.	DT (ms)	Chan.	S.C.	DT (ms)	Chan.	S.C.	DT (ms)
5	1	744	5	1	841	5	1	807
5	1	838	5	1	844	5	1	798
5	1	856	5	1	836	5	1	851
5	1	843	5	0	1570	5	1	823
5	1	812	5	1	806	5	1	827
5	1	902	5	1	740	5	1	891
5	1	904	5	1	799	5	1	920
5	1	798	5	1	875	5	1	841
5	1	825	5	1	824	5	1	801
5	1	958	5	1	821	5	1	851
5	1	910	5	1	848	5	1	776
5	1	830	5	1	787	5	1	821
5	1	943	5	1	766	5	1	781
5	1	904	5	1	790	5	1	854
5	1	881	5	1	864	5	1	810
5	1	806	5	1	861	5	1	764
5	1	883	5	1	809	5	1	803
5	1	844	5	1	864	5	1	815
5	1	796	5	1	877	5	1	818
5	1	784	5	1	802	5	1	833
5	1	821	5	1	775	5	1	940
5	1	786	5	1	812	5	1	877
5	1	742	5	1	839	5	1	807
5	1	1	5	1	734	5	1	799
5	1	742	5	1	771	5	1	836
5	1	803	5	1	745	5	1	830
5	1	829	5	1	746	5	1	802
5	1	832	5	1	759	5	1	1797
5	1	806	5	1	734	5	1	938
5	1	909	5	1	834	5	1	807
5	1	814	5	1	1698	5	1	906
5	1	767	5	1	791	5	1	831
5	0	1654	5	1	792	5	1	866
5	1	819	5	1	837	5	1	830
5	1	745	5	1	741	5	1	877
5	1	912	5	1	826	5	1	783
5	1	779	5	1	807	5	1	824
5	1	766	5	1	189	5	1	459
5	1	754						

* The first column represents the reading channel of the instrumentation (channel 5). The number 1 in the second

column labeled Seed drops Code (S.C.) correspond to a single seed strike and the number 0 correspond to more than one seed strike (double or more). The third column correspond to the time spacing between seeds in milliseconds (DT).

TABLE V

SEED DISTRIBUTION INDICATORS FROM SAS (ANOVA) ANALYSIS AT 5% SIGNIFICANCE LEVEL FOR THE TEST HYPOTHESIS "H_o: INSTRU. = MAN"

Actual[1] / Theo	Time Interval (ms)	Indicators[2]				
		N	DT	MD	Peak	SD
0.76	306.85	*[3]	**[4]			
0.95	300.38	*	**			
0.48	78.57	*	**	*		
0.66	77.87	**	*			
0.31	44.86	*	**	*		
0.56	44.78	*	**			
0.77	44.94	*	**			
0.73	26.81	*	**			
0.58	28.31		*			
0.23	31.10	*	**	*		
0.08	23.57	*	**		*	
0.25	23.45	*	**			
0.41	22.46	*	**			
0.91	44.70		**	*	*	
0.98	26.69		*	**		
1.11	224.68	*	*	**		
0.99	77.97		*	**		
1.58	165.07			*		
0.56	20.62			*		
1.35	108.35			*	**	
0.97	283.43			**	*	
1.06	44.65			*	**	
1.10	26.10			*	**	
1.12	26.79				*	
1.17	27.13				*	
0.91	20.56			*	**	
1.02	20.78				*	
1.03	20.73			*	**	
1.07	20.67				*	
1.10	20.91				*	
1.52	96.69					-
1.13	76.52					-
1.26	74.52					-
1.27	75.28					-
1.38	76.01					-
1.37	52.73					-

TABLE V (Continued)

Actual / Theo	Time Interval (ms)	Indicators				
		N	DT	MD	Peak	SD
1.12	35.90					-
1.14	41.29					-
1.25	44.43					-
1.22	33.78					-
0.18	31.08					-
1.06	26.96					-
0.91	77.49					-

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[1]. Fill ratio
[2]. N: number of seeds dropped
DT: Seed drop intervals
MD: Median value of instru. recorded data
Peak: Most recorded value of instru.
NS: Instru. significantly different from Man
[3]. *: Instru. not significantly different from Man at 5% significance level
[4]. **: Best indicator
SD: Instru. significantly different from Man

TABLE VI

TEMPERATURE TESTS RESULTS

Temperature (°C)	Spacings (DT) (ms)	STD
23.5	42.52	23.10
33.7	42.39	22.96
34.2	41.35	21.42
37.0	38.45	23.46
39.0	43.48	24.40
43.0	44.19	25.05
53.5	41.46	21.51

TABLE X

a. TEST RESULTS BASED ON INSTRUMENTATION RECORDED DATA AND MANUALLY COLLECTED SAMPLES OVER ALL THE VACUUM PRESSURE LEVELS AND SPEED SETTING 5

Vacuum Pressure (kPag)	Method	Indicator	Replication I	II	III	Average
0.23	Instru.	N	143.0	143.0	133.0	139.7
		DT	414.9	415.7	447.9	426.2
		Peak	317.0	303.0	327.0	315.7
		MD	314.0	311.0	322.0	315.7
	Man.	N	162.0	138.0	144.0	148.0
		DT	370.4	434.8	416.7	407.3
0.50	Instru.	N	183.0	186.0	182.0	183.7
		DT	326.3	320.0	325.3	323.9
		Peak	295.0	303.0	299.0	299.0
		MD	302.0	301.0	303.0	302.0
	Man.	N	194.0	186.0	188.0	189.3
		DT	319.2	322.6	309.3	317.0
0.75	Instru.	N	188.0	184.0	184.0	185.3
		DT	315.4	324.1	322.7	320.7
		Peak	277.0	271.5	291.0	279.8
		MD	285.0	286.5	286.0	285.8
	Man.	N	208.0	210.0	200.0	206.0
		DT	288.5	285.7	300.0	291.4
1.00	Instru.	N	188.0	195.0	185.0	189.3
		DT	316.3	304.8	319.8	313.6
		Peak	289.0	298.0	308.5	298.5
		MD	298.0	298.0	293.0	296.3
	Man.	N	222.0	216.0	206.0	214.7
		DT	270.3	277.8	291.3	279.8

TABLE X (a. Continued)

Vacuum Pressure (kPag)	Method	Indicator	Replication I	Replication II	Replication III	Average
2.00	Instru.	N	169.0	265.0	292.0	242.0
		DT	351.4	224.8	204.4	260.2
		Peak	254.0	266.0	244.0	254.7
		MD	271.0	224.0	189.0	228.0
	Man.	N	290.0	312.0	284.0	295.3
		DT	211.3	192.3	206.9	203.5
3.00	Instru.	N	314.0	360.0	380.0	351.3
		DT	179.3	154.9	146.9	160.4
		Peak	156.0	144.0	136.0	145.3
		MD	168.5	129.0	120.0	139.2
	Man.	N	516.0	602.0	604.0	574.0
		DT	116.3	99.7	99.3	105.1
3.50	Instru.	N	529.0	508.0	579.0	538.7
		DT	112.3	116.8	101.1	110.1
		Peak	92.5	116.0	95.0	101.2
		MD	101.0	107.0	97.0	101.7
	Man.	N	814.0	738.0	684.0	745.3
		DT	73.7	81.3	87.7	80.9
4.00	Instru.	N	219.0	221.0	271.0	237.0
		DT	270.7	267.2	218.0	252.0
		Peak	282.0	283.0	275.0	280.0
		MD	287.0	279.0	220.0	262.0
	Man.	N	334.0	344.0	422.0	366.7
		DT	179.6	174.4	142.2	165.4
4.50	Instru.	N	649.0	594.0	663.0	635.3
		DT	90.2	98.6	88.4	92.4
		Peak	89.0	89.0	92.0	90.0
		MD	88.0	93.0	88.0	89.7
	Man.	N	936.0	934.0	960.0	943.3
		DT	64.1	61.6	62.5	62.7

TABLE X

b. TEST RESULTS BASED ON INSTRUMENTATION RECORDED DATA AND MANUALLY COLLECTED SAMPLES OVER ALL THE VACUUM PRESSURE LEVELS AND SPEED SETTING 10

Vacuum Pressure (kPag)	Method	Indicator	Replication I	II	III	Average
0.23	Instru.	N	342.0	336.0	352.0	343.3
		DT	173.1	177.3	167.7	172.7
		Peak	76.0	82.0	83.0	80.3
		MD	147.5	150.0	150.0	149.2
	Man.	N	360.0	390.0	346.0	365.3
		DT	166.7	153.9	173.4	164.7
0.50	Instru.	N	498.0	523.0	528.0	516.3
		DT	119.4	113.7	112.6	115.2
		Peak	72.0	75.0	76.0	74.3
		MD	83.0	81.0	81.0	81.7
	Man.	N	506.0	520.0	504.0	510.0
		DT	118.6	115.4	119.1	117.7
0.75	Instru.	N	650.0	668.0	660.0	659.3
		DT	90.8	88.4	89.5	89.6
		Peak	77.0	74.0	65.5	72.2
		MD	78.0	78.0	77.0	77.7
	Man.	N	696.0	724.0	690.0	703.3
		DT	86.2	82.9	87.0	85.4
1.00	Instru.	N	718.0	713.0	741.0	724.0
		DT	82.4	83.0	79.7	81.7
		Peak	75.0	74.0	73.0	74.0
		MD	77.0	77.0	77.0	77.0
	Man.	N	774.0	752.0	768.0	764.7
		DT	77.5	79.8	78.1	78.5

TABLE X (b. Continued)

Vacuum Pressure (kPag)	Method	Indicator	Replication I	II	III	Average
2.00	Instru.	N	756.0	778.0	773.0	769.0
		DT	78.3	75.9	76.5	76.9
		Peak	76.0	74.0	77.0	75.7
		MD	75.0	75.0	76.0	75.3
	Man.	N	866.0	892.0	886.0	881.3
		DT	69.3	67.3	67.7	68.1
3.00	Instru.	N	756.0	764.0	799.0	773.0
		DT	78.2	77.2	74.0	76.5
		Peak	76.0	74.0	75.0	75.0
		MD	75.0	73.0	72.0	73.3
	Man.	N	1014.0	1020.0	1004.0	1012.7
		DT	59.2	58.8	59.8	59.3
3.50	Instru.	N	739.0	743.0	724.0	735.3
		DT	79.5	79.0	81.3	79.9
		Peak	75.0	72.0	75.0	74.0
		MD	73.0	73.0	74.0	73.3
	Man.	N	1024.0	1040.0	980.0	1014.7
		DT	58.6	57.7	61.2	59.2
4.00	Instru.	N	780.0	804.0	776.0	786.7
		DT	74.0	71.8	74.7	73.5
		Peak	72.0	74.0	74.0	73.3
		MD	72.0	72.0	73.0	72.3
	Man.	N	1150.0	1046.0	1060.0	1085.3
		DT	52.2	57.4	56.6	55.4
4.50	Instru.	N	1172.0	1135.0	1155.0	1154.0
		DT	49.1	50.8	49.8	49.9
		Peak	50.0	50.0	50.0	50.0
		MD	49.0	49.0	49.0	49.0
	Man.	N	1516.0	1642.0	1522.0	1560.0
		DT	39.6	36.5	39.4	38.5

TABLE X

c. TEST RESULTS BASED ON INSTRUMENTATION RECORDED DATA AND MANUALLY COLLECTED SAMPLES OVER ALL THE VACUUM PRESSURE LEVELS AND SPEED SETTING 15

Vacuum Pressure (kPag)	Method	Indicator	Replication I	Replication II	Replication III	Average
0.23	Instru.	N	377.0	381.0	343.0	367.0
		DT	158.0	155.4	173.1	162.2
		Peak	42.0	44.0	35.5	40.5
		MD	96.0	123.0	131.0	116.7
	Man.	N	446.0	432.0	370.0	416.0
		DT	134.5	138.9	162.2	145.2
0.50	Instru.	N	744.0	654.0	680.0	692.7
		DT	79.7	90.6	87.3	85.9
		Peak	41.0	46.0	44.0	43.7
		MD	52.0	55.0	53.0	53.3
	Man.	N	758.0	736.0	752.0	748.7
		DT	79.2	81.5	79.8	80.2
0.75	Instru.	N	1014.0	1007.0	1008.0	1009.7
		DT	57.8	58.2	58.1	58.0
		Peak	45.0	48.0	46.0	46.3
		MD	46.0	46.0	46.0	46.0
	Man.	N	1042.0	988.0	1070.0	1033.3
		DT	57.6	60.7	56.1	58.1
1.00	Instru.	N	1185.0	1163.0	1169.0	1172.3
		DT	49.6	50.7	50.4	50.2
		Peak	45.0	42.0	46.0	44.3
		MD	45.0	45.0	45.0	45.0
	Man.	N	1238.0	1194.0	1244.0	1225.3
		DT	44.2	50.3	48.2	47.6

TABLE X (c. Continued)

Vacuum Pressure (kPag)	Method	Indicator	Replication I	II	III	Average
2.00	Instru.	N	1309.0	1323.0	1299.0	1310.3
		DT	44.6	44.1	45.3	44.7
		Peak	42.0	45.0	44.0	43.7
		MD	43.0	43.0	44.0	43.3
	Man.	N	1436.0	1428.0	1406.0	1423.3
		DT	41.8	42.0	42.7	42.2
3.00	Instru.	N	1613.0	1666.0	1629.0	1636.0
		DT	36.4	35.4	36.1	36.0
		Peak	37.0	37.0	35.0	36.3
		MD	35.0	35.0	35.0	35.0
	Man.	N	1892.0	1870.0	1858.0	1873.3
		DT	31.7	32.1	32.3	32.0
3.50	Instru.	N	1347.0	1401.0	1426.0	1391.3
		DT	43.1	41.5	40.8	41.8
		Peak	41.0	43.0	39.0	41.0
		MD	41.0	40.0	39.0	40.0
	Man.	N	1594.0	1606.0	1752.0	1650.7
		DT	37.6	37.4	34.3	36.4
4.00	Instru.	N	1352.0	1325.0	1346.0	1341.0
		DT	42.1	43.1	42.5	42.6
		Peak	42.0	41.0	43.0	42.0
		MD	41.0	41.0	41.0	41.0
	Man.	N	1706.0	1710.0	1662.0	1692.7
		DT	35.2	35.1	36.1	35.5
4.50	Instru.	N	1777.0	1769.0	1733.0	1759.7
		DT	33.2	32.3	32.9	32.8
		Peak	33.0	31.0	32.2	32.1
		MD	32.0	31.0	32.0	31.7
	Man.	N	2162.0	2152.0	2178.0	2164.0
		DT	27.8	27.9	27.8	27.8

TABLE X

d. TEST RESULTS BASED ON INSTRUMENTATION RECORDED DATA AND MANUALLY COLLECTED SAMPLES OVER ALL THE VACUUM PRESSURE LEVELS AND SPEED SETTING 20

Vacuum Pressure (kPag)	Method	Indicator	Replication I	Replication II	Replication III	Average
0.23	Instru.	N	308.0	290.0	287.0	295.0
		DT	193.6	204.6	206.5	201.6
		Peak	28.0	27.0	32.0	29.0
		MD	147.5	131.5	136.0	138.3
	Man.	N	364.0	338.0	320.0	340.7
		DT	164.8	177.5	187.5	176.6
0.50	Instru.	N	439.0	364.0	271.0	358.0
		DT	135.7	163.9	220.2	173.3
		Peak	27.0	33.0	31.0	30.3
		MD	95.0	117.0	135.0	115.7
	Man.	N	580.0	428.0	318.0	442.0
		DT	103.5	140.2	188.7	144.1
0.75	Instru.	N	1193.0	1146.0	1141.0	1160.0
		DT	49.0	51.2	51.5	50.6
		Peak	26.0	26.0	26.5	26.2
		MD	32.0	33.0	34.0	33.0
	Man.	N	1274.0	1232.0	1204.0	1236.7
		DT	47.1	48.7	49.8	48.5
1.00	Instru.	N	1574.0	1494.0	1538.0	1535.3
		DT	37.3	39.3	38.2	38.3
		Peak	26.0	27.0	27.0	26.7
		MD	29.0	29.0	30.0	29.3
	Man.	N	1722.0	1586.0	1592.0	1633.3
		DT	34.8	37.8	37.7	36.8

TABLE X (d. Continued)

Vacuum Pressure (kPag)	Method	Indicator	Replication I	II	III	Average
2.00	Instru.	N	2117.0	2064.0	2057.0	2079.3
		DT	27.4	28.4	28.6	28.1
		Peak	25.0	25.0	26.0	25.3
		MD	26.0	26.0	27.0	26.3
	Man.	N	2170.0	2230.0	2228.0	2209.3
		DT	27.7	26.9	26.9	27.2
3.00	Instru.	N	2123.0	2107.0	2096.0	2108.7
		DT	27.7	28.0	28.1	27.9
		Peak	26.0	27.0	26.0	26.3
		MD	26.0	27.0	27.0	26.7
	Man.	N	2452.0	2460.0	2472.0	2461.3
		DT	24.5	24.4	24.3	24.4
3.50	Instru.	N	2066.0	2091.0	2059.0	2072.0
		DT	27.9	27.6	28.0	27.8
		Peak	25.0	25.0	25.0	25.0
		MD	26.0	26.0	26.0	26.0
	Man.	N	2370.0	2438.0	2252.0	2353.3
		DT	25.3	24.6	26.6	25.5
4.00	Instru.	N	2115.0	2162.0	2167.0	2148.0
		DT	26.6	25.9	25.9	26.1
		Peak	27.0	23.0	26.0	25.3
		MD	25.0	25.0	25.0	25.0
	Man.	N	2476.0	2528.0	2514.0	2506.0
		DT	24.2	23.7	23.9	23.9
4.50	Instru.	N	2146.0	2145.0	2107.0	2132.7
		DT	26.2	26.3	26.8	26.4
		Peak	23.0	25.0	22.0	23.3
		MD	25.0	25.0	25.0	25.0
	Man.	N	2562.0	2646.0	2542.0	2583.3
		DT	23.4	22.7	23.6	23.2

TABLE X

e. TEST RESULTS BASED ON INSTRUMENTATION RECORDED DATA AND MANUALLY COLLECTED SAMPLES OVER ALL THE VACUUM PRESSURE LEVELS AND SPEED SETTING 25

			Replication			
Vacuum Pressure (kPag)	Method	Indicator	I	II	III	Average
0.23	Instru.	N	194.0	185.0	210.0	196.3
		DT	308.4	322.2	284.6	305.1
		Peak	70.0	256.0	191.0	172.3
		MD	201.0	216.0	190.5	202.5
	Man.	N	184.0	218.0	218.0	206.7
		DT	326.1	275.2	275.2	292.2
0.50	Instru.	N	578.0	576.0	585.0	579.7
		DT	101.9	101.7	101.0	101.5
		Peak	20.0	23.0	23.0	22.0
		MD	68.0	70.0	71.0	69.7
	Man.	N	686.0	644.0	566.0	632.0
		DT	87.5	93.2	106.0	95.6
0.75	Instru.	N	973.0	876.0	981.0	943.3
		DT	60.5	67.2	59.9	62.5
		Peak	24.0	19.0	20.5	21.2
		MD	44.0	43.0	44.0	43.7
	Man.	N	1206.0	1114.0	962.0	1094.0
		DT	49.8	53.9	62.4	55.4
1.00	Instru.	N	1126.0	1214.0	1038.0	1126.0
		DT	52.3	48.5	57.0	52.6
		Peak	22.0	18.0	21.0	20.3
		MD	39.0	37.0	42.0	39.3
	Man.	N	1654.0	1640.0	1626.0	1640.0
		DT	36.3	36.6	36.9	36.6

TABLE X (e. Continued)

Vacuum Pressure (kPag)	Method	Indicator	Replication I	II	III	Average
2.00	Instru.	N	2321.0	2321.0	2334.0	2325.3
		DT	25.2	25.2	25.1	25.2
		Peak	20.0	19.0	22.0	20.3
		MD	22.0	22.0	22.0	22.0
	Man.	N	2576.0	2660.0	2698.0	2644.7
		DT	23.3	22.6	22.2	22.7
3.00	Instru.	N	2476.0	2458.0	2419.0	2451.0
		DT	23.8	24.0	24.4	24.1
		Peak	20.5	19.0	20.0	19.8
		MD	21.0	21.0	22.0	21.3
	Man.	N	2948.0	2956.0	2918.0	2940.7
		DT	20.4	20.3	20.6	20.4
3.50	Instru.	N	2456.0	2446.0	2441.0	2447.7
		DT	23.3	23.4	23.5	23.4
		Peak	20.0	20.0	16.0	18.7
		MD	21.0	21.0	21.0	21.0
	Man.	N	3036.0	3018.0	2892.0	2982.0
		DT	19.8	19.9	20.8	20.2
4.00	Instru.	N	2533.0	2528.0	2538.0	2533.0
		DT	22.0	22.1	22.0	22.0
		Peak	18.0	19.0	20.0	19.0
		MD	20.0	20.0	20.0	20.0
	Man.	N	3108.0	3140.0	3084.0	3110.7
		DT	19.3	19.1	19.5	19.3
4.50	Instru.	N	2509.0	2498.0	2520.0	2509.0
		DT	22.3	22.4	22.3	22.3
		Peak	19.0	19.0	20.0	19.3
		MD	20.0	20.0	20.0	20.0
	Man.	N	3136.0	3178.0	3152.0	3155.3
		DT	19.0	18.9	19.1	19.0

TABLE XI

TEST RESULTS FROM THE MEASURED SHAFT SPEED AND THE INSTRUMENTATION RECORDED DATA

Vacuum Level		Speed Settings				
		5	10	15	20	25
0.23	**RPM**	4.35	16.97	29.72	42.90	56.57
	Theo.	195.75	763.65	1337.40	1930.50	2545.65
	Theot.	306.85	78.57	44.86	31.08	23.57
	CV	55.89	80.09	93.22	99.48	105.76
0.50	**RPM**	4.44	17.12	29.78	42.87	56.86
	Theo.	199.80	770.40	1340.10	1929.15	2558.70
	Theot.	300.38	77.87	44.78	31.10	23.45
	CV	27.65	63.94	82.21	102.57	105.15
0.75	**RPM**	4.70	17.21	29.67	47.11	59.36
	Theo.	211.50	774.45	1335.15	2119.95	2671.20
	Theot.	283.43	77.49	44.94	28.31	11.46
	CV	34.82	47.77	64.73	93.94	105.45
1.00	**RPM**	4.58	17.10	29.83	49.74	64.65
	Theo.	206.10	769.50	1342.35	2238.30	2909.25
	Theot.	291.12	77.97	44.70	26.81	20.62
	CV	36.31	34.63	47.74	83.53	100.09
2.00	**RPM**	5.93	17.42	29.86	49.97	64.86
	Theo.	266.85	783.90	1343.70	2248.65	2918.70
	Theot.	224.68	76.52	44.65	26.69	20.56
	CV	66.39	42.03	37.24	57.30	79.69
3.00	**RPM**	8.08	17.89	37.14	49.47	64.18
	Theo.	363.60	805.05	1671.30	2226.15	2888.10
	Theot.	165.07	74.52	35.90	26.96	20.78
	CV	68.84	47.84	42.11	54.50	76.08
3.50	**RPM**	12.31	17.71	32.30	49.75	64.32
	Theo.	553.95	796.95	1453.50	2238.75	2894.40
	Theot.	108.35	75.28	41.29	26.80	20.73
	CV	61.14	54.49	47.36	59.49	78.16

TABLE XI (Continued)

		Speed Settings				
Pressure		5	10	15	20	25
4.00	**RPM**	4.82	17.54	30.01	49.77	64.51
	Theo.	216.90	789.30	1350.45	2239.65	2902.95
	Theot.	276.45	76.01	44.43	26.79	20.67
	CV	68.34	51.59	49.56	59.28	75.78
4.50	**RPM**	13.79	25.29	39.47	49.14	63.77
	Theo.	620.55	1138.05	1776.15	2211.30	2869.65
	Theot.	96.69	52.73	33.78	27.13	20.91
	CV	61.40	48.77	76.87	57.90	76.50

VITA

OUSSAMA EL GHARRAS

Candidate for the Degree of

Master of Science

Thesis: A PIEZOELECTRIC SENSOR FOR TESTING SEED METERS

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Marrakech, Morocco, November 22, 1962, the son of Essediq and Leila.

Education: Graduate from Abou El Abass Essebti High School, Marrakech, Morocco, in 1981; received Ingénieur d'Application Engineering from Institut Agronomique et Vétérinaire Hassan II at Rabat in 1985; completed requirements for the master of Science degree at Oklahoma State University in December, 1992.

Professional Experience: Worked as Engineer in the Ministry of Agriculture for eight months after graduation. Researcher at the Institut National de Recherche Agronomique, at the Centre Régional de Recherche Agronomique, Settat, since December, 1987.