APPLICATION OF ELECTROSTATIC SEPARATION PRINCIPLES TO CLEANING SEEDS OF CERTAIN FIELD CROPS

by

DEAN EMERSON BOOSTER

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1956

APPROVED:

Redacted for privacy

Head of Department of Agricultural Engineering

In Charge of Major

Redacted for privacy

Chairman of School Graduate Committee

Redacted for privacy

Dean of Graduate School

Date thesis is presented May 8, 1936

Typed by Margaret Barber

ACKNOWLEDGMENT

The author wishes to express his appreciation to the Agricultural Experiment Station, School of Agriculture, Oregon State College, for the assistantship which made this study possible. To Professor J. B. Rodgers, Head of the Department of Agricultural Engineering, Oregon State College, the author owes a debt of gratitude for his constructive guidance throughout the experimental work and for his suggestions in the preparation of this thesis.

Acknowledgment is made to J. E. Harmond, Senior Agricultural Engineer, L. M. Klein, Agricultural Engineer, and N. R. Brandenburg, Associate Agricultural Engineer, Seed Crops and Fiber Flax Investigation, U.S.D.A., Corvallis, Oregon, for their suggestions and loan of laboratory equipment.

The author expresses his appreciation to Mrs. L. A. Jensen, in charge, Cooperative Seed Laboratory, Oregon State College, and Dr. M. C. Parker, Assistant Agronomist, Agricultural Experiment Station, School of Agriculture, Oregon State College, for their suggestions and for their assistance in carrying out the experimental work connected with this study.

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APPLICATION OF ELECTROSTATIC SEPARATION PRINCIPLES TO CLEANING SEEDS OF CERTAIN FIELD CROPS

INTRODUCTION

One of the prime requisites for successful crop production is clean seed. Decreased yields, increased production costs, and poor quality often result when seed stocks containing weed seeds or other crop seeds are planted (22, pp.308-309). Clean seed is equally important in maintaining high quality in the many products which are manufactured from crop seeds. In the several phases of crop seed production, seed cleaning ranks high in the order of importance. Federal and state seed laws regulate the quality of seed that may be transported and marketed. Nearly always some cleaning process must be resorted to in order to have seed lots meet the minimum standards specified by law.

Seed cleaning is the process of removing the contamination contained in a quantity of crop seed. The contamination may be in the form of weed seeds, straw, chaff, rocks, clods, animal excreta, or other crop seeds (13, p.145). There are a great number of commercial seed cleaners available on the market today. The majority of these machines separate the crop seed to be cleaned from the contaminating material by means of screens, air blasts,

vibrating tables, inclined planes, fabric-covered rolls and belts, or combinations of these. The separations are made on the basis of physical differences between the crop seed and the contaminant. Size, shape, weight, surface texture, and sometimes color are the physical characteristics most commonly used. While the conventional seed cleaning equipment is indispensable in seed cleaning, there is a need for a seed cleaner that is capable of making separations on the basis of some seed characteristics other than those already mentioned. This need exists because there are a vast number of commonly occurring seed mixtures in which the seeds are quite similar in size, shape, weight, surface characteristics, and color. With such mixtures the conventional seed cleaning equipment is unable to produce satisfactory results. As a result, huge quantities of otherwise valuable crop seeds are rendered worthless or, at best, reduced in quality because present equipment is inadequate in many cases. It was with this in mind that the investigation of making useful seed separations by the electrostatic separation process was started.

The objectives of this investigation were to determine what seed mixtures could be separated by the electrostatic process, what effect exposure to high voltage might have on the seed germination, and what effect the moisture

content of the seed might have on separation. The investigation was begun by a review of the literature and by sending questionnaires to 20 seed cleaning establishments throughout the state of Oregon. The purpose of the questionnaires was to determine what seed mixtures the seedsmen consider the most difficult to clean.

REVIEW OF LITERATURE

Under certain conditions, a particular material may have the ability or capacity to attract a dissimilar material. This phenomenon was known to the Greeks as early as 600 B.C. when Thales recorded the effects of rubbing a piece of amber with fur or cloth. The amber thus treated was said to be electrified or charged with static electricity and was capable of attracting lightweight objects such as scraps of paper, dust particles, and strands of hair. The Greeks apparently did not make any useful application of this information. Approximately 2000 years later, William Gilbert, physician to Queen Elizabeth, showed that substances other than amber such as sealing wax, glass, and hard rubber, could be charged with electricity. Further experimentation showed that certain substances exhibited forces of repulsion as well as attraction depending upon the treatment to which the substance had been subjected. For example, a piece of glass which had been rubbed with silk attracted a piece of glass which had been rubbed with wool (15, p.445 and 27, p.1). This method of producing an electric charge by friction was used in the early electrostatic separators.

The first commercial electrostatic separator was developed and patented by Thomas B. Osburne of New Haven, Connecticut, in 1880. This separator, which was called a

middlings purifier, was designed to remove from ground cereal chaff and other lightweight material which would reduce the quality of the flour. The contaminating material was to be removed by passing the ground grain beneath a charged, hard rubber roll. The charged roll would attract or "lift" the lightweight material out leaving only the pure flour. The electric charge on the hard rubber roll was produced by the rubbing action of the rotating roll against a pad of wool (24). After Osborne's first machine there followed in quick succession a number of other electrostatic separators. Today there are approximately 200 United States patents on electrostatic separators of one kind or another. The majority of these separators were designed for use by the mining industry for separating minerals. Only a few were designed specifically with agricultural products in mind. A partial list of United States patents covering electrostatic separators in the latter category is shown in Table I.

Although commercial electrostatic separators have been available for more than 70 years, they have not received very wide application except in the mining industry. There are a number of probable reasons why their development has been comparatively slow. The early machines depended upon frictional means to generate the required electric charges which, at best, were not an adequate

Table I

ELECTROSTATIC SEPARATORS
DESIGNED TO PROCESS AGRICULTURAL PRODUCTS

Patent No.	Date	Inventor	Patent Title
224,719	Feb.17,1880	Osborne, T.B.	Middlings purifier
247,954	Oct.4,1881	Smith, H.E.	Middlings purifier
254,038	Feb.21,1882	Osborne, T.B.	Middlings purifier
254,039	Feb.21,1882	Osborne, T.B.	Middlings purifier
288,086	Nov.6,1883	Kuhnmunch, J.	Middlings purifier
654,442	Mar.13,1900	Troman-hauser, S.H.	Grain cleaner
880,891	Mar.3,1908	Lawson, J.S.	Electrical purification of flour, grain, etc.
1,179,936	Apr.18,1916	Kraus, J.	Electrostatic apparatus for separating and cleaning grits, grain, or the like
1,179,937	Apr.18,1916	Kraus, J.	Method of and apparatus for separating and cleaning materials in an electrostatic field
1,236,658	Aug.14,1917	Baumann, S.	Process for producing pure flour
1,355,477	Oct.12,1920	Howell, S.S.	Means of separating mixtures
2,125,812	Aug.2,1938	Robert-son, J.S.	Method and means of separating granular material
2,135,716	Nov.8,1938	Johnson, H.B.	Method and apparatus for separating foodstuff of the nature of cocoa beans
2,174,681	Oct.3,1939	Bartlett, H.S.	Electrostatic separating apparatus

method of producing high potentials. Insulating materials capable of withstanding the high voltage encountered in electrostatic separators were not readily available to the early inventors. Apparent lack of selectivity in separation and competition from other methods of separation also played a part in slowing the development of the electrostatic processes. High patent royalties made electrostatic separation impractical from an economic standpoint in some instances. The relatively uniform sizing of particles required, the limited range of particle size, and the necessary control over the surface moisture on the particles in the mixture to be separated have contributed to the utilization of methods of separation other than electrostatic (11, pp.601-602 and 31, pp.1120-1121). Many of the problems that confronted the early investigators have been solved. As a result, electrostatic separation processes are being successfully used in many commercial applications.

Because this investigation pertains to the seeds of certain field crops, the more recent applications of electrostatic separation cited are limited to only those instances where agricultural products are involved. In 1931 electrostatic separators were used to remove chaff from ground, roasted coffee. The ground coffee had previously been cleaned by means of a vibrating table and an air

blast. This method did not result in a pure product and excessive losses of coffee were experienced. An electrostatic separator was installed and produced excellent results. The cleaned product had a higher purity than the product discharged by the vibrating table, and there was no loss of coffee. A 250,000 pound shipment of mustard seed received in New York City in 1932 was condemned by the United States Department of Agriculture because it was contaminated with animal excreta. An electrostatic separator costing $2,650 was installed and salvaged over $15,000 worth of clean mustard seed (7, p.1123 and 15, p. 52). Also in 1932, research work at Oregon State College, Corvallis, Oregon, showed that ergot could be removed from bentgrass by electrostatic means (33, pp.18-19).

Another instance where electrostatic separation was used to advantage over conventional cleaning methods was in the removal of chaff from cocoa nibs. The common practice was to roast the cocoa beans, crack them open, and separate the shells and bark from the cocoa nibs by using a vibrating table with an air blast. This method produced about 80 per cent recovery of clean cocoa nibs. The electrostatic separator used was able to recover approximately 800 pounds more cocoa nibs per eight-hour shift that would have otherwise been wasted (7, p.1123 and 27, pp.111-112). In 1938 a United States patent was granted to John S.

Robertson on an electrostatic separator capable of removing drake seed from oats. This machine was constructed in such a manner that the drake seed, being longer than the oats, was electro-oriented by the electrostatic field. This caused the drake seed to stand on end and pass through openings of a screen while the oats remained flat (28). Bartlett, in 1939, patented an electrostatic separator with which leaf and stem material could be removed from raisins. This machine was also capable of separating water cress seed from unmilled rice and of separating the meat of the nut from the shell material on shelled nuts such as almonds (5, p.2).

Electrostatic separators have been used successfully to remove sheep sorrel and curly dock from clover according to Sutton (11, p.604). The most recent application of electrostatic separators has been made by the Quaker Oats Company. Andrews reported in 1952 that electrostatic separators were being used in five of the Quaker Oats plants. These separators are being used to remove contamination from corn, prior to milling, which cannot be removed by dimensional or air methods (2, pp.163-164). In 1955 Ake reported on a new electrostatic separator developed by the Mechanical Research Department of the Quaker Oats Company. This machine is characterized by only one moving part, that being an agitator in the feed hopper.

This machine is also used for the purification of corn before it is milled. It is stated that never less than 95 per cent purity is obtained in the cleaned product and that 99 and 100 per cent purities are common (1, pp.26-28).

Electrostatic separation is by no means a cure-all. This is evidenced by its relatively slow development. However, under certain conditions and for specific cleaning and separating jobs, electrostatic separation appears to offer the only solution to the cleaning problems.

DESCRIPTION OF ELECTROSTATIC SEPARATION PROCESSES

Electrostatic separation has been successfully used to separate heterogeneous mixtures of different solids, mixtures of different sizes of the same solid, and mixtures of different shapes of the same solid (27, p.2). This investigation was concerned primarily with separating seed mixtures made up of seeds of approximately the same size, shape, weight, and surface texture. If the properties of one seed in a mixture were very much different from similar properties of another seed in the same mixture, a separation problem would probably not exist and the mixture could be separated by conventional methods. This does not detract from the usefulness of the electrostatic separation processes but is presented only as a means of limiting the scope of this investigation. Electrostatic sizing and grading have not been included.

Electrostatic separation has received its widest application in the mining industry. A considerable amount of research on electrostatic separation has been carried out by various individuals in the mining industry and by the Bureau of Mines at its College Park, Maryland, station. The great majority of the published work on electrostatic separation deals primarily with separating mixtures of minerals. Only a few sketchy reports on the application of electrostatic separation to the cleaning

of agricultural products have been published. Consequently, an attempt was made to adapt the results of the research on mineral separations to the separation of mixtures of field crop seeds.

Conventional seed cleaning equipment makes separations on the basis of physical differences between the seeds such as size, weight, shape, and surface texture. Electrostatic separation, on the other hand, is made on the basis of different properties or characteristics such as electrical conductivity, contact potential, and dielectric constant. Electrostatic separators exist that utilize one or more of the above properties. However, electrical conductivity and contact potential are the properties most commonly used in making electrostatic separations (11, p.603).

Electrical conductivity is a measure of the conducting ability of a material. All materials conduct electricity to some extent, but some materials have a great deal more conducting ability than others. Materials are usually classified into two general categories as far as their electrical properties are concerned. Materials having high conductivities are commonly called conductors. Those of low conductivity are called insulators. The range of electrical conductivities for various materials is quite large. Metals are usually much better conductors

of electricity than are non-metallic materials. Silver, for example, has an electrical conductivity approximately 10^{23} times larger than that of mica. The variation of conductivities of different materials is attributed to the rate at which the electric charges on a particle move when under the influence of an electric field. Conductors, then, are those materials which permit electric charges to move with the least amount of interference (4, p.22).

Contact potential is that phenomenon which occurs when two dissimilar materials are brought into intimate contact with each other and then separated. An example of this would be sliding a mixture of particles down an inclined plane. The bumping and rubbing together of the particles cause an electron exchange to occur between the dissimilar materials in the mixture. The particles that give up electrons the more easily will become positively charged with respect to the rest of the particles in the mixture (10, pp.4-5).

Dielectric and insulator are terms that are oftentimes used synonomously. The dielectric constant of a material is the ratio of the electric flux density and the electric field strength or intensity. Both flux density and field intensity are directly proportional to the free charges in the field. Field intensity is dependent upon the material or medium under consideration while flux

density is independent of the material. An electric field which lies entirely in one medium having a particular dielectric constant may be changed or distorted from its normal shape by the introduction of particles having different dielectric constants (4, pp.26-28, 64-65).

The amount of electric charge on a particle may be changed by any one of several methods. The method of charging by contact potential has already been discussed. Other methods of producing an electric charge on a particle are by induction, by passing the particles through an ionized gas, by pyroelectric polarization, and by photoelectric action. Induction requires that the particles be in the immediate vicinity of a charged body from whence the electric charges are taken. If the particles are suspended in an ionized gas, both conductors and nonconductors will receive a surface charge. The length of time the electric charges remain on the surfaces of the particles is related to the respective conductivities of the particles. If the particles are in contact with a conducting surface, only the nonconductors will be charged. While the conductors have the same opportunity to be charged as the nonconductors, the charge will readily leak off the conducting particles and the net charging effect will be zero. Charging by pyroelectric polarization is accomplished when the particles undergo a change in

temperature. During thermal changes, some materials become polarized as a result of the strains which may be set up during heating and cooling. Charging by this method, of course, would certainly not be applicable to charging the seeds in a mixture. Photoelectric action changes the charge on particles of certain materials which are capable of emitting electrons when exposed to radiations of the proper frequency (4, pp.23-24 and 11, pp.601-602). For seed separation purposes, it appears that charging by friction or contact potential, induction, or with an ionized gas offer the best possibilities.

The principles of electrostatic separation have been enumerated by Fraas and Ralston. When an electrically charged particle is caused to pass through an electric field, certain forces act on the particle. Electrostatic separation is dependent upon these forces to deflect some of the particles from their normal paths of travel in order to effect a separation. Such a deflection cannot occur unless there exists either a difference of electrical charges among the particles or a difference between the dielectric constants of the particles and the surrounding medium. The electrical charges may differ either in sign or degree of intensity. The charged particles obey Coulomb's law of electrostatics in that charged particles tend to move toward an electrode of opposite charge. The

deflecting forces always act in such a manner that resulting motion causes a maximum decrease in the total energy of the system. Forces caused by an initial charge on the particle act in a direction parallel to the field, while the forces resulting from differences in dielectric constant act parallel to the direction of maximum variation of field strength or field intensity. The direction in which forces act on initially charged particles changes if the polarities of the electrodes are changed. This is not true, however, in the case of forces resulting from differences in dielectric constants. These forces are unidirectional. Therefore, alternating current might be applicable for separators using only differences in dielectric constants to make a separation. An electrically charged particle also has an electric field of its own. If such a particle is brought into the vicinity of an uncharged surface, forces resulting from the field of the particle may be exerted. Attraction or repulsion of the particle to the uncharged surface is determined by the dielectric constants of the particle, of the uncharged surface, and of the surrounding medium. If the dielectric constant of the surface is higher than the dielectric constant of the medium surrounding the two, a charged particle will be attracted to the surface. On the other hand, if the dielectric constant of the medium

is higher than that of the surface, repulsion of the positively charged particle will result (11, pp.600-601).

Electrostatic separation of mixtures of solids makes use of properties such as electrical conductivity, contact potential, and dielectric constant. For best results, these properties must be utilized in the proper manner. An ionic or discharging field produces the best results when utilizing the electrical conductivities of the particles to make a separation. Contact potential, on the other hand, requires a purely static field for best results. The particle response in both types of fields may be influenced by the dielectric constants of the particles and the surrounding medium (12, p.1). Even though the above properties are used to the best advantage, a clean separation may not result. There is a certain amount of interference between the particles in a falling stream which may prevent a particle from following its normal trajectory through space (31, pp.227-278). For example, suppose a weed seed had a charge opposite to that of the electrode. This seed would ordinarily be attracted toward the electrode. If, however, this weed seed collided with another seed, its flight path might be altered to the extent that it would fall into the clean seed fraction instead of into the reject fraction. This may, in part, be attributed to particle interference.

All materials do not present the same problems in electrostatic separator operations. Separation of seeds and other agricultural products presents problems uncommon to mineral separations and may require separators of different design in order to obtain satisfactory results. The electrostatic behavior of seeds is affected by size and shape, physical condition, moisture content, degree of maturity, and changes in the seeds that may occur during storage (16, p.41).

DESCRIPTION OF ELECTROSTATIC SEPARATOR

The electrostatic separator used in this investigation consisted primarily of a feed hopper with incorporated feed mechanism, a feed belt, a beam-type electrode, two adjustable splitters or dividers, and a power unit capable of developing a maximum output of 25,000 volts d.c. (See Figures 1, 2, 21, and 22.) When the separator was in operation, seed was placed in the feed hopper and was fed onto the feed belt by the feed mechanism. The moving feed belt carried the seed through the electrostatic field created by the energized electrode. After leaving the feed belt, the flight paths of the seeds were influenced by the forces in the electrostatic field and the force of gravity. By positioning the dividers in the proper location, portions of the seed distribution could be split off or divided as desired.

A number of feed hoppers and feed mechanisms were tested before finding a combination that would consistently produce a reasonably uniform feed. The shortcoming of most of the feed hoppers tested was that grass seeds tended to bridge over the feed hopper opening and not feed out. Several types of agitators were used in the feed hopper, but most of them proved to be ineffective. A positive type feed mechanism in the form of a fluted roll

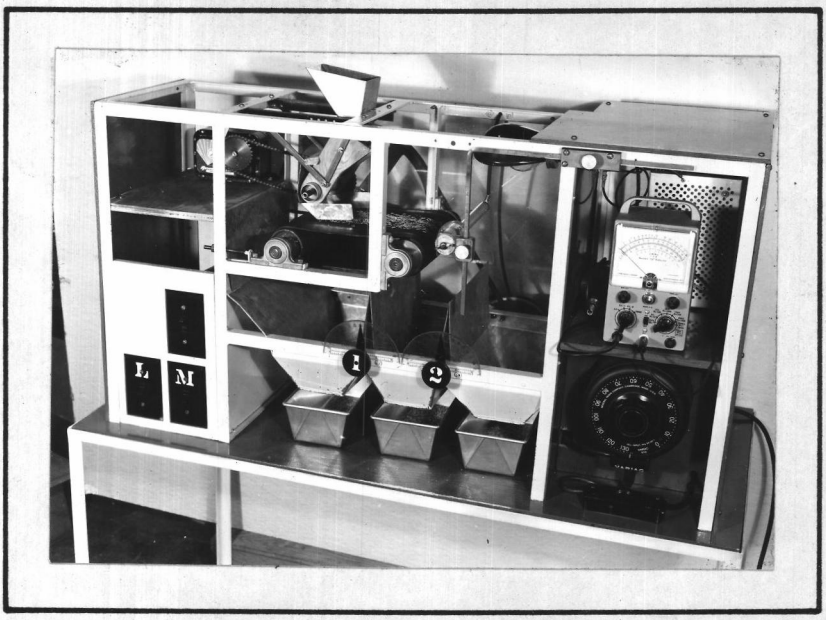


Figure 1

Front view of the electrostatic separator.

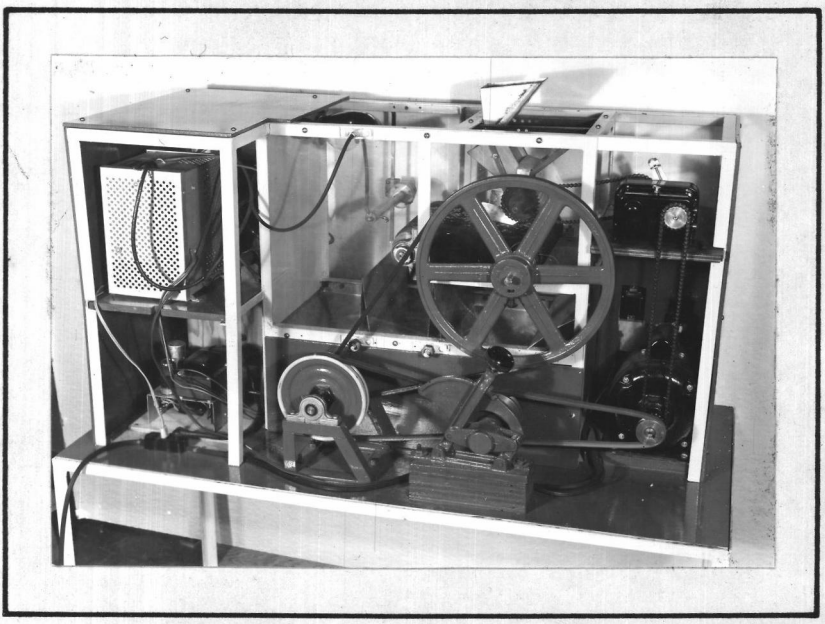


Figure 2

Rear view of the electrostatic separator.

produced the best feeding results. (See Figure 3.) The fluted feed roll offered, in addition to a relatively uniform feed, a self-cleaning quality which facilitated testing several seed lots in succession without the hazard of contaminating one seed lot with seed from a previous lot. No difficulty was encountered in feeding clovers and other legumes onto the feed belt.

The feed belt on this machine was of the endless type and made of a conducting rubber compound. Flake graphite particles mixed with the molten rubber gave the belt its conducting properties. The belt was manufactured by the Griffith Rubber Mills of Portland, Oregon. Feed belts of other materials were also tested. Cloth belts proved unsatisfactory because of the inherent fuzzy characteristics which tended to catch and hold some of the smaller grass seeds. This made it impossible to determine whether the seeds were sticking to the belt as a result of an electric charge or because of the surface finish of the belt material. A leather belt made of fine-grained calfskin also proved unsatisfactory. Although this belt had a smooth enough surface so that seeds would not stick to it, the static charge that would build up on the surface of the belt made separations impossible. Thus, the poor conducting properties of the leather belt led to the investigation of the conducting rubber compound as a belt material.

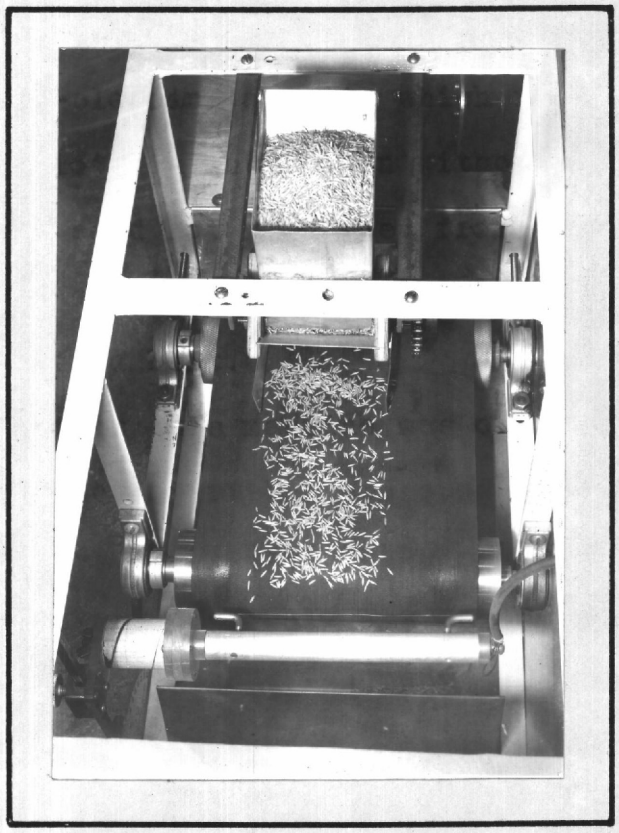


Figure 3

Bird's-eye view of the feed belt, feed hopper, and beam-type electrode. Note the relatively uniform rate of feed obtained using the fluted feed roll. The crop seed used in this illustration is alta fescue.

Early experimenting indicated that for the particular separator design being used, the feed belt had to be a conductor of electricity. As the seeds passed through the electrostatic field in the vicinity of the energized electrode, a change in the electric charge on the seed could result. If the seed had a surface charge of the same polarity as the feed belt, the seed would be repelled by the belt. On the other hand, if the seed had a charge of opposite polarity to that of the feed belt, the seed would be attracted to the feed belt. Neglecting gravity, this seed would remain in contact with the belt until the surface charge could leak off into the air or until the charge could redistribute itself over the surface of the seed and be discharged through the feed belt. If the belt is of a nonconducting material, the charged seeds must be scraped or wiped off the belt by some means, either mechanical or electrical. Even though the feed belt was a conductor, the seeds sometimes had to be wiped off the belt because of the time required for the surface charge on the seed to redistribute itself. In this investigation, a mechanical scraper in the form of a wooden block was used to clean the belt.

The electrode used in the machine was patterned after an electrode used on some of the commercial mineral separators. It is referred to as a beam-type electrode

because of the characteristic electric field pattern which may be obtained (8, p.3). This electrode consisted of a 0.75 inch diameter aluminum tube and a 0.012 inch diameter tungsten wire mounted adjacent and parallel to the axis of the tube. (See Figure 3.) The wire was in electrical and mechanical contact with the tube. This type of electrode has a great deal of versatility. Different positions of the fine wire with respect to the feed roll produced different types of electric fields when the electrode was energized. Three different electrode positions, obtained by rotating the electrode about the longitudinal axis of the aluminum tube, were used. These electrode positions produced a static or non-discharging field, a discharging field, and a combination of both the discharging and non-discharging fields. Each type of field produced its own effect on the seeds as they were transported through the field.

The static or non-discharging field produced what is termed by the minerals industry as a "lifting" effect. In this type of field, the seeds having a particular charge were attracted to an electrode having an opposite charge and repelled from an electrode having the same charge. This lifting or attracting effect was obtained by rotating the electrode about the axis of the aluminum tube until the 0.012 inch diameter wire was in the

position shown in Figure 4. The general seed distribution pattern obtained using the lifting effect was similar to that shown in Figure 4. Seeds do not stick to the feed belt when the lifting effect is employed.

The discharging field produced a "pinning" effect. With the beam-type electrode, a discharging field was produced with the electrode positioned as shown in Figure 5. When the electrode was energized, a corona discharge was emitted from the fine wire. The seeds passing through the field received a spray discharge of electricity from the discharging wire. If the rate of feed was such that the seeds were only one layer deep on the feed belt, all of the seeds would have approximately the same amount of surface area exposed to the discharging field and would receive approximately the same amount of electric charge. The behavior of the seeds in the electric field after receiving a surface charge of electricity depends upon the rate at which the surface charge is removed from the seeds. This rate of removal or dissipation is a function of the conducting properties of the seeds and of the surrounding medium. The higher the conductivity of the seeds, the faster the rate of discharge. Seeds that are poor conductors retain a surface charge longer than good conductors. These seeds, because they have a surface charge of the same polarity as the electrode, are repelled

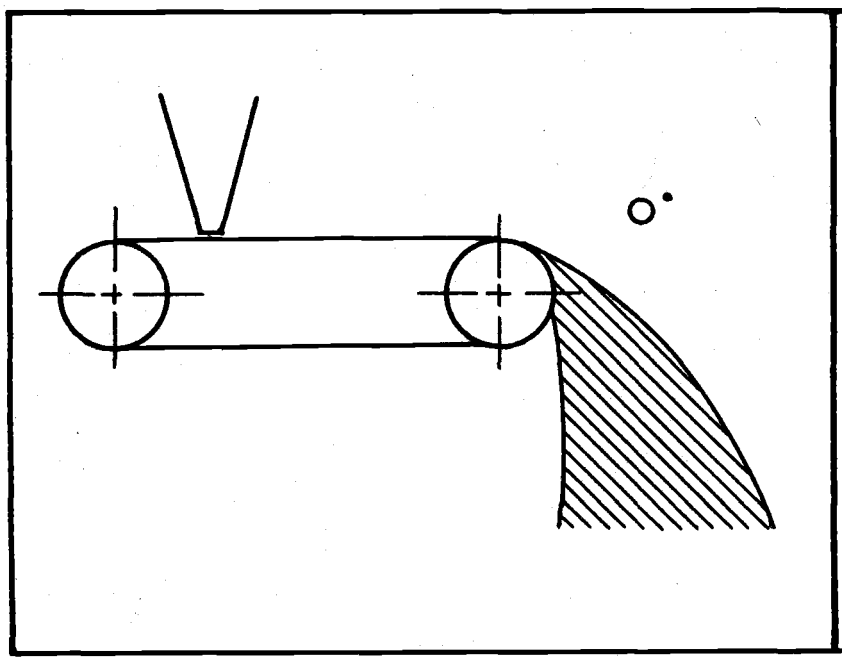


Figure 4

Schematic illustration of the "lifting" effect. The cross-hatched area represents the general seed distribution pattern obtained with the electrode positioned as shown.

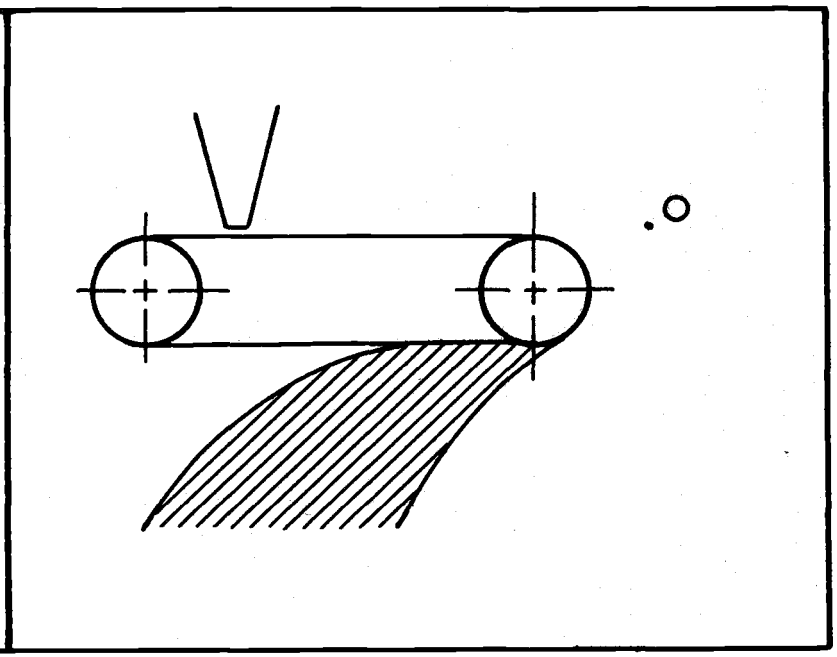


Figure 5

Schematic illustration of the "pinning" effect. The cross-hatched area represents the general seed distribution pattern obtained with the electrode positioned as shown.

by the electrode and pinned to the feed belt. Seeds that are relatively good conductors will not hold a surface charge long enough to be pinned to the feed belt and will follow a flight path similar to that which they would follow if there were no charging effect at all (8, p.2). The general shape of the seed distribution obtained when using the pinning effect is shown in Figure 5. Figures 6 and 7 show the electrostatic separator in operation and the noticeable differences between the pinning and lifting effects.

A combination pinning and lifting effect was obtained by rotating the electrode to a position such that the wire was about midway between the lifting and pinning positions. When the electrode was energized, the seeds received a spray discharge of electricity from the discharging wire and then passed through the lifting field of the large diameter aluminum tube.

The source of d.c. voltage for the electrostatic separator consisted of a power unit and accompanying high voltage unit taken from a North American Phillips Company Model PA-2A DUO-VUE self-contained television projection system. This combined unit supplied d.c. voltages up to 25,000 volts. At 25,000 volts the rated current was 90 microamperes. However, under some operating conditions, currents in excess of 200 microamperes were experienced.

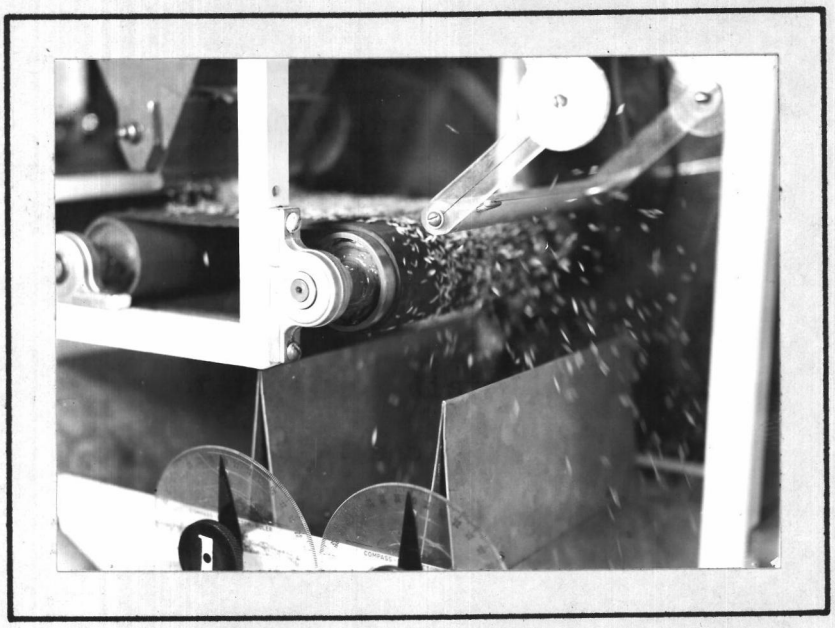


Figure 6

"Lifting" effect in a static or non-discharging electric field. The crop seed used in this illustration is alta fescue. Note that many of the seeds are attracted toward the electrode.

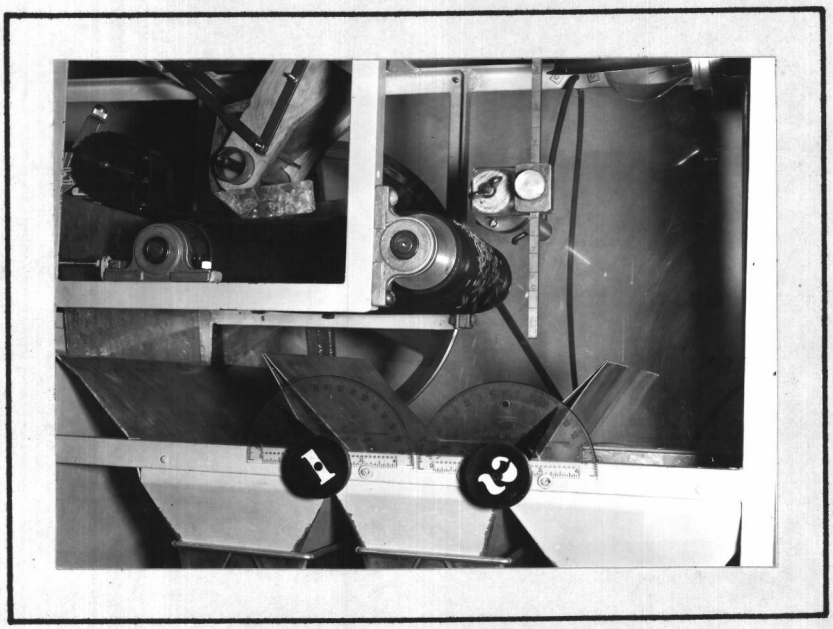


Figure 7

"Pinning" effect in a discharging electric field. The seed used in this illustration is alta fescue. Note the difference between the pinning and lifting effects.

The d.c. voltage applied to the electrode was controlled by varying the a.c. input voltage to the power unit. This was done by means of an adjustable auto-transformer.

SEED SAMPLES USED FOR TESTING PURPOSES

Quantities of the various crop seeds to be used in the testing program were obtained from commercial seed dealers. An effort was made to obtain seed lots of as high purity as practicable. Very few difficulties were encountered in obtaining relatively pure lots of the field crop seeds. However, weed seeds had to be hand picked from screenings which would ordinarily be discarded by the commercial seed dealer. Purity analyses and germination tests on all of the seed lots used were conducted by the Cooperative Seed Laboratory, Oregon State College, Corvallis, Oregon. Results of the purity analyses are shown in Table IV.

Storage of Seed Samples

The seed samples were stored in a room in which the temperature and humidity were thermostatically controlled. Figure 8 shows the room conditioning equipment used to obtain the desired air conditions in the seed storage room. Such storage facilitated controlling the moisture content of the seed by varying the temperature and humidity in the room. The particular temperature and humidity conditions under which the various phases of the testing program were conducted were selected primarily because they could be easily maintained with the equipment

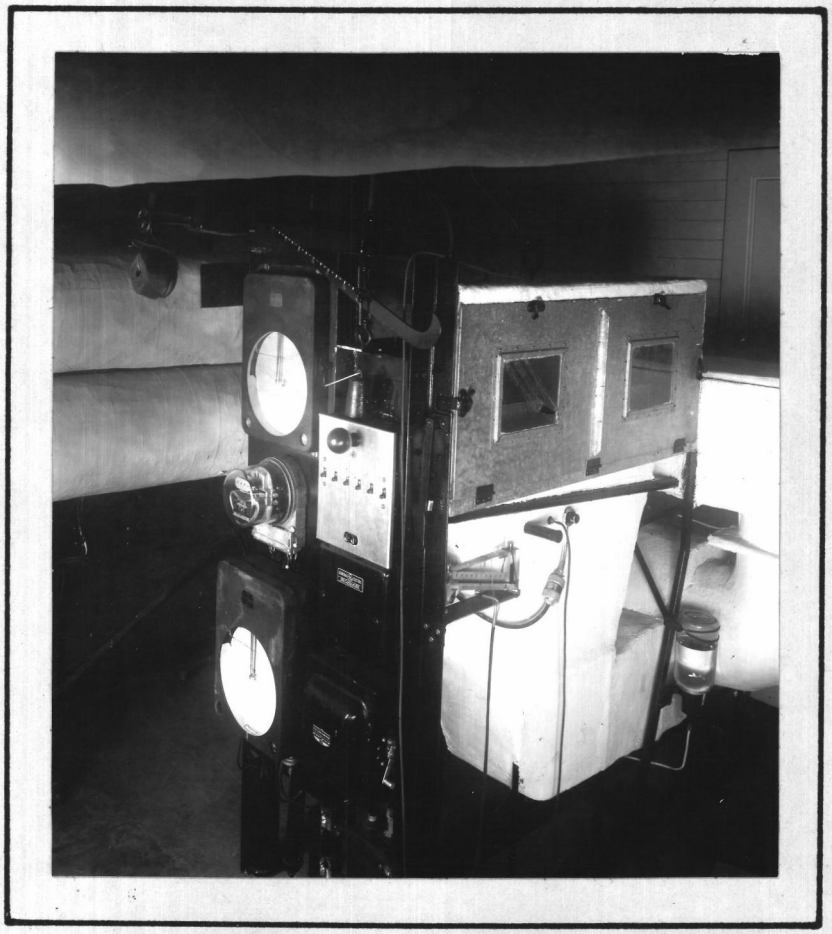


Figure 8

Room conditioning equipment. This equipment was used to obtain the desired temperature and humidity conditions during the testing program. Heat was added to the incoming air by thermostatically controlled electric heating elements. Automatic controls operated a steam injection valve to maintain a constant wet bulb temperature. The conditioner was equipped with a blower to circulate the air in the room.

available. The room conditioning equipment had no provisions for cooling the incoming air. Therefore, conditions had to be selected which could be maintained by adding heat and moisture to the incoming air.

The portions of the seed samples which were actually used in the testing program were stored in shallow pans as shown in Figure 9. The shallow pans permitted a large amount of seed to be directly exposed to the atmosphere. This was desirable since the moisture content of the seed was varied by changing the moisture content of the air. By having a large amount of seed surface area exposed to the atmosphere, the moisture pick up or the moisture reduction of the seed, as the case might be, occurred more rapidly and more uniformly than if the seed were stored in deep containers with only a relatively small amount of surface area exposed.

Preparation of Seed Samples for Testing

In all tests, seed samples having approximately one per cent contamination were used. The percentage of contamination is based on the total sample weight which includes the crop seed to be cleaned and any contamination contained therein. Per cent contamination, then, is the quotient of the weight of contamination divided by the total sample weight. This method of computing the

Figure 9

Christian Becker analytical balance. Components of synthetic seed mixtures and the moisture determination samples were weighed on this balance. The shallow, seed storage pans may be seen on the shelf behind the balance.

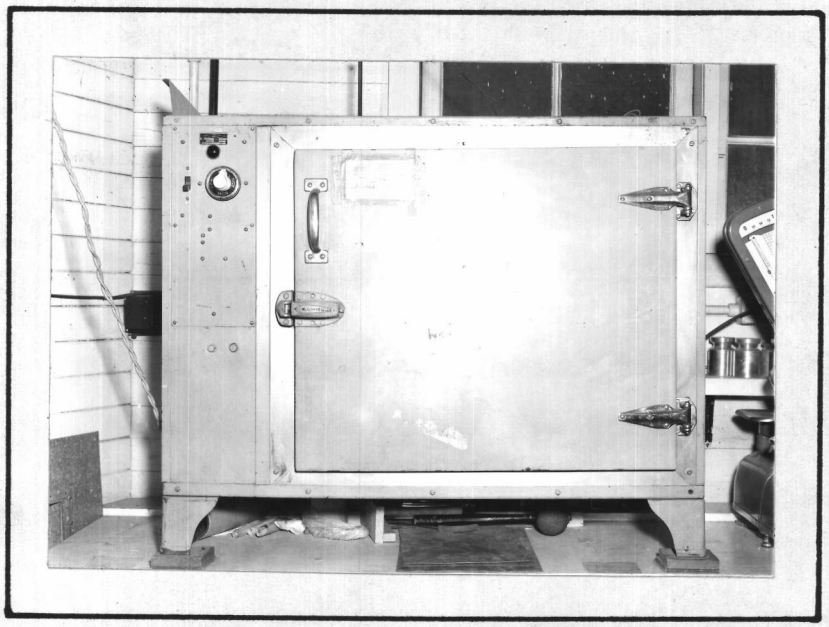


Figure 10

American Instrument Company electric oven. Seed samples that were used in seed moisture content determinations were dried in this thermostatically controlled oven.

percentage of contamination of seed lots is that prescribed by the Cooperative Seed Laboratory, Oregon State College, Corvallis, Oregon.

The samples used in the testing program were prepared in the following manner. All samples for a particular moisture condition were prepared immediately before the time of testing. A pure seed lot which had been stored in shallow pans in a room having a controlled atmosphere was thoroughly mixed to minimize the effect of any seed moisture content gradient which may have existed between seeds in the top layer and the seeds in the bottom layer of a particular pan. Samples of the crop seed of approximately 49.5 grams were weighed out on a Christian Becker analytical balance. (See Figure 9.) Samples of the contaminant seed of approximately 0.5 grams were weighed out on the same balance. A synthetic mixture of approximately one per cent contamination and weighing approximately 50 grams was then made by mixing one 49.5-gram lot of crop seed with a 0.5-gram quantity of contaminant seed. Three replications for each seed mixture were prepared for each of the three seed moisture conditions at which tests were conducted.

Seed moisture samples were prepared immediately after the synthetic mixtures were prepared and just prior to the beginning of the testing for that particular moisture

condition. Moisture samples of each seed being tested ranging from three to 10 grams in weight, depending on the particular seed, were weighed out on the Christian Becker analytical balance. These samples were then oven dried at 105 degrees centigrade for 24 hours. (See Figure 10.) The samples were then re-weighed to determine the weight loss during drying. The moisture content of the seed at the time of testing was calculated by dividing the weight loss which occurred during the drying by the weight of the bone-dry matter in the sample. This method of computing the moisture content is commonly referred to as the dry-basis method (13, p.274). Two replications were used for each moisture content determination.

TESTING PROCEDURE

The object of testing the electrostatic seed separator was to determine what seed mixtures could be separated by the electrostatic separation process. A seed mixture is construed to mean a quantity of seed consisting of a crop seed which is to be recovered and the contaminating material contained therein which is to be removed. The contaminating material is anything other than the crop seed which is to be cleaned and recovered. Examples of contaminating material in a seed mixture are other crop seeds, weed seeds, straw and chaff, and clods. In testing the electrostatic seed separator, seed mixtures were used in which the contaminant consisted only of another crop seed or a weed seed. There are at least two methods or testing procedures that may be used to determine what seed mixtures may be separated by the electrostatic separation process. These two testing procedures shall hereinafter be referred to as the "mixture" method and the "pure-seed" method. These methods were adapted from testing procedures used for separating minerals (30, p.371).

The mixture method consisted of putting a seed mixture through the machine at a particular machine setting and then analyzing the separates or fractions after each run. A number of machine settings and fraction analyses

were required to determine which machine setting offered the best possibilities for separating a given seed mixture. This method was used in the early stages of the investigation but was abandoned because of the excessive amounts of time and analytical work involved. In many seed mixtures, the crop seed and the contaminating seed are very similar in appearance. To the untrained eye, these seeds are oftentimes indistinguishable. Therefore, the services of a trained seed analyst must be employed to carefully check the resulting seed fractions from each pass over the machine. This method offered the advantage of testing a seed mixture directly to determine its behavior in the electrostatic separator. However, because the services of a trained seed analyst were not always available when needed and because of the cost involved, this method was superceded by the pure-seed method of testing.

The pure-seed method consisted of determining the behavior of pure seed lots at different machine settings. Then a comparison of the results of test runs of two kinds of seed was made to determine which machine settings offered the best possibilities for separating a mixture containing those two seeds. In using this testing procedure, the assumption must be made that each kind of seed behaves in the same manner in the synthetic mixture as it does when going through the machine in the pure state.

The pure-seed method of testing had the advantage of not requiring any analytical work in the preliminary testing phases. Analyses of the seed fractions were required only when two kinds of seed were combined in a synthetic mixture. The pure-seed method was an indirect method, and some accuracy may have been sacrificed because of the assumptions which necessarily had to be made.

Twenty-five different machine settings were used in processing each of the pure seed samples. The arrangement of the equipment used in the preliminary testing program is shown in Figure 11. In the preliminary testing of the pure seed samples, two 20-gram samples were used. Each of the two samples for the several kinds of seed were tested in the following manner. For identification purposes, the samples were labelled sample A and sample B. Sample A was passed through the machine at a particular machine setting, and the dividers were adjusted to such a position that the sample of pure seed was divided in half. The half and half divisions of the 20-gram samples were determined by weighing the quantities of seed collected in the three seed pans. The divider setting is shown schematically as position 1 in Figure 12. The divider settings which included 95 per cent of the seed sample were also determined. These latter divider settings were necessary to define the limits of the

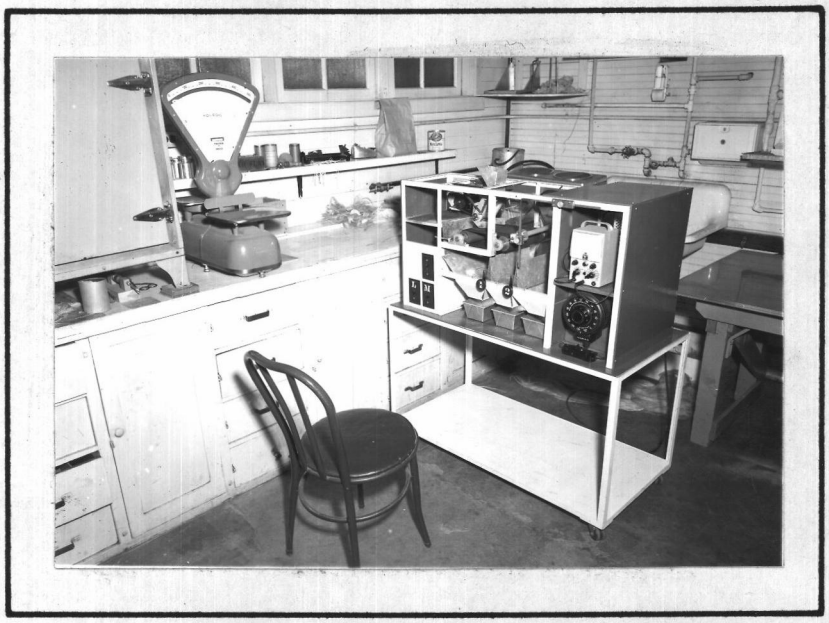


Figure 11

Arrangement of equipment for preliminary testing program. The pure-seed method of determining the optimum machine settings for a particular separation required a large number of weighing operations. The Toledo direct-reading balance shown on the work bench to the left of the electrostatic separator greatly facilitated making the necessary weight determinations of the seed collected in the seed pans.

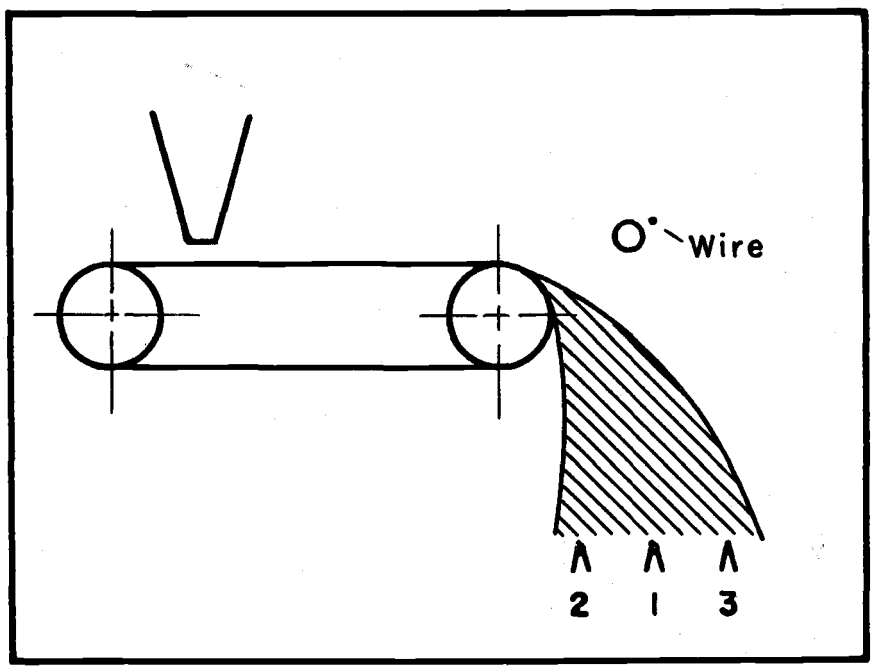


Figure 12

Schematic illustration of the three divider positions determined for each pure seed lot. Position 1 represents the divider setting that will split the seed lot in half. Positions 2 and 3 represent the divider settings that will permit 95 per cent of the seed sample to fall between the two divider positions.

distribution of the seed after it passed through the electrostatic field. The 95 per cent figure was selected on the basis of experimentation. For some crop seeds it was found that at certain machine settings the dividers could not be adjusted to include 100 per cent of the sample. In nearly every instance, however, a divider setting which would exclude 2.5 per cent of the sample on either side of the distribution could be obtained. These divider settings are denoted as positions 2 and 3 in Figure 12. After these three divider settings had been determined for each of the twenty-five machine settings used, the second 20-gram sample, sample B, was used to verify the settings determined using sample A.

A comparison of the divider positions for the twenty-five machine settings for a crop seed and the divider positions for corresponding machine settings for a weed seed was made. Machine settings that yielded the greatest difference between the 50 per cent points for the two kinds of seed were selected as offering the best possibilities for making a separation. The ideal condition for making a separation is shown in Figure 13 where the distributions of the two components of the mixture are completely separated from each other. However, in actual practice, there was an overlapping of the distributions similar to that shown in Figure 14. This necessitated making a comparison

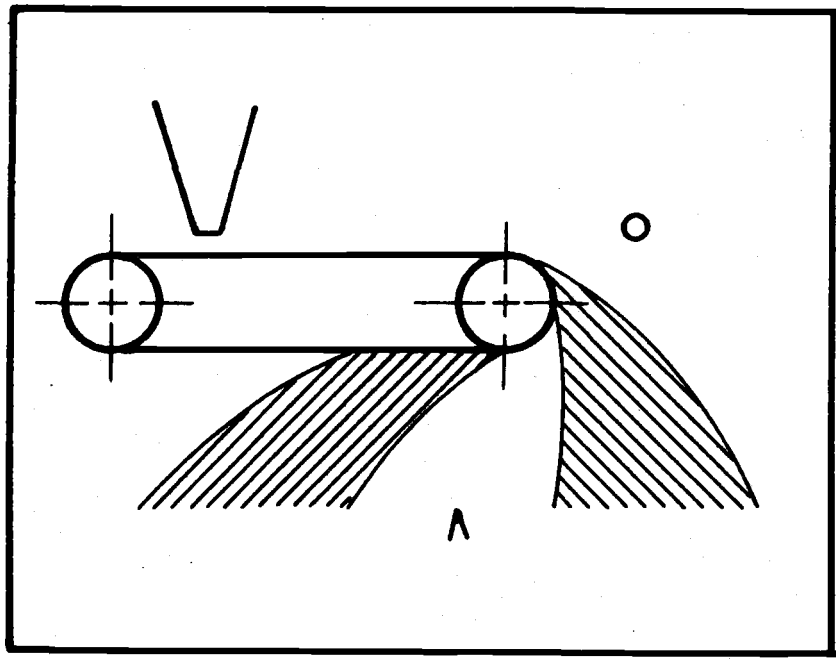


Figure 13

Ideal seed distributions for making a separation. In such a case, a mixture can be separated into its components by placing the divider in the position shown.

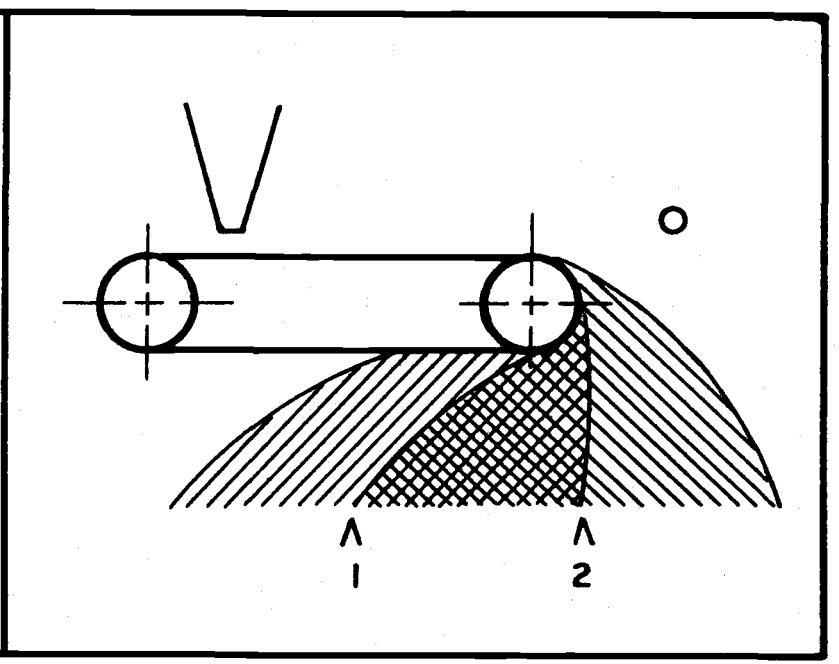


Figure 14

Superposition of the distributions of two kinds of seed. The overlapping of the seed distributions makes separation of the components of the mixture more difficult than in the case illustrated in Figure 13.

of the outer limits of the two seed distributions to determine what divider position to use for separating the two kinds of seed if they were in a mixture. Again, Figure 14 is more or less an ideal case where a clean seed fraction would fall to the left of divider position 1 and a clean fraction of the second seed in the mixture would fall to the right of divider position 2 with a mixture of the two kinds of seed falling between the two divider positions. Usually, it was possible to obtain only one relatively clean seed fraction because of the extensive overlapping of the distributions of the two seeds. The machine settings thus selected using the pure-seed method were further checked by running a 100-gram sample of pure seed through the machine. The procedure outlined above was followed in selecting machine settings with which to attempt a separation for each seed mixture tested.

The final phase of the testing program consisted of running synthetic seed mixtures of approximately one per cent contamination through the machine. Three replicates of each seed mixture were tested. These tests were conducted in the following manner. The seed sample for the first replicate was run through the machine with the electrode in the pinning position and energized with 20,000 volts. This preliminary treatment was required to minimize the effect of initial charging which was apparently

present in some seeds. The machine was then set at the optimum electrode voltage, electrode position, and divider setting as determined by the preliminary testing described above. The seed sample was then run through the machine. Upon completion of the first pass through the machine, two fractions or separates resulted. One of these fractions was placed in an envelope, marked with the proper identification, and set aside to be sent to the Cooperative Seed Laboratory at a later time for analysis. The remaining fraction was then re-run. Again, two fractions resulted. One fraction was placed in an envelope and the other re-run. This procedure was followed for five passes. The seed still remaining after five passes was also placed in an envelope and set aside for analysis. After five passes the original sample of approximately 50 grams had been divided into a total of six fractions, all of which were analyzed by the Cooperative Seed Laboratory. Each of the replicates for the four seed mixtures tested were handled in a similar manner.

All tests were conducted in the seed storage room. Temperature and humidity conditions in the room during actual testing were the same as those maintained for conditioning the seeds to the various moisture contents. This precautionary measure was taken to minimize any changes in the seed moisture contents during a test.

RESULTS OF ELECTROSTATIC SEPARATION TESTS

A list of some of the seed mixtures which the seedsmen consider difficult to separate was compiled from the returns of the seed cleaning questionnaires. This list of seed mixtures is shown in Table III. Four seed mixtures were selected from this list and were tested in the manner described under Testing Procedure. The seed mixtures used were (a) alta fescue and bachelor's button, (b) common ryegrass and bachelor's button, (c) perennial ryegrass and bachelor's button, and (d) red clover and alfalfa. Figure 15 shows a comparison of the sizes and shapes of these seeds. Selection of these particular seed mixtures was based partly on the importance of the crop seeds from the standpoint of relative quantities produced and partly because of the ease with which the constituents of the mixtures could be distinguished from each other. The results of the electrostatic separation tests for each seed mixture will be discussed separately.

Separation of Alta Fescue and Bachelor's Button

The optimum machine settings for making a separation with the seed mixture at moisture condition A were determined by the preliminary testing program using the pure-seed method. The machine settings used were (a) the electrode in the pinning position and energized with 22,500

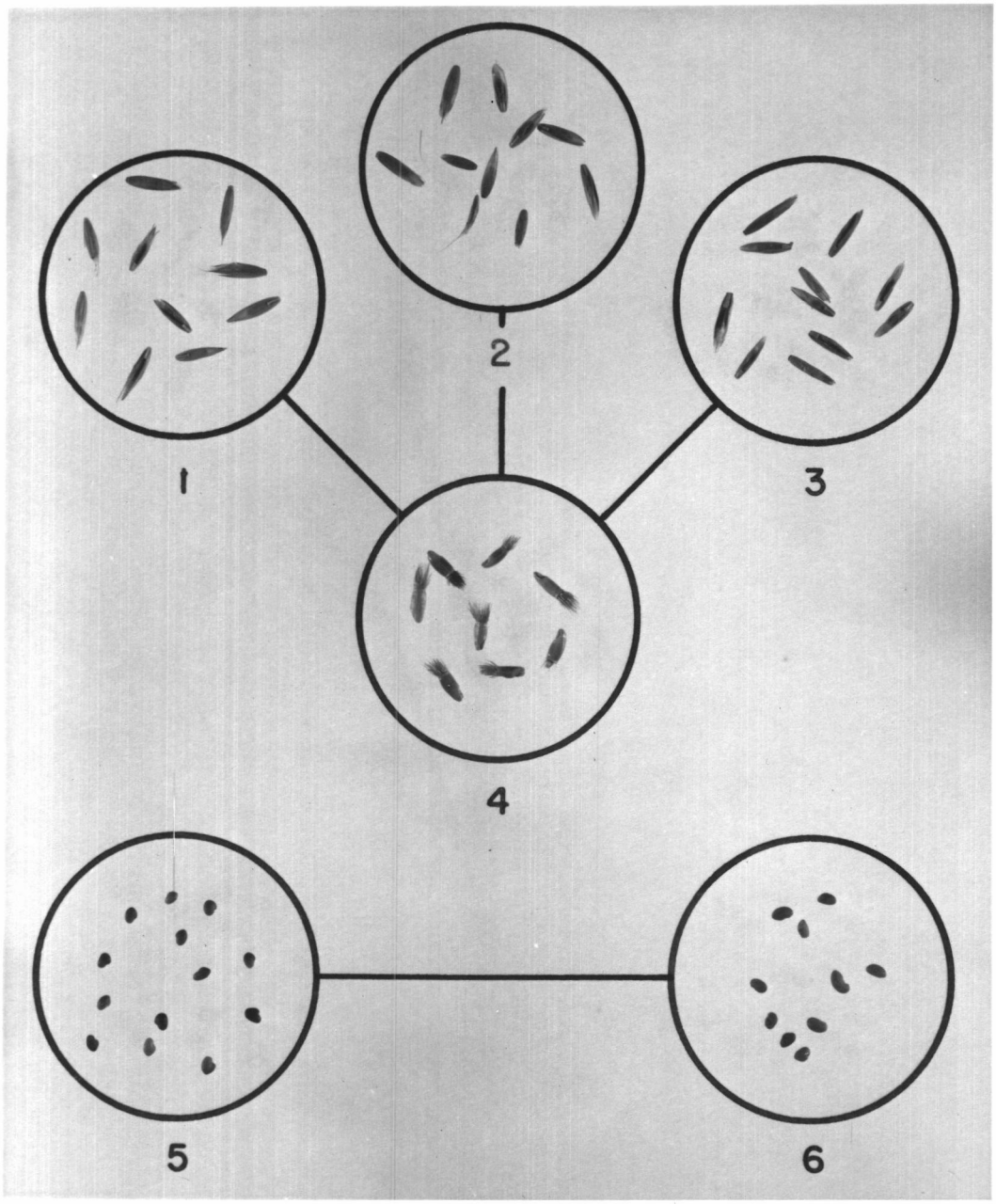


Figure 15

Crop seed and weed seed components used in the synthetic seed mixtures tested. The following seeds were used in the testing program: (1) Alta Fescue, (2) Common Ryegrass, (3) Perennial Ryegrass, (4) Bachelor's Button, (5) Red Clover, and (6) Alfalfa.

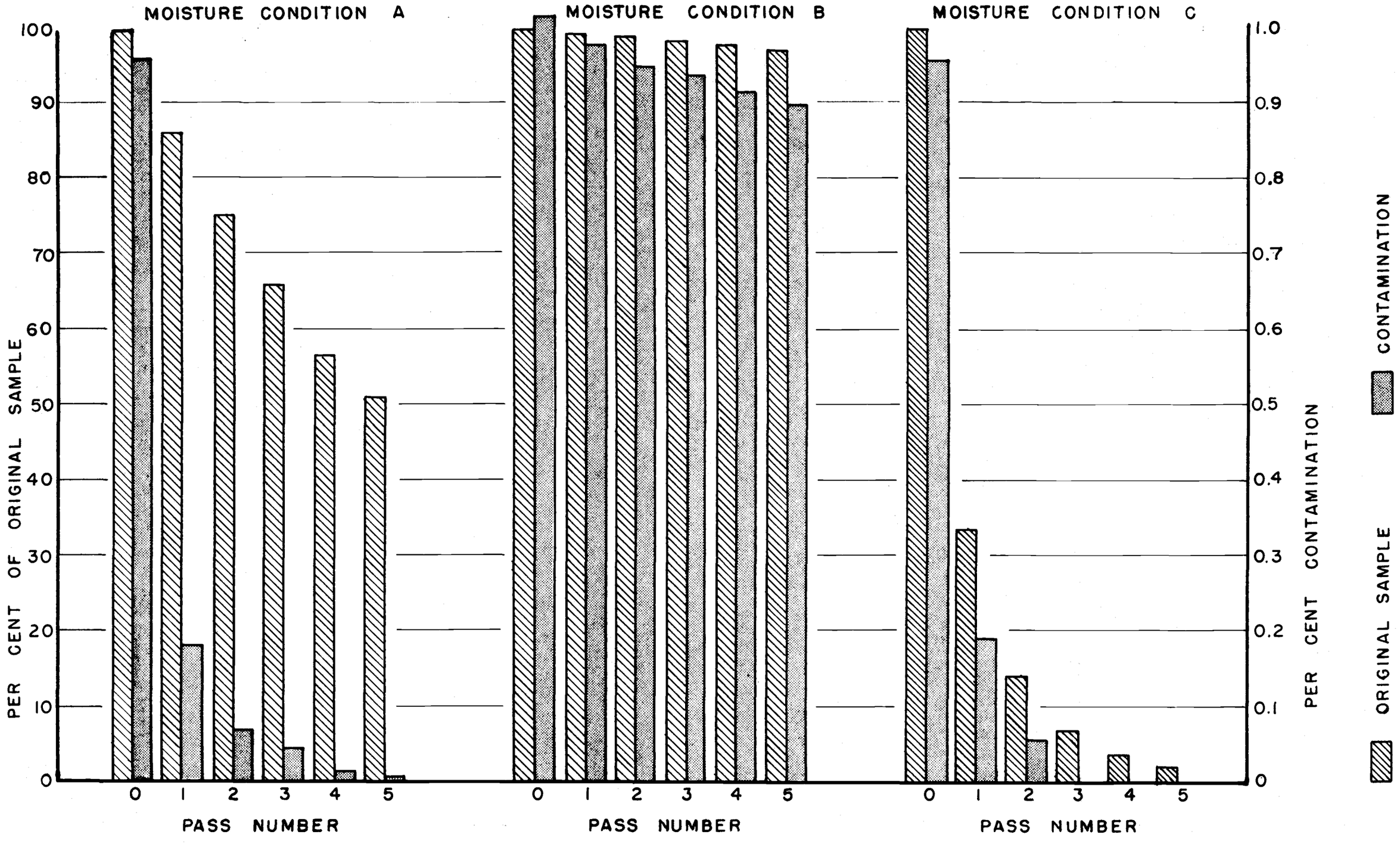
volts and (b) the divider set at 95 on the divider scale. These machine settings were used also for the separations attempted with the alta fescue-bachelor's button mixtures at moisture conditions B and C. The tests conducted for each of the moisture conditions were replicated three times. Table V shows the dry-basis moisture contents of the alta fescue and the bachelor's button for moisture conditions A, B, and C. Test results for each replication have been tabulated and are shown in Table VI. The replication averages are presented as bar graphs in Figure 16. For moisture condition A, the average contamination was reduced from 0.960 per cent to 0.183 per cent after one pass through the machine and to 0.006 per cent after five passes. The reduction of the contamination was also accompanied by a reduction of the percentage of the original sample that remained in the clean seed fraction after any particular pass. In this case, 86.5 per cent of the original sample remained after one pass. This was further reduced to approximately 51.3 per cent after five passes.

As was mentioned, the same machine settings were used for the tests conducted at all three moisture conditions. For the alta fescue-bachelor's button mixtures at moisture condition B, the reduction of the contamination was very small. The contamination was reduced from an average of 1.018 per cent to 0.985 per cent after one pass

Figure 16

Separation of alta fescue and bachelor's button (next page). Separations were attempted with the seed at each of three moisture conditions. The dry-basis moisture contents of the alta fescue were approximately 9.6 per cent, 13.0 per cent, and 7.0 per cent for moisture conditions A, B, and C, respectively. Under the same storage conditions, the bachelor's button had dry-basis moisture contents of approximately 7.0 per cent, 8.4 per cent, and 4.4 per cent for moisture conditions A, B, and C, respectively. Each bar represents the average of three replications. The bars for pass 0 show the average contamination of the samples before being passed through the machine. The bars for passes 1 through 5 represent the per cent of the original sample remaining in the clean seed fractions and the percentage of contamination of the clean seed fractions.

SEPARATION of ALTA FESCUE and BACHELOR'S BUTTON



and to 9.903 per cent after five passes. Approximately 90 per cent of the original sample remained after five passes. The results of the tests for moisture condition C were quite different from those for moisture condition B. The contamination was greatly reduced after one pass and was entirely eliminated from the clean seed fraction after the third pass. However, the total amount of the original samples remaining after three passes was less than seven per cent.

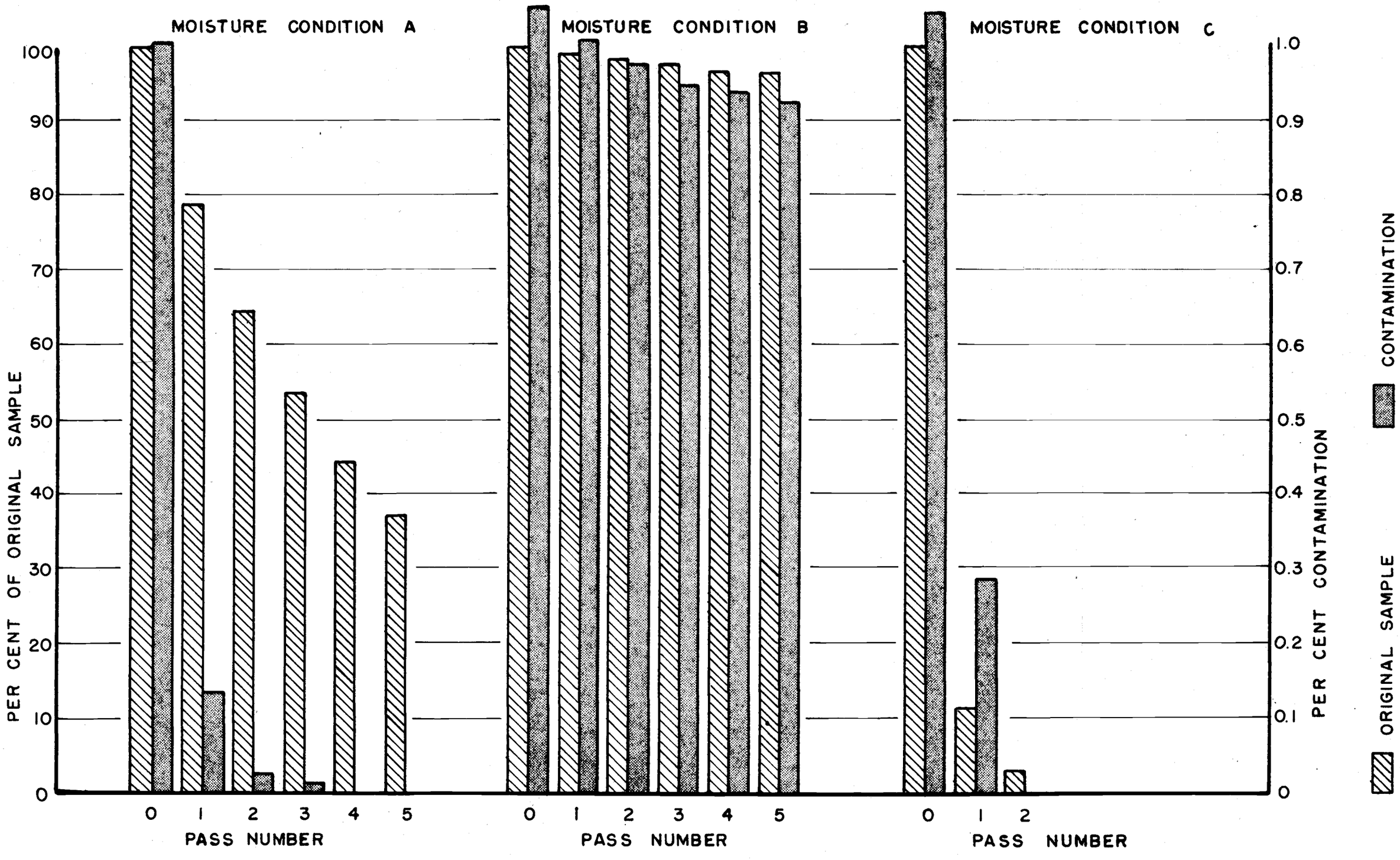
Separation of Common Ryegrass and Bachelor's Button

The optimum machine settings for this separation were determined in the same manner as for the above separation. All attempted separations of common ryegrass and bachelor's button were made using the same machine settings. These settings were (a) the electrode in the pinning position, (b) the electrode energized with 22,500 volts, and (c) the divider set at 95 on the divider scale. Table V shows the dry-basis moisture contents for common ryegrass and bachelor's button at each of the three moisture conditions. As in the case of the previous seed mixture, all tests were replicated three times. Separation results for each replication are shown in Table VII. Figure 17 shows the averages for the replications. At moisture condition A, the contamination was reduced from slightly more than one

Figure 17

Separation of common ryegrass and bachelor's button (next page). The dry-basis moisture contents of the common ryegrass were approximately 9.3 per cent, 12.9 per cent, and 6.7 per cent for moisture conditions A, B, and C, respectively. The dry-basis moisture contents of the bachelor's button were approximately 7.0 per cent, 8.4 per cent, and 4.4 per cent at the three moisture conditions. At moisture condition C, the tests were stopped after two passes because of the relatively small amounts of the original samples remaining in the clean seed fractions. The rate at which the electric charges on the seeds were dissipated was too slow to permit a separation on the electrostatic separator used in this investigation. Each of the bars represents the average test results of three replicates.

SEPARATION of COMMON RYEGRASS and BACHELOR'S BUTTON



per cent to 0.137 per cent with 79.3 per cent of the original sample remaining after one pass. No contamination remained after four passes, but only 44.2 per cent of the original sample remained. Moisture condition B resulted in very little reduction in either contamination or amount of the original sample remaining. The contamination was reduced to slightly less than 0.3 per cent after one pass with the seed mixtures at moisture condition C. The tests at moisture condition C were discontinued after the completion of the second pass because the total amounts of the original samples remaining were less than three per cent and were of an impractical size to pass through the machine.

Separation of Perennial Ryegrass and Bachelor's Button

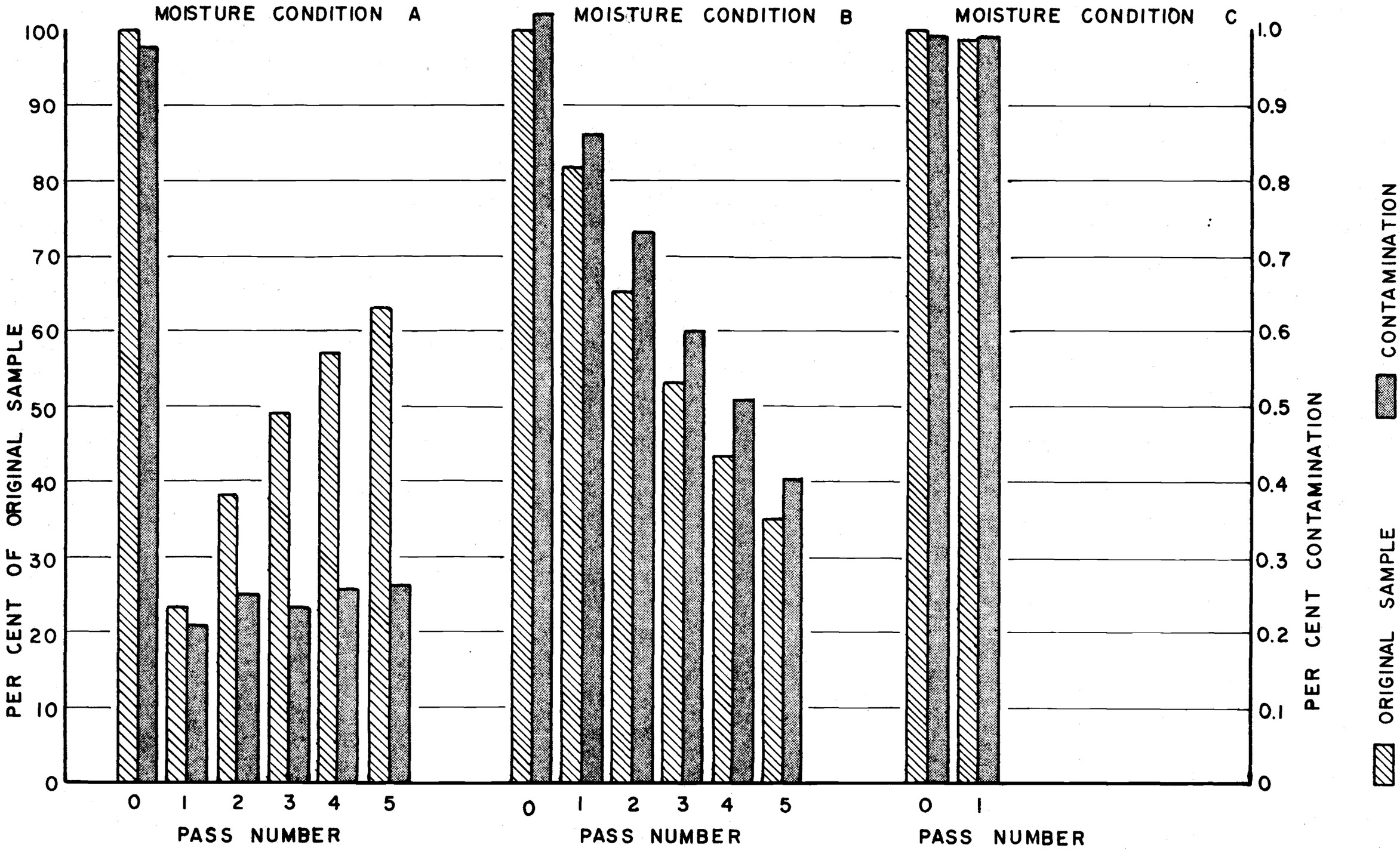
The machine settings used for the separation of perennial ryegrass and bachelor's button were (a) the electrode in the combination lifting and pinning position, (b) the electrode energized with 25,000 volts, and (c) the divider set at 130 on the divider scale. The same machine settings were used for all attempted separations of this mixture. The dry-basis moisture contents for the seed mixture constituents used for testing at each moisture condition are shown in Table V. Test results for the three replications of the perennial ryegrass-bachelor's

button separations are shown in Table VIII and the averages of the tests are presented in Figure 18. The percentages of the original sample in the clean seed fraction are cumulative percentages for the tests conducted at moisture condition A. In these tests, a portion of relatively clean seed was removed from the mixture each time the sample was passed through the machine. Thus, after five passes, approximately 63.0 per cent of the original sample had been reclaimed and this quantity of seed contained 0.261 per cent contamination. For tests conducted at moisture conditions B and C, the percentages of contamination and of original sample remaining are not cumulative. The contamination was reduced from 1.026 per cent to 0.859 per cent after one pass and to 0.408 per cent after five passes when the seed mixture was at moisture condition B. The amount of the original sample remaining in the clean seed fraction was reduced to 81.9 per cent and 35.5 per cent after one and five passes, respectively. At moisture condition C, practically all of the seed mixture was pinned to the feed belt making a separation of any kind impossible. The tests at moisture condition C were halted after the first pass.

Figure 18

Separation of perennial ryegrass and bachelor's button (next page). The dry-basis moisture contents of the perennial ryegrass were approximately 9.1 per cent at moisture condition A, 12.9 per cent at moisture condition B, and 6.9 per cent at moisture condition C. The bachelor's button had moisture contents of approximately 7.0 per cent, 8.4 per cent, and 4.4 per cent at the three moisture conditions. The bars representing the test results at moisture condition A indicate cumulative percentages. The tests were stopped after only one pass at moisture condition C because practically all of the seeds were pinned to the feed belt making a separation impossible. Each bar represents the average of three replications.

SEPARATION of PERENNIAL RYEGRASS and BACHELOR'S BUTTON



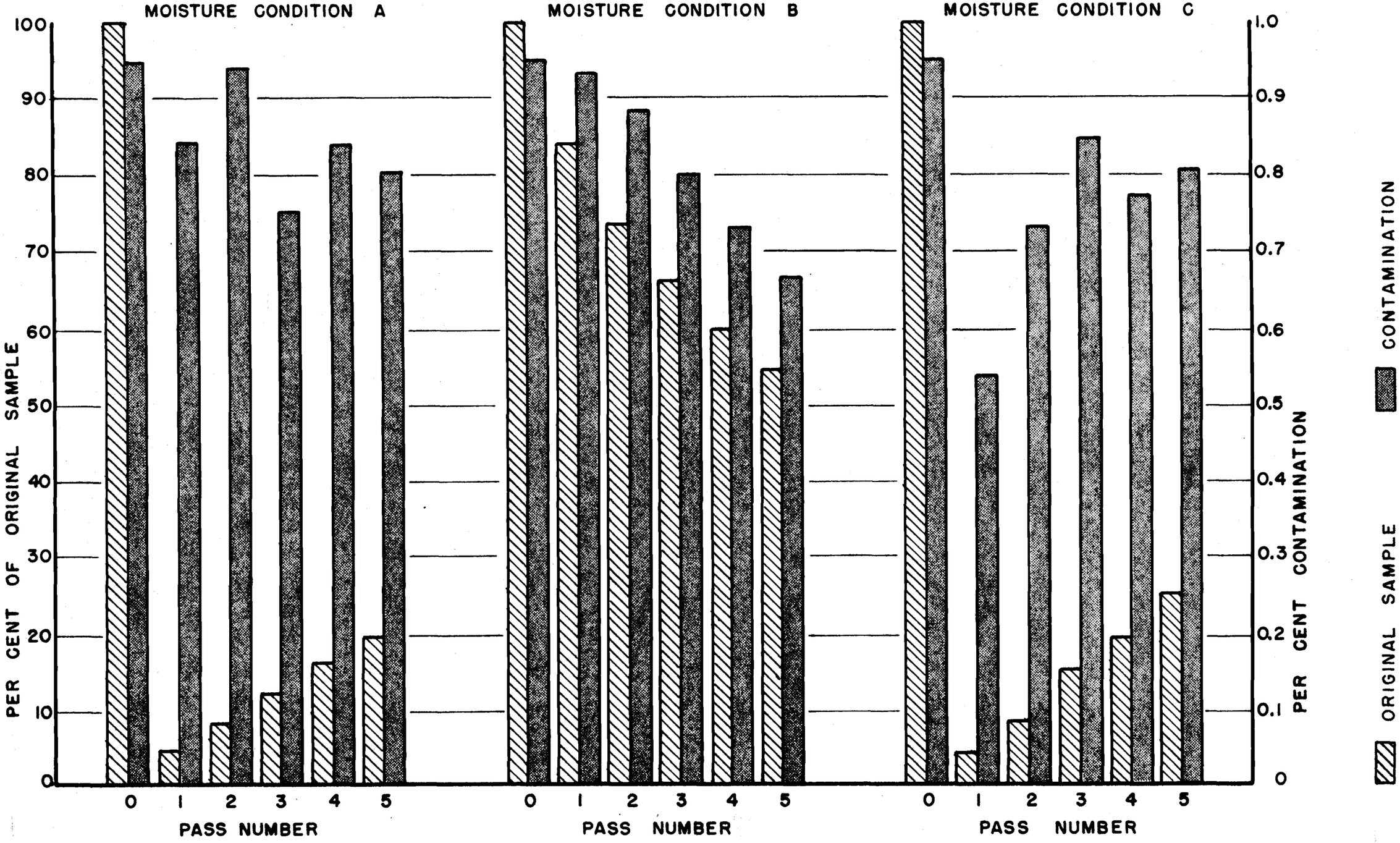
Separation of Red Clover and Alfalfa

Separations of the red clover-alfalfa mixtures were attempted with the following machine settings. The electrode was in the pinning position and energized with 15,000 volts. The divider was set at 140 on the divider scale. These machine settings were determined using the pure-seed method. Table V shows the dry-basis moisture contents for the red clover and the alfalfa at each of the three moisture conditions. Table IX and Figure 19 show the test results for each replication and for the averages of the replications respectively. The percentage figures shown are cumulative for moisture conditions A and C. Only 19.8 per cent of the original samples were reclaimed after five passes when the separations were attempted at moisture condition A and this amount contained 0.806 per cent contamination. Using the same machine settings for moisture condition B, a reduction of the contamination from 0.969 per cent to 0.932 per cent after one pass resulted. The contamination was further reduced to 0.668 per cent after five passes. Approximately 84.2 per cent of the original sample remained in the clean seed fraction after the first pass, and after the fifth pass 53.4 per cent remained. At moisture condition C, slightly more seed was reclaimed after five passes than was reclaimed at moisture condition A. The percentage of contamination after five passes was

Figure 19

Separation of red clover and alfalfa (next page). The dry-basis moisture contents of the red clover were approximately 7.7 per cent, 9.8 per cent, and 6.2 per cent for moisture conditions A, B, and C, respectively. Under the same storage conditions, the alfalfa had moisture contents of approximately 6.4 per cent, 8.0 per cent, and 5.9 per cent. The bars representing the test results at moisture conditions A and C indicate cumulative percentages. Each bar represents the average of three replications.

SEPARATION of RED CLOVER and ALFALFA



also very similar to the contamination remaining in the clean seed fraction of the moisture condition A tests.

EFFECTS OF HIGH VOLTAGE ON GERMINATION

One of the objectives of this investigation was to determine what effect the exposure to high voltage might have on the germination of seeds. An extended testing program was carried out on common ryegrass. It was hoped that the results of this testing program would answer several questions. First, is the germination of common ryegrass affected if the seeds have been exposed to high voltages? Second, if the answer to the first question is affirmative, is there a particular voltage or voltage range where the effects on germination are more pronounced? Third, if the germination is affected by exposure to high voltage, is the effect apparent immediately after treatment or does a period of time elapse before the effect becomes noticeable?

The testing program to determine the effects of exposure to high voltage on the germination of common ryegrass was conducted in the following manner. A quantity of common ryegrass seed was divided into eight portions, one for each of the eight voltage treatments used. These eight portions of seed were then put through the electrostatic separator with a different voltage treatment being used for each seed lot. The voltages to which the different seed lots were exposed were 0, 5,000, 10,000, 15,000,

17,500, 20,000, 22,500, and 25,000 volts. The rate of feed, the feed belt speed, and the electrode position were the same for each voltage treatment. Upon completion of the voltage treatments, each of the eight seed lots were divided into 24 parts. Each part was placed in an envelope which was labelled with the proper identification as to voltage treatment. Three envelopes or samples of seed were then randomly selected from each of the eight voltage treatments and placed in a large envelope. A total of eight large envelopes was thus filled with seed samples constituting three replications of each of the eight voltage treatments used. One envelope was sent immediately to the Cooperative Seed Laboratory for germination tests. At intervals of approximately one month, thereafter, an envelope containing 24 seed samples was sent to the Cooperative Seed Laboratory for germination tests. Because of the limited capacity of the germination testing equipment available at the Cooperative Seed Laboratory, it was not always possible to have the germination tests started on the same day each month. This resulted in unequal time intervals between the germination tests.

The germination tests were conducted as a randomized block experiment with eight voltage treatments and seven date replications. Data obtained from the germination tests are shown in Table X. At the one per cent

significance level, the analysis showed that germination of common ryegrass was not affected by the voltage treatments. The statistical analysis is shown in Table XI. The experimental design did not permit the study of the effects on germination caused by the length of time elapsing between voltage treatments and the start of the germination tests. However, the date replication averages in Table X do not indicate any consistent trend of increase or decrease in the germination resulting from the time interval.

A much less elaborate test was conducted on several other kinds of seed to determine if the exposure to high voltages affected the germination. Table XII shows the various seeds tested and the germination test results before and after the voltage treatments. These seed samples were used in the preliminary testing program. Each of the samples was passed through the machine 50 or more times and was exposed to voltages varying from 0 to 25,000 volts. A statistical analysis of the data in Table XII was conducted to determine if the germination was affected by the voltage treatments. An analysis of variance paired comparison test indicated that at the one per cent significance level the numerous exposures to high voltage had no effect on the germination of various seeds tested.

CONCLUSIONS

A seed separation or seed cleaning process consists of removing contaminating material from a quantity of a crop seed. The contamination may be in various forms such as weed seeds, clods, straw, chaff, animal excreta, or other crop seeds. The ideal separation process would be one in which all forms of contamination were removed with no resulting loss of the crop seed which is being cleaned. Because the ideal is seldom attained, certain limits or permissible tolerances of seed lot contamination must necessarily be established. These limits or tolerances are dictated by state and federal seed laws and vary from crop to crop. From a practical standpoint then, a seed separation may be considered successful if the original contamination has been reduced to within the permissible contamination tolerances which have been established. For this investigation, the maximum permissible contamination for a successful separation was arbitrarily set at 0.50 per cent. This coincides with the contamination limits for the "certified seed" classification for most of the grasses and legumes grown in Oregon (23, pp.6-26).

The separations of bachelor's button from alta fescue, common ryegrass, and perennial ryegrass at moisture condition A are considered successful separations. In each case, the contamination was reduced well below the 0.50

per cent limit after only one pass through the machine. The feasibility of these separations was further enhanced by the relatively large percentages of the original samples that remained in the clean seed fractions after one pass through the machine. The separation of red clover and alfalfa at moisture condition A was not considered successful. The reduction of the contamination was not sufficient to allow the seed lots to meet the minimum requirements for the grade of certified seed.

In an attempt to determine the effects of seed moisture content on separation, tests were conducted at moisture condition B in which the dry-basis moisture contents of the various seed mixtures ranged from approximately 1.5 to 4.0 per cent higher than at moisture condition A. (See Table V.) The increased moisture content of the seeds produced a noticeable change in the rate at which the seeds dissipated electric charges. In effect, the conductivities of the seeds were increased and very few seeds were pinned to the belt. Consequently, the distributions of the seeds after leaving the feed belt were more concentrated than the seed distributions at moisture condition A. These concentrated streams of falling seeds resulted in increased difficulty in making any successful separations. No successful separations were made for either alta fescue and bachelor's button or common

ryegrass and bachelor's button at moisture condition B. In both cases, after five passes the percentages of contamination were practically the same as in the original samples. The perennial ryegrass and bachelor's button mixtures had their contamination percentages reduced to below 0.50 per cent after five passes. The separation of red clover and alfalfa was not successful at moisture condition B. Even after five passes, the clean seed fractions still had more than 0.6 per cent contamination.

At moisture condition C, the seed mixtures were from 1.5 to 3.0 per cent lower than at moisture condition A. (See Table V.) Again, a definite change in the rate at which the seeds dissipated electric charges was observed. In these tests, nearly all of the seeds were pinned to the feed belt. For some mixtures, such as common ryegrass and bachelor's button or perennial ryegrass and bachelor's button, practically the whole sample remained pinned to the feed belt and had to be scraped off the underside of the feed belt by a wooden scraper. In these instances, it was impossible to make any separation. The separation of bachelor's button from alta fescue at moisture condition C was successful from the standpoint of reducing the contamination to within the specified limits, but the percentage of the original sample remaining in the clean seed fraction was reduced to approximately one third after

one pass through the machine. Red clover and alfalfa mixtures produced separation results when tested at moisture condition C that were quite similar to the results obtained at moisture condition A. Even after five passes, the percentages of contamination were substantially higher than the 0.50 per cent value which is the maximum contamination allowed for the separation to be considered a successful one. A summary of successful and unsuccessful separations at the various moisture conditions is presented in Table II.

It should be pointed out that though many of the attempted separations were unsuccessful at moisture conditions B and C, it is not implied that separations of these mixtures cannot be made under these conditions. The machine settings used for all of the tests were determined using pure seed lots whose moisture contents corresponded to moisture condition A. The tests were purposely conducted in this manner to determine the effects of moisture content on the separations. It is possible that machine settings could be determined for each moisture condition that would produce successful separations.

The germination test results of common ryegrass exposed to high voltage were not statistically significant. Also, they were not significant from a practical standpoint because of the variables involved which are not

Table II

SUMMARIZATION OF SEED SEPARATION RESULTS

Separation of	Moisture Condition	Contamination reduced to 0.50 per cent or less	
		After 1 pass	After 5 passes
Alta Fescue and Bachelor's Button	A	yes	yes
	B	no	no
	C	yes	yes
Common Ryegrass and Bachelor's Button	A	yes	yes
	B	no	no
	C	yes	yes
Perennial Ryegrass and Bachelor's Button	A	yes	yes
	B	no	yes
	C	no	no
Red Clover and Alfalfa	A	no	no
	B	no	no
	C	no	no

accounted for in the statistical analysis. The statistical analysis is concerned only with the final results of the germination tests. In practice, there are a number of variables, such as temperature and humidity changes in the germinator, that affect the final results of the germination tests. It is these variables that are not accounted for in the statistical analysis. Therefore, greater tolerances are permitted in practice than would be permitted on the basis of the statistical analysis alone. All of the germination percentages are well within the permitted tolerances prescribed by the Association of Official Seed Analysts (3, p.76).

No attempt was made to determine the cleaning capacity or cleaning rate of the electrostatic separator since the machine used in this investigation was not designed for use as a commercial separator. Machine capacity, however, is only one of the factors which must be considered before the electrostatic separation process can be recommended as being economically feasible for commercial seed separation purposes. Other factors which also must be considered are the monetary value of the seeds being cleaned and whether or not a satisfactory separation can be made with conventional seed cleaning equipment. The electrostatic separation process does appear to have possibilities for making seed separations that are impracticable or impossible with conventional seed cleaning

equipment. In this respect, the electrostatic separator would probably be classed as a finishing machine in a seed cleaning plant. The seed mixture to be cleaned might first be processed on the conventional equipment and then with the electrostatic separator as the final step in the cleaning sequence.

Summary of Conclusions

Conventional seed cleaning equipment makes separations on the basis of differences in size, shape, weight, and surface characteristics of the seeds in the mixture to be cleaned. Electrostatic separators utilize different physical properties of the seeds to effect a separation. The properties used by the electrostatic separator are electrical conductivity, contact potential, and dielectric constant. Therefore, the electrostatic separation process may be used to make separations that are impracticable or impossible with conventional seed cleaners.

Test results indicated that successful separations of bachelor's button from alta fescue, common ryegrass, and perennial ryegrass could be made with the seeds at moisture condition A. In each of these mixtures, the percentages of contamination were reduced well below the arbitrarily set 0.50 per cent value after only one pass through the machine. Red clover and alfalfa were found

not to be separable under the conditions tested. Test results further indicated that the seed moisture content has a definite effect on the separations. The electrical conductivities of the seeds increase as the moisture content increases. This resulted in an increase in the rate at which seeds are capable of dissipating electric charges. Likewise, a decrease in moisture content causes a very noticeable reduction in the rate at which the seeds are able to dissipate electric charges. Exposure of the seeds to high voltages apparently had no effect on the germination of the seeds tested. Results of the germination tests of common ryegrass conducted at different time intervals, ranging up to six months after exposure to high voltages, show no practical differences in the germination of the seed.

RECOMMENDATIONS FOR FUTURE STUDY

This investigation did not by any means cover all of the phases of the electrostatic separation of crop seed mixtures. It was found that certain seed mixtures could be separated under particular seed moisture conditions and that the separation was affected by changing those moisture conditions. Future research on electrostatic separation should be concerned with expanding the list of seed mixtures found to be separable by this method. The optimum seed moisture content or the moisture content range for separation of the various seeds needs to be investigated. In their work on the influence of relative humidity on the conducting properties of solid dielectrics, Cohn and Guest show the effects of moisture pick up from the air on the conducting properties of several fibrous and nonfibrous materials (9, pp.22-23, 29-36). It may be possible to bring crop seeds to their optimum moisture conditions for separation merely by passing them through a humidity conditioning chamber which might well be an integral part of the electrostatic separator. The commercial value of the electrostatic separation processes will be lessened if extensive seed conditioning is required to obtain the optimum seed moisture conditions necessary to effect a separation. The study of moisture conditioning

methods for seeds along with the study of other ways and means of charging the seeds are subjects recommended for future study.

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APPENDICES

APPENDIX A

SEED CLEANING QUESTIONNAIRE AND SEED CLEANING QUESTIONNAIRE RETURNS

OREGON STATE COLLEGE
Department of Agricultural Engineering

SEED CLEANING QUESTIONNAIRE

Business Name _____

Address _____

_____

Manager _____

Please list the seed mixtures with which you have had difficulty cleaning or have been unable to separate at all. (Examples: Alta Fescue and Common Ryegrass or Clover and Sheep Sorrel.)

Seed Mixtures	Type of cleaning equipment used for separation at present time
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

Do you have any of the above seed mixtures on hand at the present time for which arrangements could be made for us to obtain samples for testing purposes? If so, please indicate these seed mixtures by placing a check mark (x) in the margin beside the available mixture.

Thank you for your cooperation in filling out this questionnaire.

_____

Figure 20

Example of seed cleaning questionnaire sent to 20 Oregon seed cleaning establishments

Table III

SEED MIXTURES THAT OFFER CLEANING PROBLEMS IN OREGON AS DETERMINED FROM SEED CLEANING QUESTIONNAIRES

Alfalfa and
- Black medic
- Dodder
- Red clover
- Sweet clover

Bentgrass, Astoria and
- Big mouse-ear
- Bluegrasses
- Chickweed
- Path rush
- Redtop
- Seaside bentgrass
- Sticky mouse-ear
- Western bentgrass

Bentgrass, Highland and
- Bluegrasses
- Canadian Thistle
- Clods of dirt
- Ergot
- Nematode galls
- Redtop
- Silver hairgrass
- Yarrow

Bentgrass, Seaside and
- Astoria bentgrass
- Big mouse-ear
- Bluegrasses
- Chickweed
- Path rush
- Redtop
- Sticky mouse-ear
- Toad rush
- Western bentgrass

Bluegrass, Kentucky and
- Astoria bentgrass
- Dandelion
- Immature quackgrass
- Seaside bentgrass
- Sedge

Bluegrass, Merion and
- Canadian thistle
- Ladino clover
- Quackgrass
- Sheep sorrel

Clover, Alsike and
- Dodder
- Hop clover
- Ladino clover
- Lambsquarter
- Pigweed
- Red clover
- Sheep sorrel
- White clover

Clover, Crimson and
- Mustard
- Rape
- Wild peas
- Wild vetch

Clover, Ladino and
- Alsike clover
- Dodder
- Lambsquarter
- Merion bluegrass
- Pigweed
- Red clover
- Sheep sorrel
- Western witchgrass
- White clover

Clover, Red and
- Alfalfa
- Alsike clover
- Black medic
- Dodder
- Ladino clover
- Mustard
- Spreading amaranth
- White clover

Fescue, Alta and
- Bachelor's button
- Bristly dogtail
- Canadian thistle
- Chess
- Common ryegrass
- Perennial ryegrass
- Quackgrass

Fescue, Chewings and
- Canadian thistle
- Common ryegrass
- Creeping red fescue
- Illahee fescue
- Quackgrass
- Rattail fescue

Fescue, Creeping red and
- Canadian thistle
- Chewings fescue
- Common ryegrass
- Illahee fescue
- Perennial ryegrass
- Quackgrass

Fescue, Illahee and
- Chewings fescue
- Creeping red fescue

Johnson grass and
- Canadian thistle
- Quackgrass
- Sudan

Ryegrass, Common and
- Alta fescue
- Bachelor's button
- Bristly dogtail
- Canadian thistle
- Cheat
- Chewings fescue
- Creeping red fescue
- Perennial ryegrass
- Quackgrass
- Tarweed
- Tualitan oatgrass

Ryegrass, Perennial and
- Alta fescue
- Bachelor's button
- Canadian thistle
- Chewings fescue
- Common ryegrass
- Creeping red fescue
- Quackgrass
- Tarweed
- Tualitan oatgrass

Sudan and
- Canadian thistle
- Johnson grass
- Quackgrass

Vetch, Hairy and
- Common vetch
- Garlic
- Rough peas
- Wheat

Wheat and
- Barley
- Hairy vetch

APPENDIX B

TEST DATA AND STATISTICAL ANALYSIS

Table IV

PURITY OF ORIGINAL SEED LOTS

Seed	Pure Seed %	Crop Seed %	Inert Matter %	Weed Seed %
Alfalfa (Medicago sativa)	99.94	0.00	0.06	0.00
Bachelor's Button (Centaurea cyanus)	100.00	0.00	0.00	0.00
Clover, Red (Trifolium pratense)	99.07	0.04	0.75	0.14
Fescue, Alta (Festuca arundinacea)	99.53	0.06	0.15	0.26
Ryegrass, Common (Lolium multiflorum)	98.95	0.20	0.79	0.06
Ryegrass, Perennial (Lolium perenne)	99.49	0.02	0.35	0.14

Table V

SEED MOISTURE CONTENT (DRY-BASIS) AT TIME OF TESTING

Seed	Replication	Moisture Condition		
		A	B	C
Alfalfa (Medicago sativa)	1	--	8.06	5.87
	2	6.65	8.08	5.86
	Average	6.65	8.07	5.86
Bachelor's Button (Centaurea cyanus)	1	7.04	8.15	4.40
	2	7.02	8.59	4.43
	Average	7.03*	8.37	4.41
Clover, Red (Trifolium pratense)	1	7.64	9.75	6.14
	2	7.69	9.82	6.24
	Average	7.66	9.78	6.19
Fescue, Alta (Festuca arundinacea)	1	9.61	13.04	7.04
	2	9.51	13.04	7.02
	Average	9.56	13.04	7.03
Ryegrass, Common (Lolium multiflorum)	1	9.29	12.86	6.71
	2	9.31	12.96	6.67
	Average	9.30	12.91	6.69
Ryegrass, Perennial (Lolium perenne)	1	9.11	12.91	6.90
	2	9.11	12.96	6.94
	Average	9.11	12.93	6.92

*Moisture samples were taken after completion of testing program.

Table VI

SEPARATION OF ALTA FESCUE AND BACHELOR'S BUTTON

Moisture Condition	Weight of Seed Samples Tested (grams) Rep. 1	Rep. 2	Rep. 3	Average
A	50.57	50.65	50.71	50.64
B	48.70	48.64	48.57	48.64
C	50.03	50.08	50.04	50.05
	Per Cent of Contamination in Seed Samples (by weight)			
A	0.93	1.00	0.95	0.96
B	1.00	1.03	1.03	1.02
C	0.97	0.96	0.95	0.96

COMPOSITION OF CLEAN SEED FRACTION

Pass	Per Cent Original Sample in Clean Seed Fraction (by wt.) Rep.1	Rep.2	Rep.3	Ave.	Per Cent Contamination in Clean Seed Fraction (by wt.) Rep.1	Rep.2	Rep.3	Ave.
			Moisture Condition A					
1	86.57	86.78	86.16	86.50	0.16	0.20	0.20	0.18
2	76.61	75.23	74.62	75.49	0.05	0.10	0.07	0.07
3	67.28	65.86	65.10	66.08	0.04	0.06	0.03	0.04
4	59.50	57.73	56.73	57.98	0.02	0.02	0.02	0.02
5	53.50	51.14	49.12	51.25	0.02	0.00	0.00	0.01
			Moisture Condition B					
1	99.51	99.57	99.58	99.55	0.97	0.97	1.01	0.99
2	99.09	99.14	99.10	99.11	0.94	0.95	0.97	0.95
3	98.66	98.66	98.66	98.66	0.94	0.93	0.95	0.94
4	98.22	97.97	98.14	98.11	0.91	0.90	0.94	0.92
5	97.68	97.44	97.70	97.61	0.89	0.88	0.94	0.90
			Moisture Condition C					
1	33.26	34.11	32.18	33.18	0.23	0.26	0.09	0.20
2	14.44	15.52	12.78	14.25	0.06	0.06	0.06	0.06
3	7.32	7.73	6.48	7.17	0.00	0.00	0.00	0.00
4	3.82	4.31	3.73	3.96	0.00	0.00	0.00	0.00
5	2.44	2.64	1.95	2.34	0.00	0.00	0.00	0.00

Table VII

SEPARATION OF COMMON RYEGRASS AND BACHELOR'S BUTTON

Moisture Condition	Weight of Seed Samples Tested (grams) Rep. 1	Rep. 2	Rep. 3	Average
A	50.64	50.67	50.56	50.62
B	49.22	49.25	48.67	49.05
C	49.98	49.83	49.98	49.93
	Per Cent of Contamination in Seed Samples (by weight)			
A	1.02	1.00	1.00	1.01
B	1.06	1.03	1.01	1.03
C	1.10	1.00	1.05	1.05

COMPOSITION OF CLEAN SEED FRACTION

Pass	Per Cent Original Sample in Clean Seed Fraction (by wt.) Rep.1	Rep.2	Rep.3	Ave.	Per Cent Contamination in Clean Seed Fraction (by wt.) Rep.1	Rep.2	Rep.3	Ave.
	Moisture Condition A							
1	80.61	79.35	77.96	79.31	0.12	0.18	0.12	0.14
2	65.66	64.94	62.68	64.43	0.02	0.03	0.04	0.03
3	54.99	54.06	51.19	53.41	0.00	0.00	0.05	0.02
4	45.91	44.56	42.14	44.20	0.00	0.00	0.00	0.00
5	38.67	37.66	35.48	37.27	0.00	0.00	0.00	0.00
	Moisture Condition B							
1	99.37	99.35	99.40	99.37	1.03	1.00	1.00	1.01
2	98.67	98.68	98.68	98.68	1.00	1.00	0.96	0.98
3	97.82	97.92	98.02	97.92	0.96	0.95	0.93	0.95
4	96.96	97.18	97.47	97.20	0.95	0.93	0.94	0.94
5	96.13	96.43	96.83	96.47	0.93	0.93	0.91	0.92
	Moisture Condition C							
1	10.16	12.10	12.38	11.54	0.26	0.51	0.10	0.29
2	2.26	3.34	2.92	2.84	0.00	0.00	0.00	0.00
3	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--

Table VIII

SEPARATION OF PERENNIAL RYEGRASS AND BACHELOR'S BUTTON

Moisture Condition	Weight of Seed Samples Tested (grams) Rep. 1	Rep. 2	Rep. 3	Average
A	50.74	50.76	50.84	50.78
B	48.66	48.83	48.03	48.50
C	49.46	49.63	49.81	49.63
	Per Cent of Contamination in Seed Samples (by weight)			
A	0.98	0.98	0.97	0.97
B	1.01	1.01	1.06	1.03
C	1.01	0.99	0.99	1.00

COMPOSITION OF CLEAN SEED FRACTION

Pass	Per Cent Original Sample in Clean Seed Fraction (by wt.) Rep.1	Rep.2	Rep.3	Ave.	Per Cent Contamination in Clean Seed Fraction (by wt.) Rep.1	Rep.2	Rep.3	Ave.
			Moisture Condition A					
1	23.54	22.13	22.72	22.79	0.20	0.21	0.23	0.21
2	39.28	37.84	38.83	38.65	0.22	0.27	0.24	0.24
3	49.82	48.84	49.64	49.43	0.19	0.23	0.28	0.23
4	57.28	56.78	58.16	57.41	0.25	0.24	0.29	0.26
5	63.09	62.49	63.67	63.08	0.22	0.24	0.32	0.26
			Moisture Condition B					
1	83.61	81.73	80.24	81.86	0.71	0.97	0.90	0.86
2	70.25	66.31	60.18	65.58	0.58	0.85	0.79	0.74
3	58.31	54.78	46.58	53.22	0.49	0.68	0.66	0.61
4	49.24	45.07	36.06	43.46	0.42	0.63	0.49	0.51
5	41.18	37.48	27.77	35.48	0.46	0.39	0.37	0.41
			Moisture Condition C					
1	99.17	99.79	99.76	99.75	1.01	1.00	1.00	1.00
2	--	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	--	--

Table IX

SEPARATION OF RED CLOVER AND ALFALFA

Moisture Condition	Weight of Seed Samples Tested (grams) Rep. 1	Rep. 2	Rep. 3	Average
A	50.62	50.57	50.50	50.56
B	48.53	48.77	48.53	48.61
C	49.51	49.56	50.20	49.76
	Per Cent of Contamination in Seed Samples (by weight)			
A	0.90	0.95	0.99	0.95
B	0.96	0.97	0.98	0.97
C	0.94	0.97	0.94	0.95

COMPOSITION OF CLEAN SEED FRACTION

Pass	Per Cent Original Sample in Clean Seed Fraction (by wt.) Rep.1	Rep.2	Rep.3	Ave.	Per Cent Contamination in Clean Seed Fraction (by wt.) Rep.1	Rep.2	Rep.3	Ave.
			Moisture Condition A					
1	4.09	5.15	4.06	4.34	0.68	1.23	0.63	0.84
2	7.80	9.31	6.98	8.03	0.94	1.08	0.79	0.94
3	12.50	13.73	10.56	12.26	0.85	0.95	0.75	0.85
4	16.23	17.89	13.92	16.02	0.96	0.96	0.60	0.84
5	19.95	21.34	18.25	19.85	0.87	0.90	0.65	0.81
			Moisture Condition B					
1	88.01	83.56	80.90	84.15	0.93	0.95	0.92	0.93
2	75.17	72.54	72.60	73.44	0.87	0.90	0.87	0.88
3	65.52	67.23	64.82	65.85	0.79	0.84	0.77	0.80
4	59.32	62.59	59.02	60.31	0.77	0.75	0.69	0.74
5	53.20	56.35	53.65	54.40	0.69	0.71	0.60	0.67
			Moisture Condition C					
1	3.29	4.65	4.23	4.51	0.49	0.61	0.52	0.54
2	7.97	8.53	8.71	8.40	0.81	0.66	0.71	0.73
3	15.68	15.19	13.72	14.86	0.91	0.89	0.74	0.84
4	20.61	19.06	18.71	19.46	0.73	0.85	0.73	0.77
5	27.55	25.00	23.65	25.40	0.81	0.80	0.82	0.81

Table X

PER CENT GERMINATION OF COMMON RYEGRASS FOR EIGHT VOLTAGE TREATMENTS AND SEVEN TIME INTERVALS

Date Replication / Number of days after exposure	Voltage to Which Seeds Were Exposed								Date Replication Averages
	0	5,000	10,000	15,000	17,500	20,000	22,500	25,000	
12	95	95	95	94	94	92	95	95	
	96	96	93	90	93	96	95	94	94.3
	93	95	95	95	93	94	94	96	
35	95	98	96	99	97	96	93	97	
	95	95	96	95	95	93	94	95	95.5
	97	94	94	95	97	93	95	98	
62	96	96	95	97	95	96	93	92	
	98	97	95	95	96	97	97	95	95.3
	96	96	94	93	96	96	92	95	
96	97	97	93	97	96	97	96	98	
	96	97	95	94	96	97	95	95	96.0
	98	93	97	96	97	94	96	97	
118	96	93	96	96	96	96	96	96	
	96	96	93	95	95	96	96	95	95.5
	97	95	97	95	98	95	94	94	
161	96	93	94	94	96	96	92	94	
	94	95	95	94	92	94	92	94	94.2
	93	97	97	94	94	94	94	92	
189	97	97	96	94	93	93	96	96	
	96	95	94	98	94	95	91	94	95.2
	96	96	97	93	96	96	96	97	

Table XI

STATISTICAL ANALYSIS TO DETERMINE THE EFFECTS OF EXPOSURE TO HIGH VOLTAGE ON THE GERMINATION OF COMMON RYEGRASS

Source of Variation	D.F.	Sum of Squares	Mean Square	F	Remarks
Total	167	423.28	--	--	
Replication	6	95.16	10.86		
Treatments	7	27.47	3.92	2.15	**
Experimental Error	42	76.65	1.82		
Sampling Error	112	254.00	2.27	--	

**Not significant at the one per cent level.

Table XII

EFFECTS OF HIGH VOLTAGE ON THE GERMINATION OF SEVERAL CROP AND WEED SEEDS

Seed	Length of Germination Test in Days	Per Cent Germination	
		Before exposure to high voltage	After 50 or more exposures to high voltage
Alfalfa (Medicago sativa)	7	82	84
Bachelor's Button (Centaurea cyanus)	10	76	75
Clover, Alsike (Trifolium hybridum)	7	77	80
Clover, Dutch White (Trifolium repens)	7	67	68
Clover, Red (Trifolium pratense)	7	84	83
Fescue, Alta (Festuca arundinacea)	14	85	85
Fescue, Chewings (Festuca rubra var. commutata)	14	94	95
Fescue, Creeping Red (Festuca rubra)	14	97	97
Ryegrass, Common (Lolium multiflorum)	14	95	96
Ryegrass, Perennial (Lolium perenne)	14	97	93

APPENDIX C

FRAME AND ASSEMBLY DRAWINGS OF ELECTROSTATIC SEPARATOR

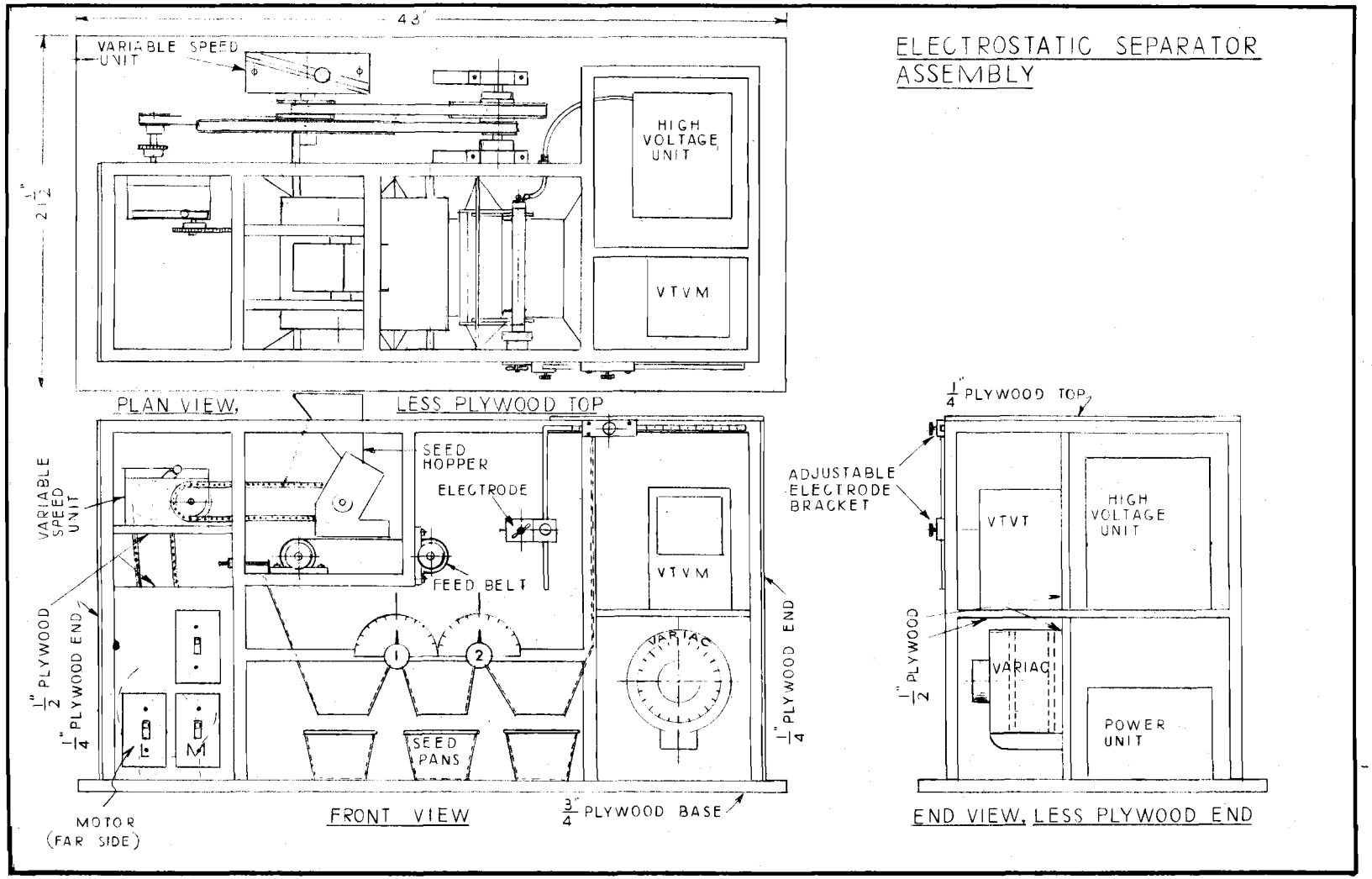

Figure 21
Assembly drawing of the electrostatic separator.

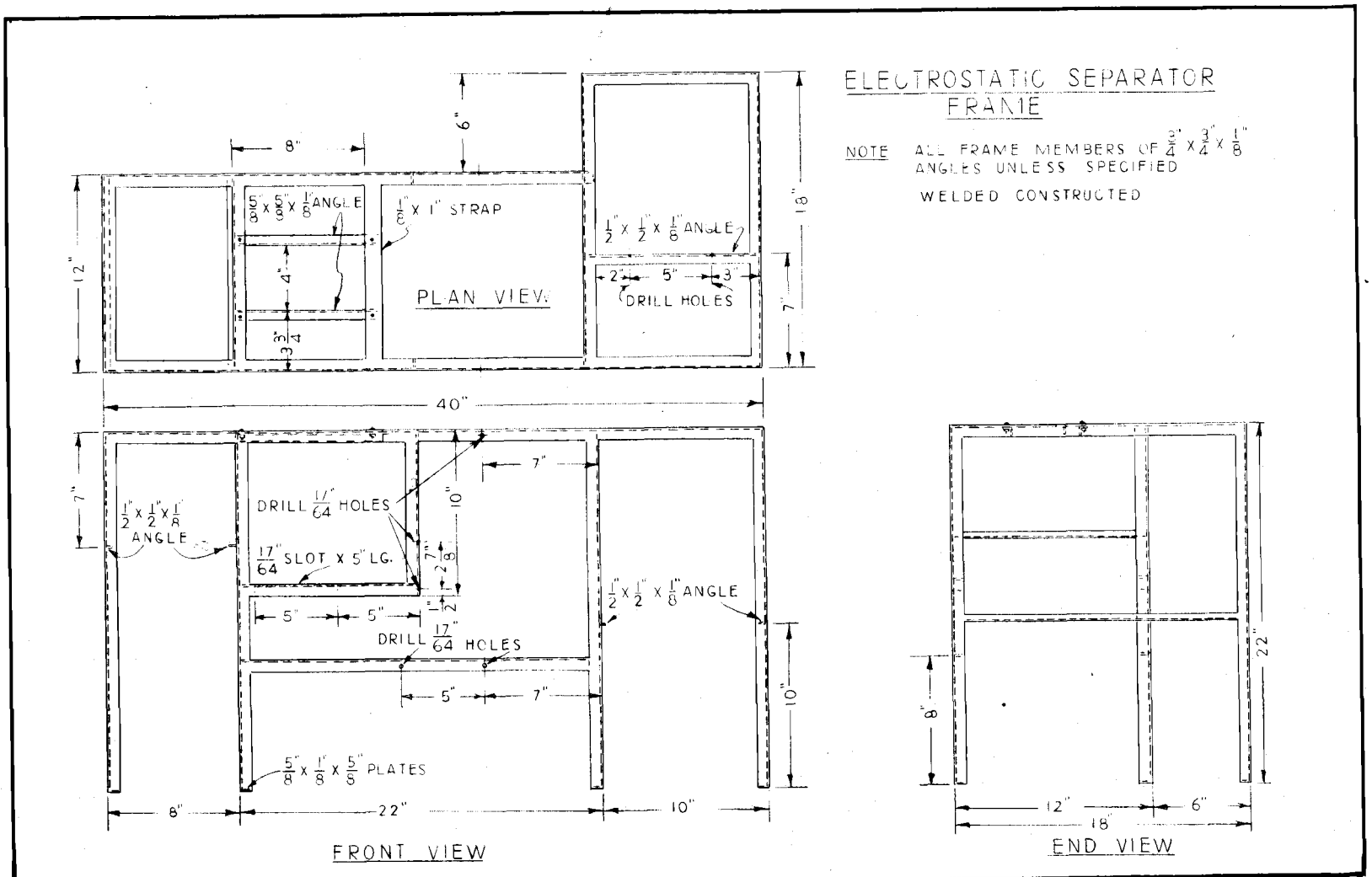

Figure 22

Frame of electrostatic separator.

APPENDIX D

ELECTRIC FIELDS IN THE ELECTROSTATIC SEPARATOR

ELECTRIC FIELDS IN THE ELECTROSTATIC SEPARATOR

Electric fields surround energized electrical conductors. The configuration of the electric field depends upon the shape of the conductor and the presence of other nearby conductors. There are a number of mathematical graphical and experimental methods available for plotting the shape of an electric field. Some methods are extremely cumbersome and applicable to only the simplest shapes of conductors. Other methods require elaborate laboratory equipment. In this investigation, a General Electric Company analog field plotter was used to obtain two-dimensional plots of the fields in the electrostatic separator for various electrode positions.

The analog field plotter consists of a d.c. power supply unit, an instrument detecting unit, and a searching or marking probe along with the necessary leads and connecting accessories. With this device it is possible to map electric fields which are set up in a thin sheet of conducting paper. The electrodes and boundaries are established on the conducting paper by means of a silver conducting paint or by attaching metal electrodes of the proper shape to the paper. For convenience, the paper is mounted on a plotting board. The electrodes are connected to the power unit and the detecting unit in the prescribed

manner. The power unit is equipped with a voltage divider with which the output voltage may be varied as desired. The detecting unit is a d.c. microammeter having the zero reading point at the center of the scale. For a particular voltage divider setting, the detecting unit will read zero when the marking stylus or probe is on a line of equipotential. This permits the operator to trace an equipotential line on the conducting paper for each voltage divider setting. A typical analog field plotter set-up is shown in Figure 23.

The electrode and boundary conditions used in making the field plots were those of a vertical plane passing through the center of the feed belt of the electrostatic separator. A vertical cross-section of the frame of the separator constituted the boundaries of the field plots. The boundaries and the electrode were painted on the conducting paper with silver conducting paint. One end of a piece of wire was fastened to the painted electrode while the other end was placed on the conducting paper at positions depending upon the particular field that was being plotted. Figure 23 shows the electrode in the lifting position. The lines appearing on the conducting paper represent equipotential lines. A completed field plot includes not only the equipotential lines but also the lines representing the electric flux in the field.

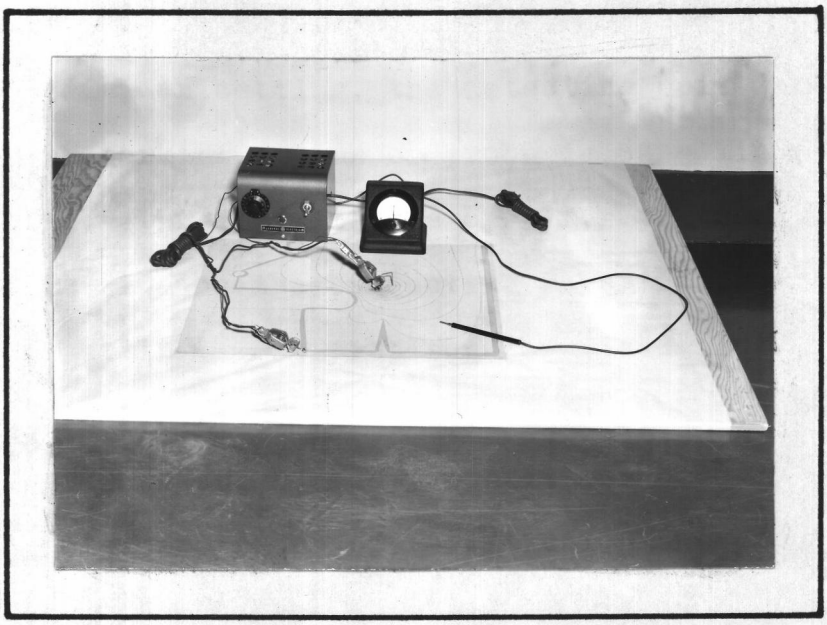

Figure 23

General Electric Company analog field plotter.

Figures 24, 25, and 26 are completed field plots showing the electrode in three different positions.

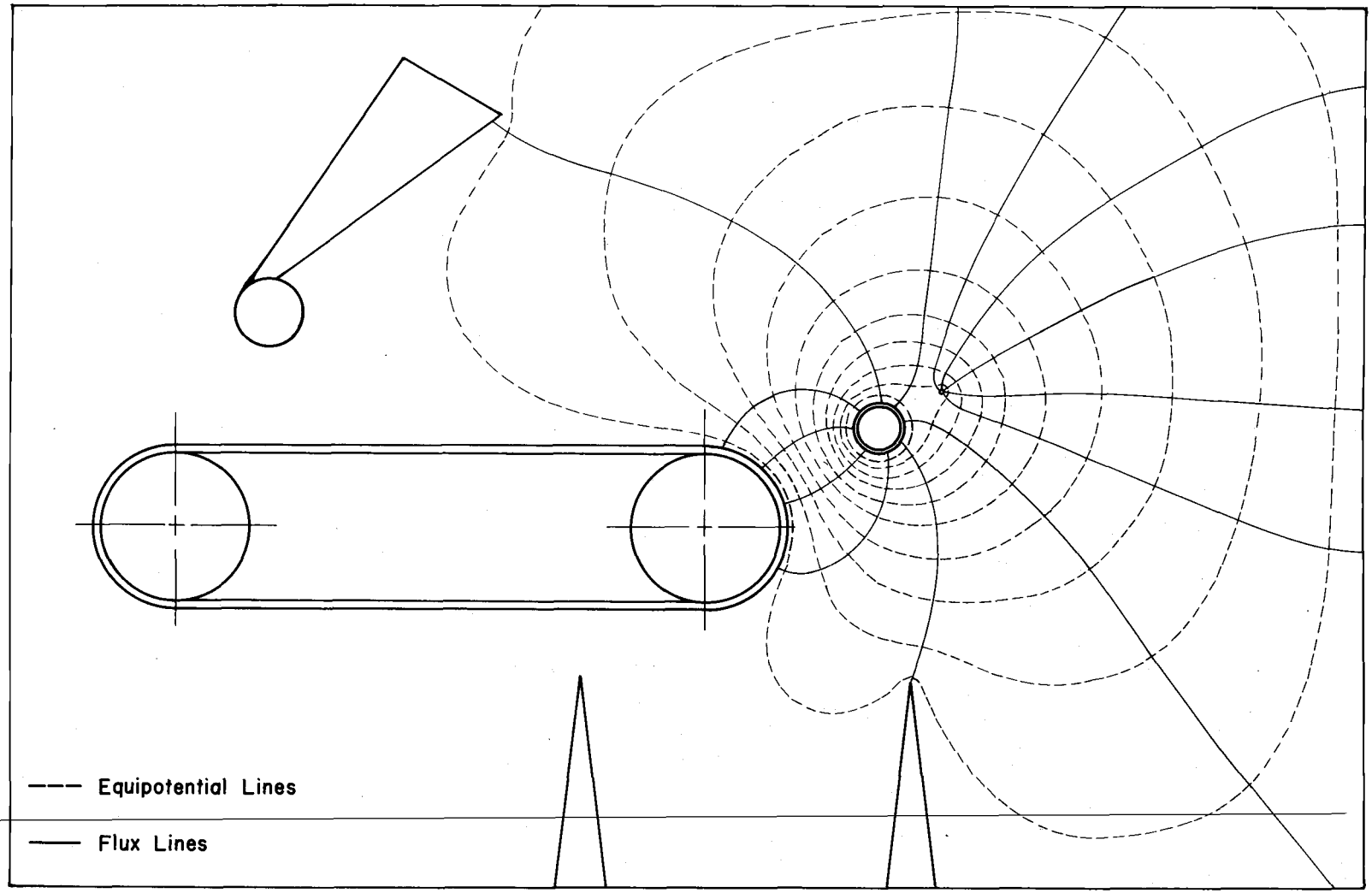

Figure 24

Field resulting from electrode in the lifting position.

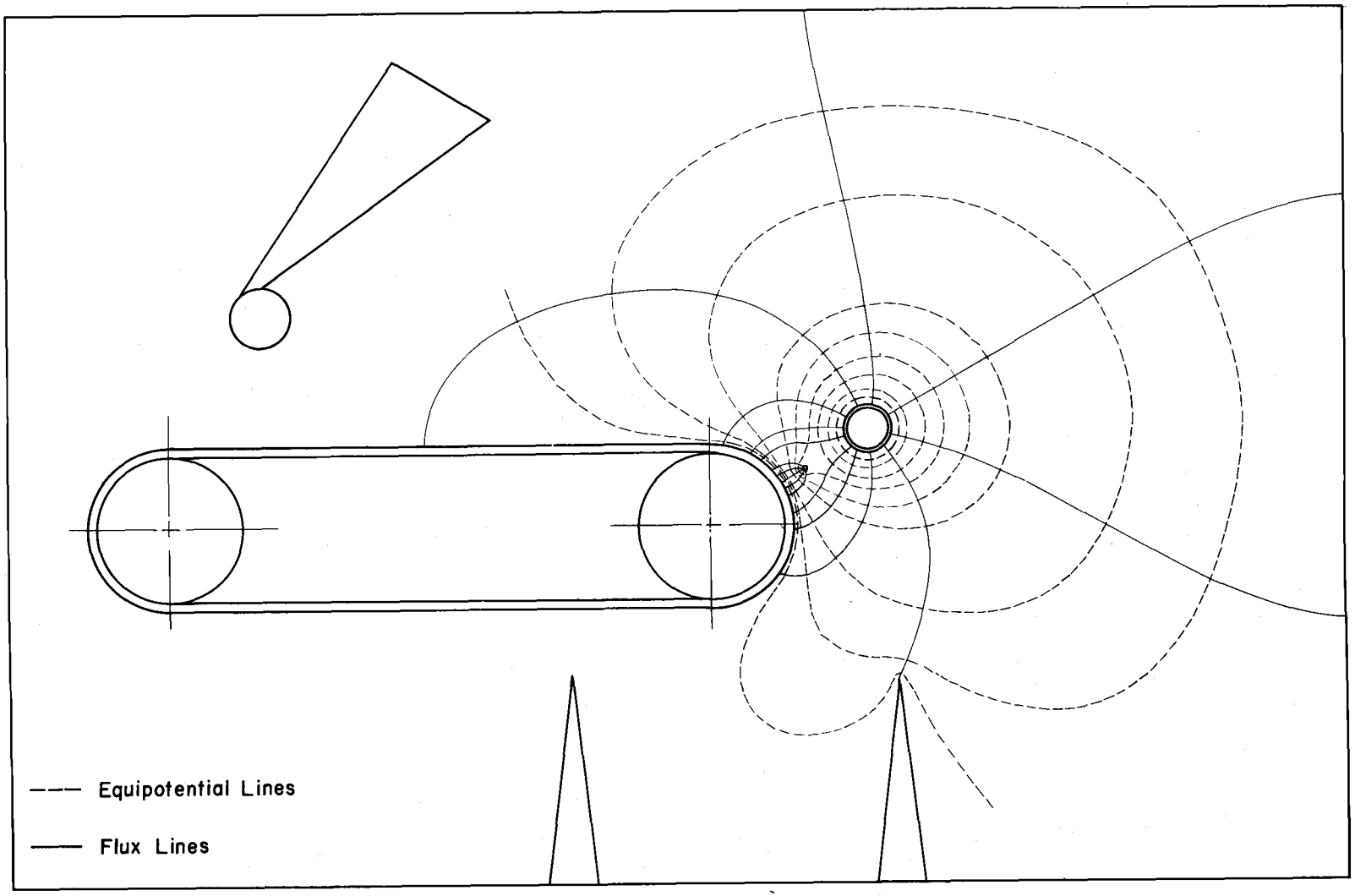

Figure 25

Field resulting from electrode in the pinning position.

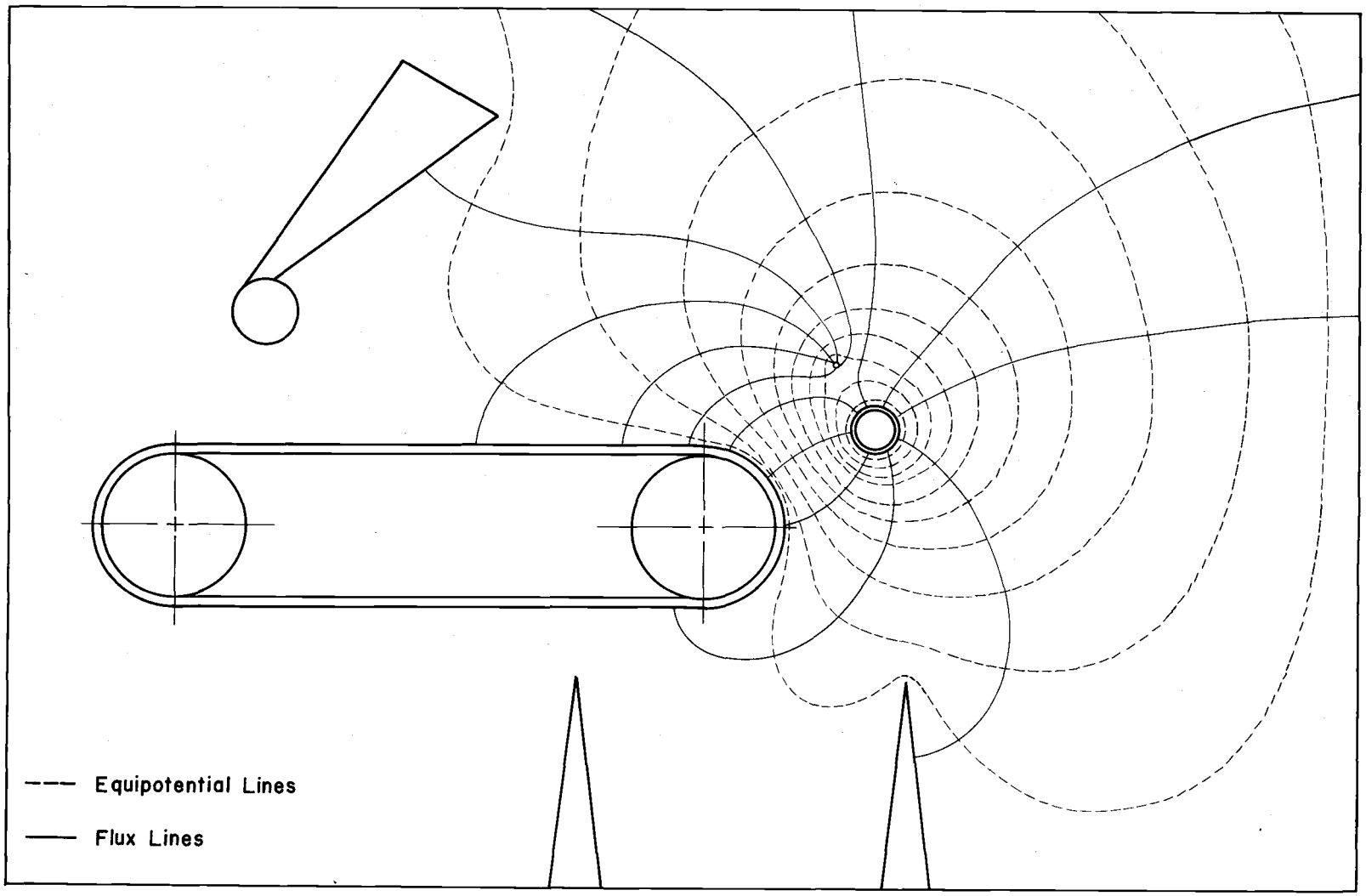

Figure 26

Field resulting from electrode in the combination lifting and pinning position.