

Abstract

Ercan, Erkmen. Method for Measuring Static Potential on Moving Fabrics (under the direction of Dr. Perry L. Grady, Dr. Donald Shiffler and Dr. Behnam Pourdeyhimi)

There is no clear explanation for static potential generation. There are many factors that affect charge generation such as environment (temperature, humidity), structural (polymer type, structure of fabric) and working factors (fabric speed, tension, and contact area between fabric and machine parts, material type that is in contact with fabric). With a good knowledge of these parameters, generation of static charge can be minimized.

During production, static potential on a moving web can cause web breakage, ignition of flammable atmosphere, or shock risk.

The main objective of this research is to develop a method to measure static electricity on moving nonwoven machine belts. In this project the instruments to measure and eliminate static potential on moving fabrics, design of test apparatus, relationship between charge decay values and charge generation of different fabrics, static potential measurements under different conditions are discussed. Spunbond technology is one of the nonwoven production methods have a high static charge generation problem; tests were done by using a spunbond belt on an actual spunbond machine. These belts are mostly made of woven fabrics with different structures (different number of layers, fabric design, structure of polymers used). A goal of manufacturing these belts is to reduce static electricity during production.

Among all parameters that cause static charge generation, tension is the most important one. A small amount of increase in tension can double the charge on belt. Separation is also a reason for charge generation and as roller-fabric friction increases –because of the increased contact area- more charge will be generated during separation. A new parameter, contact area, also needs to be considered.

Static charge generation may not be same at cross direction on a belt. As all areas are in the same situation (working and environment conditions) the only thing that was different was the tension. Because of the spunbond machine setup, tension –for this reason, static charge- was different in cross direction. The effect of this and other parameters can be seen more clearly when a non-conductive belt is used.

Method for Measuring Static Potential on Moving Fabrics

by

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1. Introduction

During production, static electricity can cause overload of electrical equipment, explosion in an operating room and there is always shock risk. In textile industry, especially for nonwovens, it can increase the production time. Static electricity can cause the product stick to machine or other parts, and make it unable to move easily. This can cause break apart of textile products and this will be a reason of higher process time. Also, during production, static electricity on the material can cause breakage of fibers. This will decrease the fabric strength.

During the recent years, different types of belts are being produced for spunbond and meltblown processes. The goals of producing these belts are decreasing static charge generation during production and helping dissipation of charge. To reach these aims, many different belts with different structures are being produced. But, as researchers are dealing with dissipation of electrostatics, the main material that is being used in belt structure is carbon suffused polyamide (Nylon 6.6). The difference in belt structure, warp and web densities, the percentages and types of monofilaments that form belt determine the amount of charge generated. The behavior of belts can be affected by speed, tension, humidity and temperature.

The experimental study discussed here evaluates the charge generation characteristics of different types of belts. Belts were tested at different speed, tension and humidity values. A spunbond machine in Nonwoven Cooperative Research Center (NCRC) Partners' Laboratories was used.

The instruments that are used for measuring static potential and neutralizing were discussed and a new multi-probe fieldmeter was purchased. This type of fieldmeter is one of the sensitive one and 4 probes can be connected to it. This helps to see the effect of cylinder, separation, grounded metal layer that is in contact with cylinders and charge generation and dissipation during transportation. Tests were done by handheld, one and multi-probe types of fieldmeters.

As it is not available to setup the belt onto a spunbond machine every time, a quick method that can give an idea about charge generation characteristics was used. Charge decay results for conductive and non-conductive belts give pretty similar results with the results got from fieldmeters. But, to see the behavior of belt at real working conditions, a real environment and test machine should be used.

2. Literature Review

2.1. Definition of Static Electricity

For many years it was known that if a piece of amber was rubbed it acquired the ability to attract small bits of straw, paper and such.

According to electron theory, materials are composed of three types of particles. These are the electrons which carry negative electrical charges, protons which carry a positive electrical charge and neutrons which do not carry electrical charge [1].

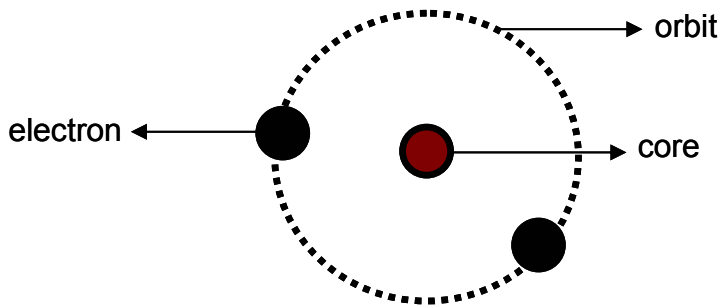


Figure1 Simplified drawing of an atom

All atoms are very similar in construction which means there is always a core and one or more electrons. Figure 1 a simplified drawing of an atom is shown.

When the atoms have a number of electrons, some are closer to the core than others. The core exerts a **pulling force** on the electron. As the distance between electron and core increases, this force decreases. This force is also called 'force of attraction'. The attracting force which the nucleus sends out is said to be a positive (+) charge. The neutralizing force, which the electron supplies, is said to be a negative (-) charge. These terms are used to indicate the two types of charges [2].

2.2. Contact and Frictional Charging

When two insulating materials are rubbed together, the surfaces will have a net electric charge. One will become negative and other positive. For some materials even touching has same effect [3].

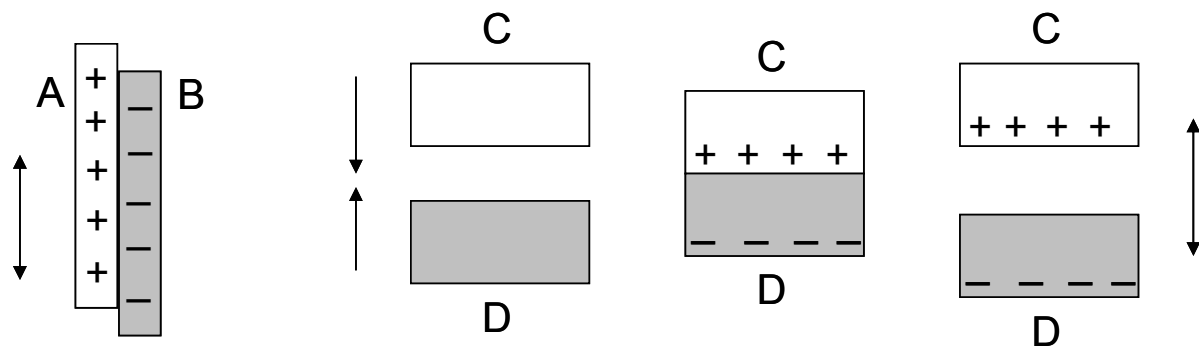


Figure 2 Charge separations during friction and contact

In figure 2, two solid materials are shown. They are brought in contact and rubbed against each other and electrons move across the interface [4]. To determine the polarity of each material that is in contact, **the triboelectric series** is useful. According to the triboelectric series, every material charges positive against materials below it in the table

Positive end	
Rabbit fur	
Human hair	
Nylon	
Wool	
Silk	
Cotton	
Paper	
Steel	
	Wood
	Rubber
	Acetate rayon
	Dacron
	Polyester
	Polystyrene
	Polyethylene
	PVC
	Teflon
	Negative end

Table 1: Triboelectric series

when the two be rubbed. There are several lists of triboelectric series which are quite different than each other [3].

Triboelectrification, frictional charging, is one of the oldest known forms of charging. In some cases it is not even clear how to explain the sign of a charge on a particular surface for a given pair of surfaces.

It is possible from the relative position in a

series to predict the sharing of polarity. But the magnitude of charges separated by contact and friction can only be predicted with a high degree of uncertainty [4,5].

2.3. The Causes of Electrostatics

2.3.1 Structure of material: All atoms in materials have a certain number of electrons. They are placed in orbits around the atom and every orbit has a fixed number of electrons. As the distance between electron and core increases, the energy of an electron decreases. Electrons stay in orbits which are energy bands. The outer electrons of the atoms have a greater influence on each other than inner ones as they can move to other atoms orbits.

If the outer energy band is partially empty that means the material is a conductor. If the band is full, the material is insulator. There are two electrons for every possible energy band which can exist in the band. This is the number allowed by quantum mechanical rules. For this reason no electrons can increase an insulator's energy. Figure 3 shows energy bands of a conductor and an insulator. The electrons that on the outer layer are called valance electrons and they create a band called valance band. A conduction band is formed by energy levels which correspond to excited states of the outer electrons [3].

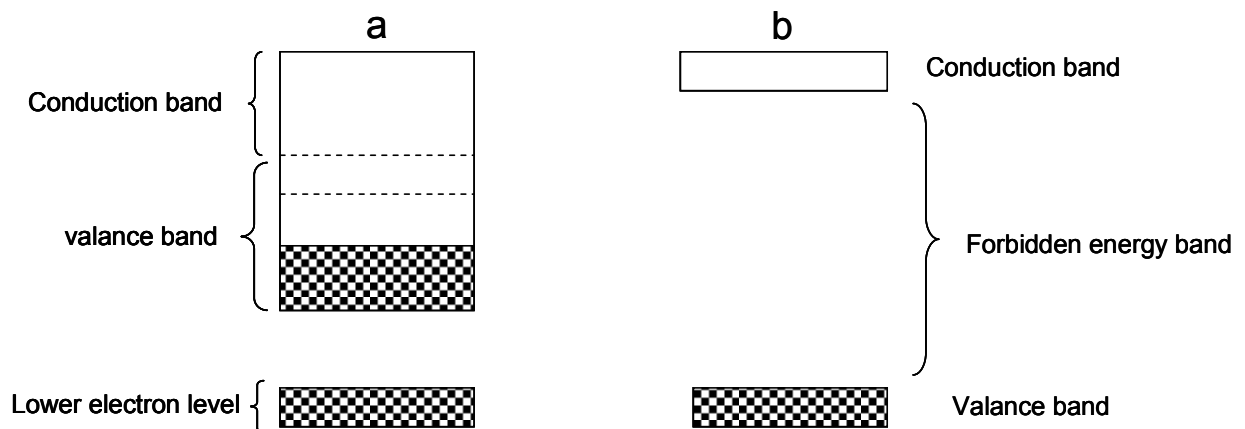


Figure 3: The band structure of (a) a metal and (b) an insulator [3]

2.3.2 Friction (Asymmetric and Symmetric)

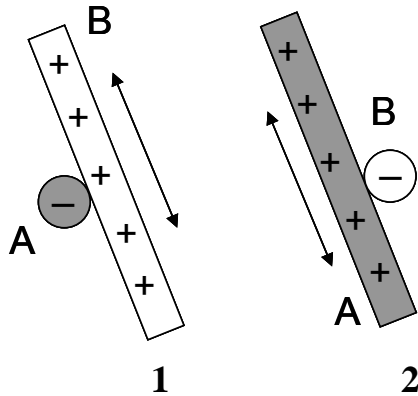


Figure 4: Asymmetric friction [4]

The charge on a surface increases as the contact area between surfaces increase. The degree of friction between two materials influences the contact area, thus exchange of charge. Triboelectric series and material type affect charge exchange. What if there are identical materials in the system (like in most textile products)?

The fabrics that are tested are woven belts for spunbond and meltblown machines. Because of its structure, there are asymmetric frictions through the web between yarns. This is illustrated in figure 4.

Two pieces, A and B, are identical materials and rubbed against each other. In (1), A is stationary and in (2), B is stationary. It can be clearly seen that B is positive charged in (a), and negative charged in (b).

The degree of polarity (charge that is generated) is affected by speed and type of fabric. As speed increases there will be more charge. When material type changes the amount of friction may change, which has a direct effect on charge generation.

2.3.3. Separation:

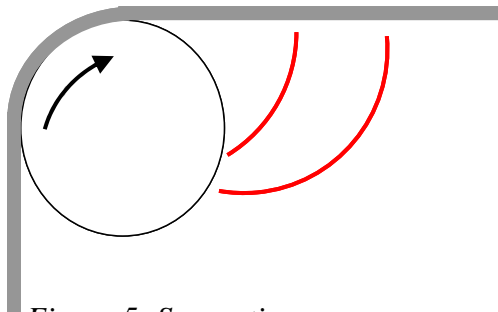


Figure 5: Separation

The faster the separation of the materials, the higher the charge generated. Slow speed provides enough time

for electron transfer between materials. As shown in the figure, the charge on belt moves to the roller. If there is not enough time for charge movement after separation, charge on belt will tend to move to the roller. This will increase charge generation. It also depends on the charge content on the two materials. If the roller is grounded, generation of charge will be high with high speeds.

2.3.4. Humidity and moisture content: The dryer the environment, the higher the level of static charge generated. This is a general rule that is known in the textile industry. If relative humidity is high, a moisture film will be absorbed on the surface of solid materials. So, surface resistivity of materials decreases and charges can move. This effect occurs if relative humidity is higher than 30-35%, and it exceeds its maximum if the relative humidity is 65-70% [8].

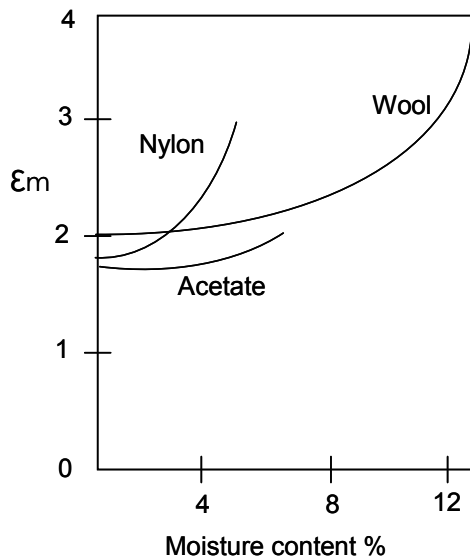


Figure 6 Variation with moisture content of dielectric properties of various fibers [7]

Formation of the moisture film depends on whether the material is hydrophobic or hydrophilic. With hydrophilic surfaces there will be less static charge problems.

Effective relative electrical permittivity – permittivity is capacitance of a condenser with the material between parallel plates, relative permittivity is 'permittivity/permittivity of a vacuum- of nylon, acetate and wool fibers are

shown is figure 6. As moisture content increases the permittivity increases. Non-absorbing fibers show no variation in dielectric constant [7].

As there are no free electrons in the fibers, a large thermal activation, kT , is required to promote electrons from the top of the valance band to the bottom of the conduction band. For metals and semiconductors kT at room temperature is sufficient to move the electrons from valance band to conduction band [10].

Electrical conductivity, σ , is:

$$\sigma = nq\mu$$

n = number of charge carriers per unit volume,

q = charge per carrier, and

μ = mobility of the carrier

Conductivity is the reciprocal of resistivity, ρ :

$$\sigma = 1 / \rho$$

Resistivity is a geometry independent material property.

$$\rho = R(A / L) \quad \text{A: Area} \quad \text{L: Length}$$

[10]

2.3.5. Temperature: If material is cooler than the surrounding air, moisture will condense on it and its insulation resistance will deteriorate. If it is warmer, it will tend to dry out and its resistance will become high, even if the relative humidity of the surroundings is high.

Also, as material cools down, it has a tendency to generate charge. A rise in temperature causes an increase in permittivity in solid materials.

2.3.6. Repetition: Repeated actions increase the static charge generation.

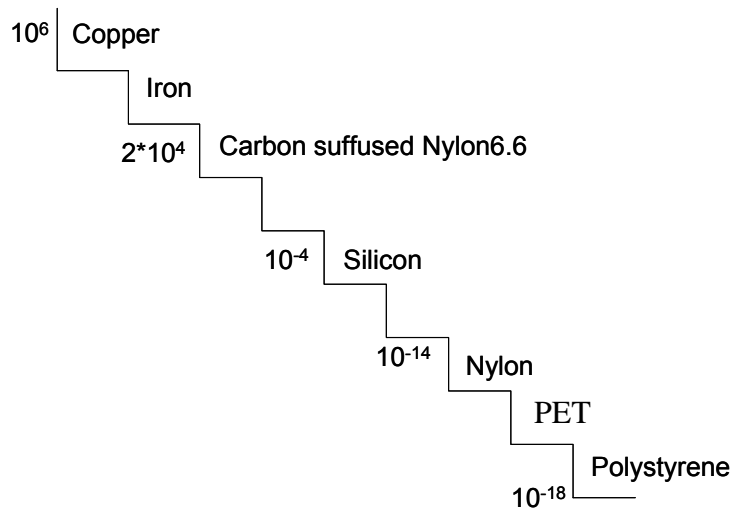
2.4. Conductivity of Fibers

Textile fibers are electrical insulators. As explained above, all electrons are bound to the nucleus core or shared in the covalent bonds. No electrons are free to move.

Electrical conductivity of materials is a property which spans a very wide range. It may occur through the movement of either electrons or ions.

Conductivity values show how good can a material conducts charge. Figure below shows some textile materials' conductivity values [9].

Figure 7 Conductivity levels of some materials ($\Omega^{-1}cm^{-1}$)



In this project, fabrics are formed of

- 100% polyester, polyester and polyamide
- 85% polyester and 15% carbon suffused conductive polyamide fibers.

The conductivity values of these fibers are shown in table 3. Conductive polyamide is made of carbon suffused Nylon 6.6.

To produce this fiber nylon fibers are sent to an acid bath and a single layer is removed from the surface. Then, carbon molecules are applied to the polyamide fiber by spraying or a bath. To avoid losing carbon molecules during production because of friction, fibers are then covered with a very thin layer of silicon.

2.5. Problems That Static Electricity Causes

In the textile industry, static electricity may cause many problems if it is not under control. These problems may be:

- Electronic equipment can be overloaded and break down
- Static discharge in an operating room may lead to an explosion
- Risk of shock.
- Increased production time: In some areas very long textile materials are produced. Because of the static charge on it, roll should be used for some time to allow static charge dissipation.
- Fiber breakage and decreased fabric strength: Spunbond machine during production, before transferring the web to calender bonding, the fabric sticks to the belt. This may cause fabric breaks during production and higher process time.

2.6. Measuring Electrostatics

The parameter of basic importance for static electricity is charge. Electrostatic measuring instruments require sensors. These can respond to the related quantities of electric field, potential and charge.

Two different types of instruments are used for electrostatic measurement. These are:

- Electrostatic Fieldmeter
 - Pocket size electrostatic fieldmeter
 - Radioactive sensor type fieldmeter
 - A.C carrier type fieldmeter
 - Chopping electric field by rotor
 - Vibrating capacitor fieldmeter
- Electrostatic Voltmeter

2.6.1. Electrostatic Fieldmeter

The ideal electrostatic fieldmeter should have following characteristics:

- It would be very small
- It would determine the polarity as well as the magnitude of charge
- It would assume the potential in space of the point where field intensity measurements are desired [11]

In general, a fieldmeter should measure the field without distorting that field in any way.

Fieldmeters that are used today are ground referenced measuring devices. The readings are affected by the distance between sensing surface and the layer containing the charge.

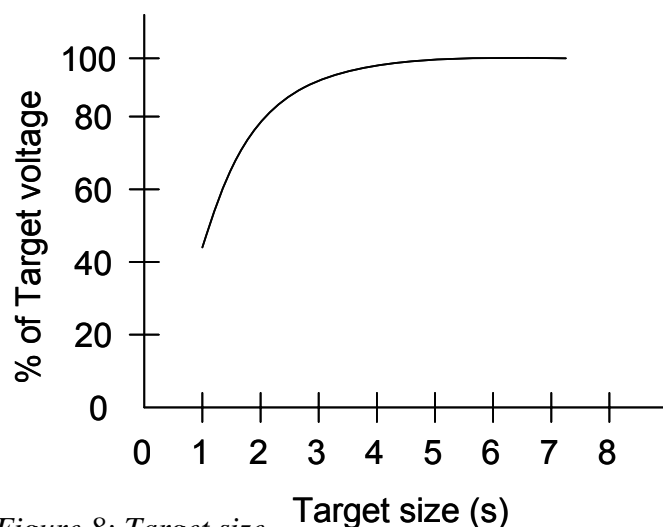


Figure 8: Target size

For this reason, the distance between fieldmeter and layer should be known in order to have precise readings.

Field of view of the probe is also important. For accuracy, the target size should be three to four times

the distance from the probe to the surface under the test. Unless measuring large surfaces are being measured, the probe should be very close to the web. As spacing gets smaller, the variations in spacing become much more critical to the accuracy of readings.

2.6.1.1. Type of fieldmeters

1) Pocket size electrostatic fieldmeter has a capacitively coupled D.C amplifier.

Advantages of this type of fieldmeter are:

- Low cost
- Very easy to use
- Simple
- Ability to make extremely high speed measurements [11]

Disadvantages are:

- Inability to monitor an area over an extended period of time
- Need to periodically zero the instrument
- Inability to use these in an ionized environment [11]

2) Radioactive sensor type fieldmeter is a simple D.C. coupled measuring unit. It ionizes air and when this is exposed to an electric field, a current will flow which is same amount as electric field. The current is then measured and gives data about the electric field.

Results can be affected by dirt on the radioactive element. Also, radioactive elements have a limited half-life and need to be changed periodically.

The radioactive voltmeter must be used at a fixed distance from the charged surface. If the space is changed, the sensitivity of the instrument must be adjusted [3, 11].

3) The most widely used instrument for measuring electric fields is the rotating-vane field meter. This is an induction field meter with a grounded rotor placed in front of the sensing surface as shown in figure 9.

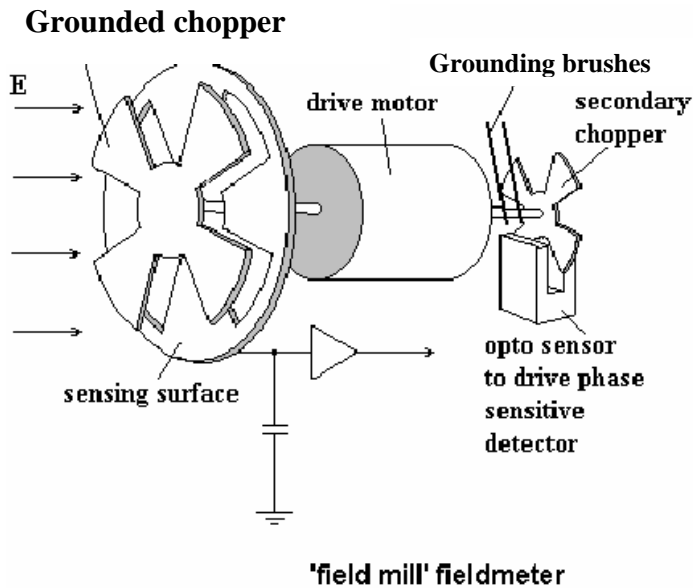


Figure 9: A rotating-vane fieldmeter [13]

combining the data from sensitive detector and sensing surface, system gives the data about static potential under it [3].

A small electric motor is used to drive the vanes. Because of the grounding brushes, the instrument is noisy. Also, it limits the speed of the rotor. Because of the friction, these brushes must be changed after some time.

4) Vibrating capacitor fieldmeter, like a rotating-vane fieldmeter, is also provides an oscillatory signal. In this instrument, the aperture is placed in from of the sensing surface. The sensing surface is vibrated perpendicularly to the electric field. The signal detected at the plate is then proportional to the displacement between the sensor surface and the aperture, and to the electric field.

Vibrating fieldmeters are more compact than rotating vane instruments [11].

As the rotor turns, it chops the electric field and the sensing surface is alternately exposed to the field and shielded from it. The speed of response is limited by the chopping speed of the rotor. The sensitivity of the instrument is changed by altering the value of the internal capacitance. By

2.6.2. Electrostatic Voltmeter

There are two types of electrostatic voltmeters available today. These are vibrating capacitor type and tuning fork chopper type voltmeters. In the second system, there are two sets of vanes, one set is fixed, and other one is mounted on a spring and attached to a pointer. When the voltage is applied, one vane is repelled from the stationary one by a force which is proportional to the square of the potential. The pointer moves across the

dial and stops when the electrostatic force equals the restoring torque of the spring [3].

The advantage of an electrostatic voltmeter compared to fieldmeter is high resolution providing accurate reading within short periods. It gives excellent results

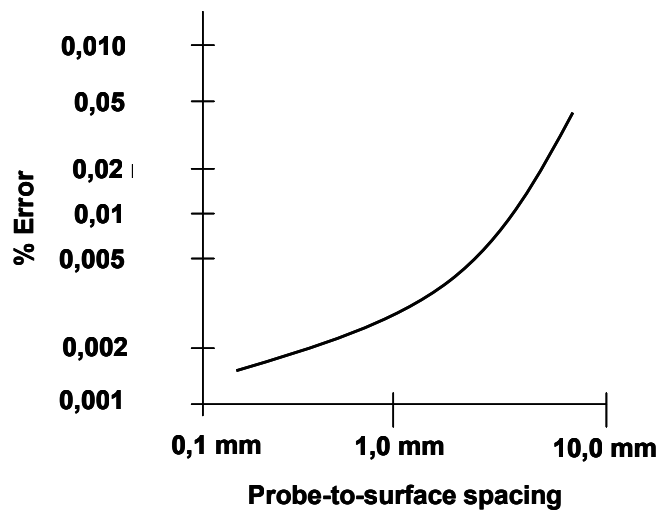


Figure 10: Error rate vs. probe-to-surface distance

with small probe-to-surface distance. Figure 10 shows that voltmeters can indeed be used over a wide range of spacing with good results [11].

Table 2. Fieldmeter vs. Voltmeter

	Electrostatic Fieldmeter	Electrostatic Voltmeter
General rec.	testing of large surfaces	large and small surfaces
Cost	low cost	high cost
Spatial resolution	poor resolution	good resolution
Accuracy	good at the large probe-to-surface distance	good at the small probe-to-surface distance
Distance independent	no	no

Electrostatic field measuring devices that were used in this project

In this project, three different types of fieldmeters were used. Fieldmeters were selected for measuring static potential rather than voltmeters because the resolution and accuracy are good enough for our tests. The instruments used and their specifications are:

1) Simco Handheld Fieldmeter (FMX-002)



- Easy to use, small size
- Range: +/- 20 KV
- Ability to make extremely high speed measurements
- Best results at <1" distance

Figure 11: Simco handheld instrument [14]

- Distance between web and instrument effects the result. As it is a handheld instrument, it is hard to keep the instrument at the same point during tests.
- Need to periodically zero
- Inability to monitor [14]

2) Monroe Electronics One Probe Fieldmeter (Model SE0054)



Figure 12. Probe of fieldmeter model SE0054

- Range: +/- 10 KV
- Distance can be kept constant
- Accuracy: Better than 2%
- Response: Less than 0.5 sec.
- Ability to connect to a computer [15]

3) Monroe Electronics Multi-probe Fieldmeter (Model 177)

- 4 point static meter: It is possible to use 4 fieldmeter probes at the same time. Static electricity on a web may change with time. To see the effect of some parameters on different areas, measurements should be done at the same time. For this reason, a multi-probe fieldmeter should be used.

- Accuracy: Better than 1%
- Response: 250 msec.
- Range: +/- 20 KV [16]



Figure 13: A multi-probe type fieldmeter [15]

2.7. Charge Neutralization

The management of electrical charge is critical to the success of electronic component manufacturing. Mostly, insulating materials create problems during production. High static charge on those materials may create electrical forces and discharges. Materials may stick together; electronic devices and circuits may be damaged. Electrostatic charges can be neutralized by eliminators, which neutralize surface charges on solid materials [8, 17].

2.7.1. Types of eliminators

There are different types of methods to neutralize the charge on materials. Eliminators can be subdivided into 4 groups:

- 1) passive eliminators
- 2) active eliminators
- 3) air ionizers
- 4) radioactive eliminators

2.7.1.1. Passive eliminators

This is the simplest type of eliminator. They operate by using the charge on the surface. The intensity of the neutralizing ion current depends on the value of the static charge. If

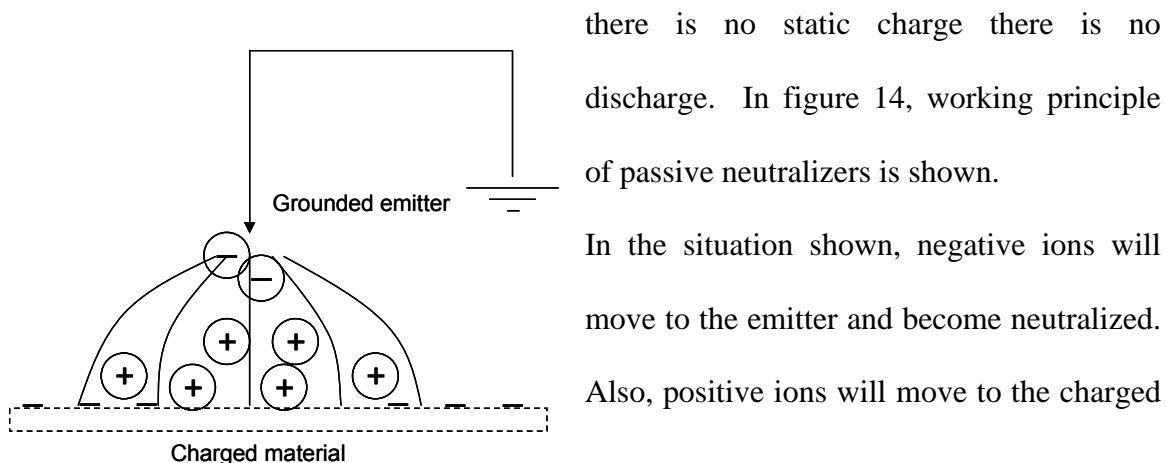


Figure 14: Passive neutralizer

material and neutralize it. The system should be positioned a few centimeters from the material. For points which are 10 mm from a surface, this will be equivalent to a potential of about 5kV on the surface. This type works well with highly charged material. If charge becomes very low, neutralization stops. To neutralize all the charge on a web a passive neutralizer should be used.

These instruments work equally well with positive and negative charges. The problem is corona discharge stops at a certain charge level –charge remains on the surface-, so there is an amount of charge on surface. Other disadvantage of this approach is their tendency to overcompensate. This may be reduced by using second neutralizer [3, 18, 19].

Passive neutralizer may be made of carbon brushes which are in contact with the material. This direct contact does not increase the efficiency of the neutralization [18].

2.7.1.2. Active Neutralizers

These units are similar to passive ones but they are more complex. They can be completely effective with low or highly charged materials. They can be easily controlled

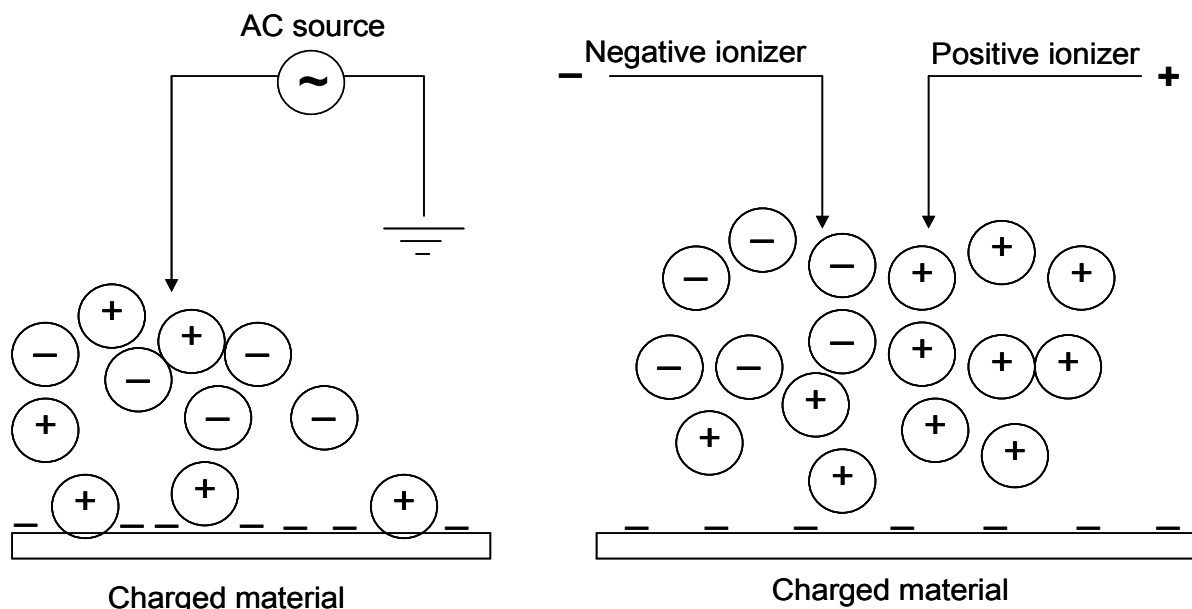


Figure 15: AC and DC type active neutralizer

and their efficiency is higher than any of the other types [8].

These types are mostly used in the cases where passive ones do not provide sufficient neutralization during production.

Figure 15 shows AC and DC type active neutralizers. Like passive ionizers they consist of a row of points placed parallel with the charged material, but in this case the points are connected to a voltage source.

An A.C. type neutralizer produces positive and negative ions in a fraction of each half period which is determined by the voltage and the radius of the points. The frequency of the voltage must be increased at high speeds. The disadvantage of this A.C type of neutralizers is that when charged material is moving past the neutralizer, the neutralization may be incomplete.

D.C. type neutralizers are the most effective ones. They consist of two emitters –one has positive and other one has negative polarity-. They can be used where the A.C. type is insufficient. Negative output can be used when the charged material is positive, and positive output can be used when charged material is negative. To avoid overcompensation of the neutralization; a double D.C. ionizer can be used. An advantage of active neutralizers is this unit can operate as a passive neutralizer if the high voltage power supply should fail [18, 19].

2.7.1.3. Air Ionizers

These are similar to active ionizers and good for larger work areas. An air flow is used to project air ions of both polarities. But some air ionizers have only one polarity. One polarity will never be enough to neutralize the web and it can recharge the material. So,

air ionizers should have equal positive and negative polarities. Ionizer can be electrical (usually D.C- single or double) or radioactive.

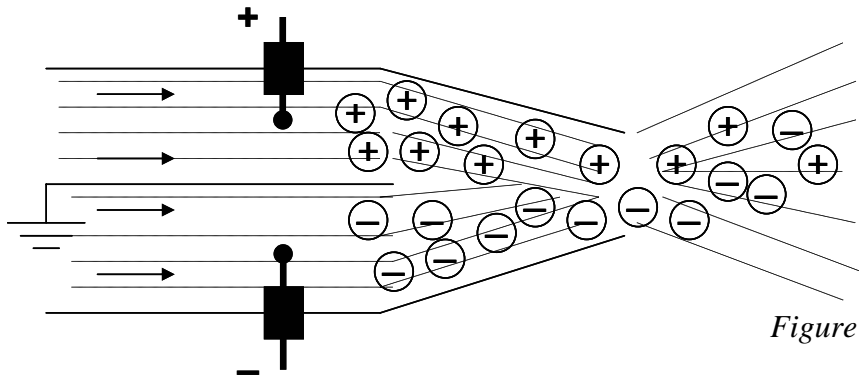


Figure 16: Air Ionizer

By blowing air, it is possible to create an air stream with relatively high ion content. But because of the small distance between emitters and the grounded layer between them, the fraction of the air form will never reach the air outside the ionizer. So, the ion concentration is reduced because of repulsion, diffusion and combination process.

With the help of blowing air, this system is good for hard-to-reach surfaces. But it is very difficult to maintain high ion concentration over long periods. Also, it is hard neutralize materials at long distances.

2.7.1.4. Radioactive Neutralizers

These types are simple. Their shape and dimensions can be changed easily. They don't require an external energy source. But because of the half life of the radioactive element, they have to be renewed systematically. The application of radioactive eliminators is advantageous in an inflammable atmosphere and places where static charging is not too

low. In a radioactive neutralizer, the radioactive source is placed upon a base material and covered with an extremely thin protective layer –this can be gold-.

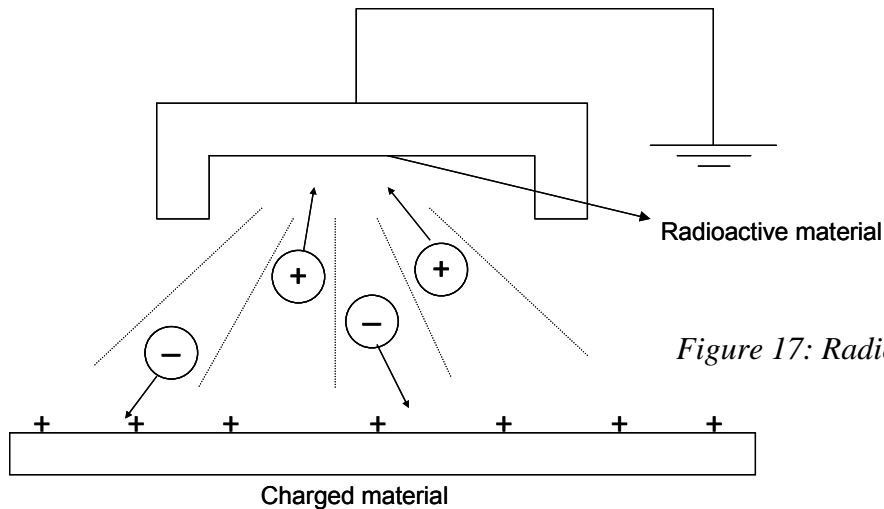


Figure 17: Radioactive neutralizer

Radioactive neutralizers can be used for low charged or slow speed material. The advantage of this type is that they don't require electrical installations, and they function without electrical discharges. The limitations are it can not be used for highly charged or high speed webs. Also because of the radioactive material, care has to be taken [8, 19, 20].

2.8. Charge Decay

Textile materials easily become electrostatically charged when rubbed against other materials. This kind of charge triboelectric charge is called and causes many problems in the industry. So, the ability of materials to dissipate static charges on themselves is important for avoiding a variety of problems.

The meaning of the term 'resistivity' in electrostatics is the difficulty of passing charge through the material. If the charge decay properties of materials are needed, information

from the resistivity properties of materials can be used to assume these behaviors [21, 24].

Basically, to remove the charge on a web, a low surface resistivity is required. But there are some unclear situations with the measuring of surface resistivity. First of all, the tests should be made under very ideal conditions; because:

- The resistivity depends on the field strength from the decaying charge
- The driving field from a given charge depends on the permittivity properties of environment [22]

The method that is used to measure resistivity is Federal Test Method 4046.1. The sample is clamped between the two electrodes as shown in figure 18. Charge is applied on the fabric and the dissipation time is measured.

In our tests the Electro-tech Systems static charge meter was used.

The reason for running charge decay tests in this project is to have an idea about charge decay rates of different fabrics during production. On the machine there are some grounded and ungrounded parts that the fabric contacts. During production fabric generates charge. When a grounded part of the machine (roller and/or layer) contacts the charged web, static charge on the fabric will move to it.

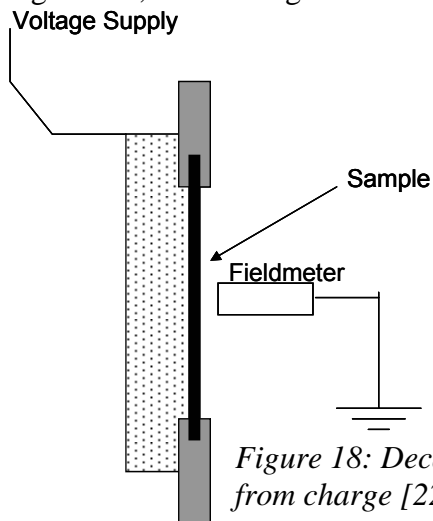


Figure 18: Decay of field from charge [22]



Figure 19: Charge Decay Instrument, ETS, Model 406D

The amount of charge that moves to the grounded part depends on the charge decay properties of material. If it is highly resistive, that means high charge decay rate and the amount of charge that moves to machine part will be low. So, one of the aims of this project was to determine the relationship between charge decay rate and fabric behavior during production. If this kind of relationship can be proved, there is no need to run an experiment on a nonwoven production machine to see charge decay rates.

2.9. Surface Charge Density

Charge measurement by a fieldmeter can be effected by local low potential regions. This depends on the web linear velocity, on the resistivity of the web material and the whole electrostatic system.

These local changes create problems when controlling the static electrification process on moving webs. To find an approach, one assumes that the surface charge density is uniform and constant with time. But in practice, there is a difference between the web areas that are in contact with the grounded machine parts (roller, etc.) and true web potential [25].

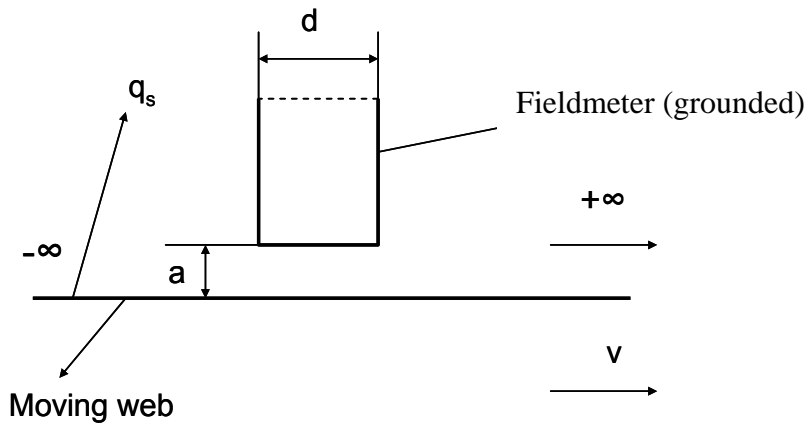


Figure 20: Schematic diagram of the measuring system

An ideal measuring system can be seen in figure 20. The fieldmeter is mounted a distance from the web. 'v' is the velocity of the web, 'a' is

the air gap thickness and q_s is the charge density.

Velocity, charge and electrical properties are related by [25]:

$$\frac{\partial V}{\partial y} v - k \frac{\partial V}{\partial x} = E_0 \quad (1)$$

Where:

$k: \sigma/\epsilon_0$

$E_0: q_s/\epsilon_0$

ϵ_0 and σ are the permittivity of a free space and the web surface conductivity, V is the velocity and q_s is the charge density.

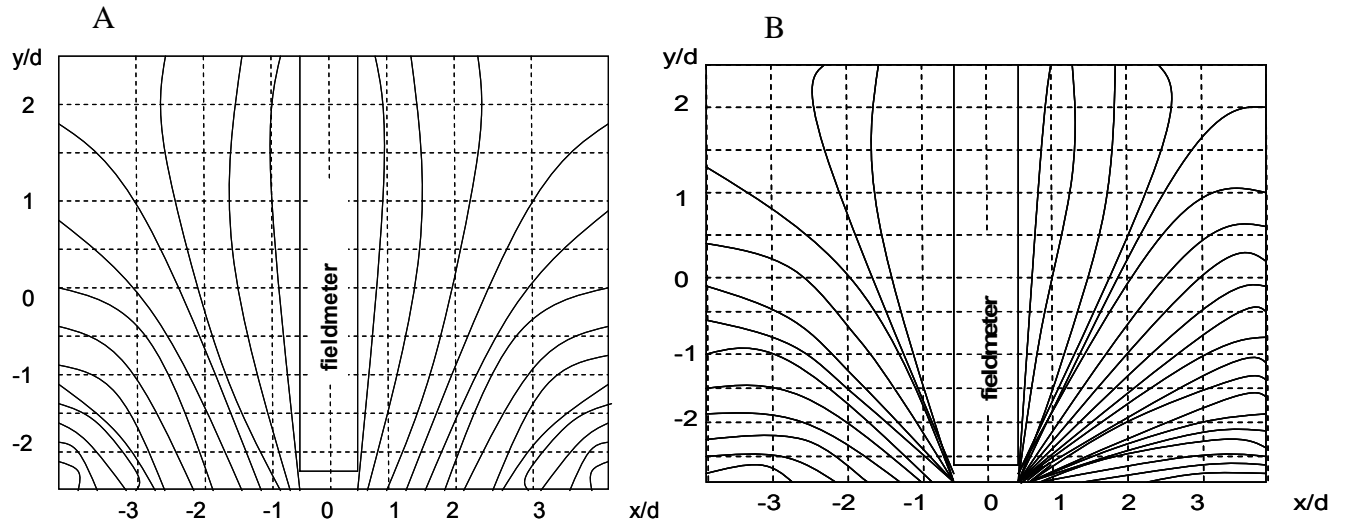


Figure 21: Comparison of static field distributions A) $-k=0$ (steady position)
B) Moving position

As can be seen in figure 22, if the web is not conductive the areas before and after the fieldmeter will be similar in terms of static density. But for conductive fabrics, any grounded material near the web will affect the static density distribution through the web.

We can hardly talk about a constant charge value on the belt.

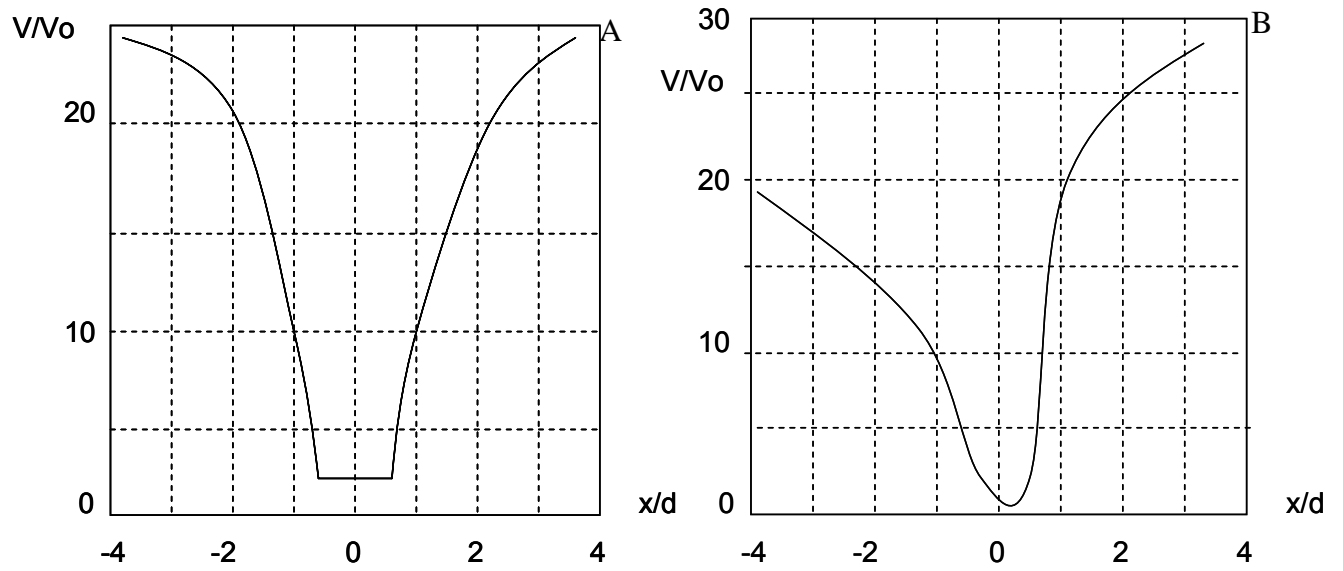


Figure 22: Surface potential distributions obtained under the same conditions. The difference is only 'k' value. A) $k=0$ and B) $k=0.75$ [25]

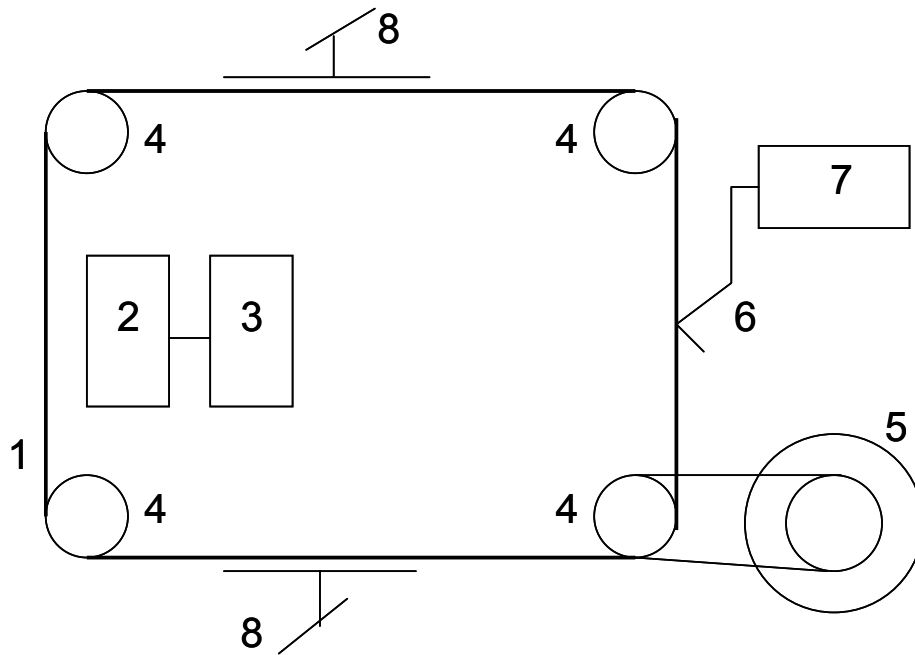


Figure 23: Example of a machine design [25]

Figure 23 gives an example of a machine design to measure the static potential to see the effect of grounded near by objects (8). Linear velocity of belt (1) can be changed by a

motor (5). Charge on belt is generated by friction between rollers (4) and high voltage supply (7). Fieldmeter (2) gets the data and recorder (3) keeps records with time.

2.10. Charge on Both Sides

Materials that are close to a moving web, affect the charge on it. Also, for thick webs, the charge on both sides will be different. By the help of a near by object, these charges can be identified with only one fieldmeter.

During transport of an insulating web, friction between rollers generates charge also this charge dissipates by time. So, this will cause the charge differences between the two sides of the web. In figure 24 a set-up to measure the static potential on both sides is shown. The fieldmeter is located a distance 'd' above the web and the web is located a distance 'L' above a uniformly charged object [26].

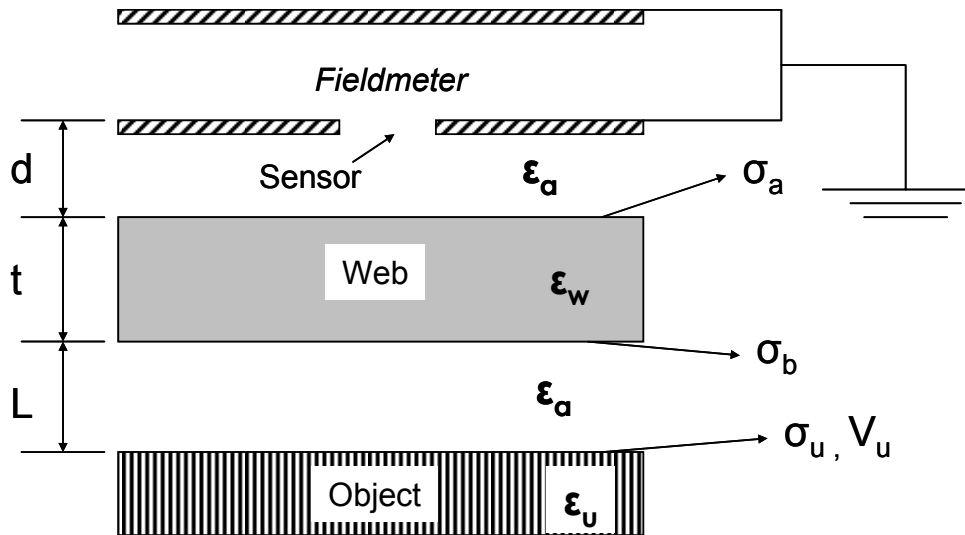


Figure 24: A design to measure charge on both sides of a web [26]

If:

d = Distance between the fieldmeter and the upper surface

t = Thickness of the web

k_1 = Constant containing charge density of both surfaces

k_2 = Constant containing charge density of upper surface

E_m = The magnitude of the electric field at the fieldmeter

E_{m1} = Fieldmeter reading when L is at $L_0 + \Delta$

E_{m2} = Fieldmeter reading when L is L_0

E_{m3} = Fieldmeter reading when L is $L_0 - \Delta$

L = Distance between the lower web surface and the lower ground plate

L_0 = Equilibrium distance of L

V_u = Potential at the plate or object below the web (set to zero in this pare)

Δ = Maximum distance moved by lower ground plate from L

ϵ_a = Permittivity of gas surrounding the web

ϵ_u = Permittivity of object under web

ϵ_w = Permittivity of the web

σ_a = Surface charge density on the upper web surface

σ_b = Surface charge density on the lower web surface

σ_u = Surface charge density on the object under the web

$$\sigma_a = \epsilon_w k_2 \quad (2)$$

$$\sigma_b = \epsilon_a k_1 - \sigma_a \quad (3)$$

$$k_1 = \frac{L_0 + d + \frac{\epsilon_a}{\epsilon_w} t}{2\Delta} (E_{m1} - E_{m3}) + \frac{E_{m1} + E_{m3}}{2} \quad (4)$$

$$k_2 = \frac{L_0 + d + \frac{\epsilon_a}{\epsilon_w} t}{t} E_{m2} - \frac{L_0}{t} k_1 \quad (5)$$

Equations (3) and (4) allow us to compute web surface charges on the top surface and on the bottom surface with the help of k_1 and k_2 .

By changing the position of the grounded layer a fieldmeter measures different values. In figure 25, the distance between the grounded plane and web is changed from 0 to 100 mm. As 'L' becomes infinite, the fieldmeter reading will be constant. If it is far away from the web, e.g. 100 mm, then a small change will produce only a small change in fieldmeter reading. But, if the ground plane is too close to web, then the same amount of change will produce much larger change in the fieldmeter reading [26].

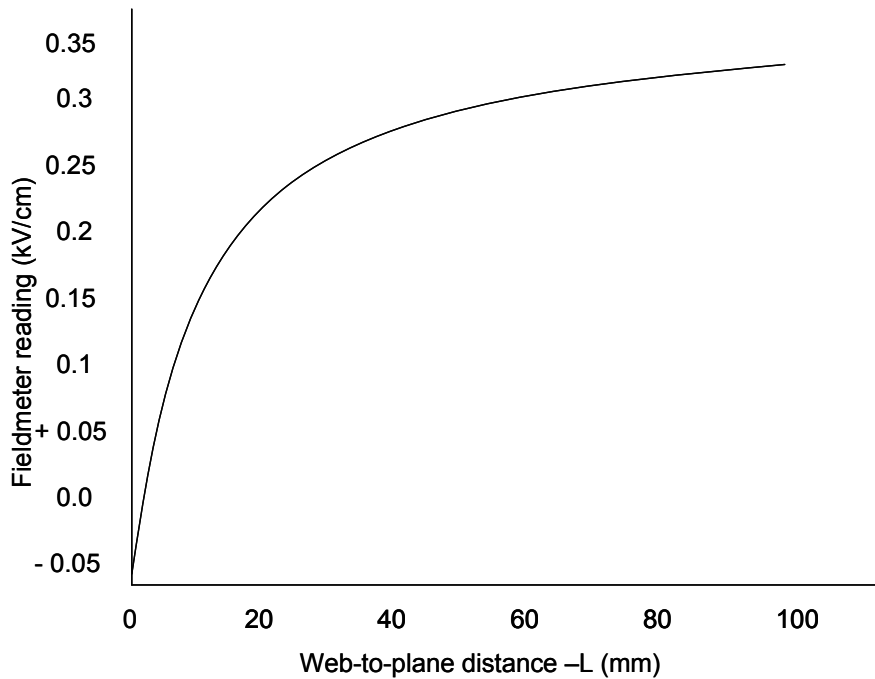


Figure 25: Distance (L) vs. charge on web [26]

2.11. Effect of Near By Objects

To understand the effect of near by objects what happens during generation of static electricity should be understood clearly. Let's start with the definition of 'volt'. When we say that there is 250 volts on web, what we want to say? To understand the meaning,

we must understand **electrical work**. Volt is potential difference against which one joule of work is done in the transfer of one coulomb of charge [27]. Work is done when opposite charges are separated. All measurements must be done by using the difference material and reference location. For electrostatics, this reference location is earth. Earth ground is defined as the zero of potential. When a spot on web has 250 volts, it means that it takes 250 volts of electrostatic work to separate charges from all the surrounding grounds [27].

During measurements the person must reduce the influence of the surrounding grounds. This is especially important doing measurement with voltmeters [27].

When the rollers are grounded, the area between web and roller can be used as the ground location with the voltmeter/fieldmeter placed over the center of the web-roller contact region.

An electrostatic fieldmeter measures the electric field between the web and the instrument. The web potential can be found from the reading of the fieldmeter and the distance between probe and the web. This works only if there are no grounded objects near the web. For this reason tests should be done on a large web, in which the distance of rollers is far, or person must know the capacitance of each grounded object [27].

Figure 26 shows the non-conducting web surface potential when grounded rollers are used. The charge on web is almost constant between the rollers. The middle section between rollers would have the highest web potential and it is called **free-span** of web.

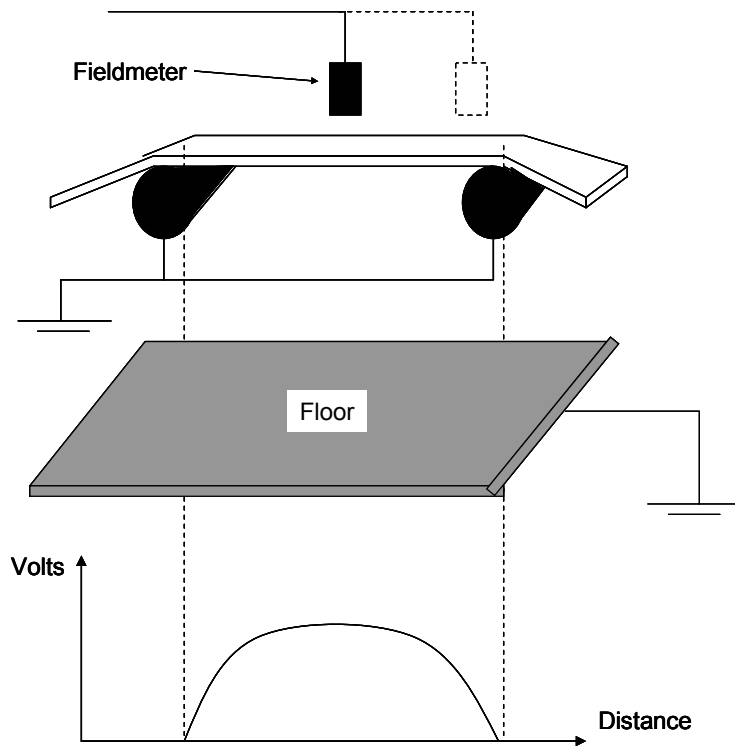


Figure 26: Web surface potential between two rollers

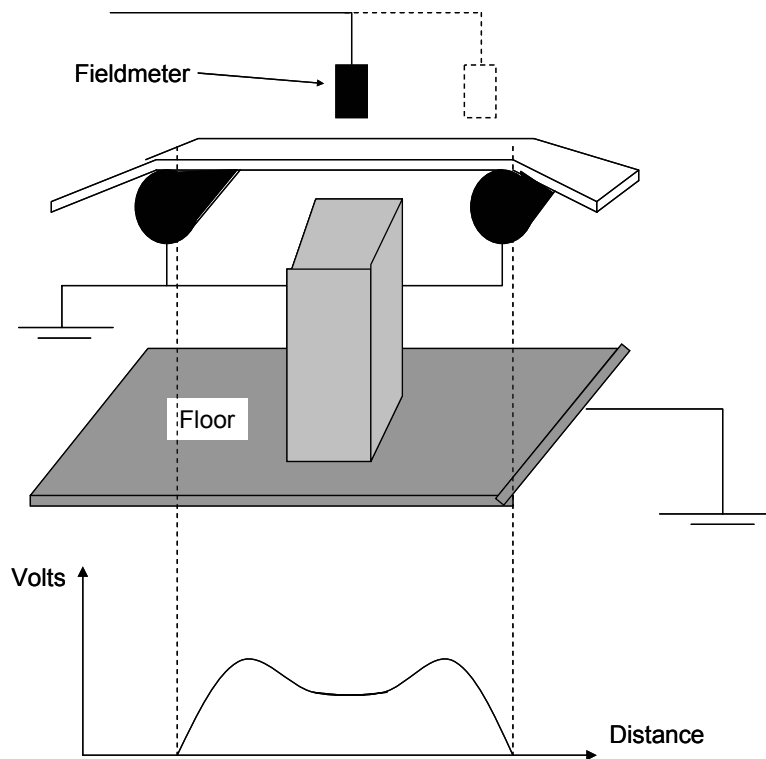


Figure 27: Effect of near by object

When a grounded object is placed close to the web, it will effect the measurement (as shown in figure 27). A person is also a grounded object, so while doing the tests; a person shouldn't be close to the web unless the capacitance is known [27].

If there are no grounded near-by objects, a fieldmeter is the best instrument to use. Otherwise, the electrostatic voltmeter should be used.

Industry tries to keep static potential below 5000 volts. This is also called '**5000 volts rule**'.

This measurement should be done by using a fieldmeter at a distance of 1 inch (2,5 cm).

Measurements should be done at a true span of web. This means while changing the distance between fieldmeter and web, the value should not change [27].

2.12. Problems with the measurements

One problem is approximation of the electric charge density on the web. If the web has high enough electrical resistivity the net charge density can not be affected by the fields. In this situation we can assume uniform charge density. But, webs generally do not have uniform charge. Figure 28 shows comparison between uniform and non-uniform web potentials.

The fieldmeter face might also be a problem during the calculations. The surface is a conductor and the constraint on a conductor is that the electric field must be zero within it. Calculations should be done whether the charge on the face is uniform or not [28].

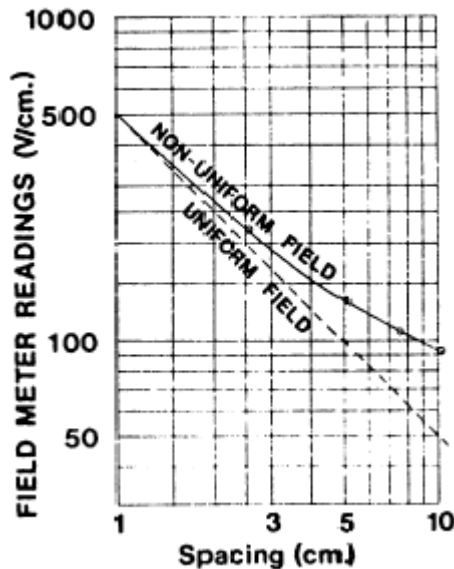


Figure 28: Uniform vs. non-uniform field [29]

One common thing that is being done is assuming the system as a capacitance. This can give correct results when having two parallel plates long enough. Generally, to have 2 parallel plates, a conductive plate that is around the fieldmeter is used. The ratio of this plate and sensing surface of the probe should be around 5:1 [28]. Some researches have noted that the electric

field that is measured is affected by geometry, including the fieldmeter head geometry. Also, some papers say that using a parallel plane system can cause more errors during calculations [28].

3. Experimental Setup and Apparatus

This experimental setup was devised to study the influence of material properties, fabric design, components of fabrics, environmental properties (temperature, humidity) and working conditions (fabric speed, tension, machine parts) on generation of static potential on moving fabrics. Developing the equipment was the primary objective of this research.

3.1. Materials

Five different kinds of fabrics were used during the tests. These were:

- 85% polyester and 15% conductive polyamide (A type of Albany International belt)
- 100 % polyester woven fabric (Guardian™ – AstenJohnson)
- 100 % polyester spiral fabric (SpiralTuf™SW-70 – AstenJohnson)
- 85% Polyester and 15% conductive Polyamide woven fabric (Webmaster™ F325 – AstenJohnson)
- 85% Polyester and 15% conductive Polyamide woven fabric (Webmaster™ G1340D – AstenJohnson) It is a 1.5 layer fabric.

Conductive monofilament yarns are in both machine and cross direction of the fabric. The diameter of polyester that is used as warp yarns is 0.03556 mm (0.014 inches), and 0.04064mm (0.016 inches), 0.7112mm (0.028 inches) for weft yarns. Conductive monofilament has 0.04064 mm (0.014 inches) diameter in cross and 0.7112 mm (0.016 inches) in machine direction.

Conductive monofilament yarns are in both machine and cross direction of the fabric. The diameter of polyester that is used in machine direction is 0.020”, and 0.031” in cross

direction. Conductive monofilament has 0.020” diameter in cross and 0.031” in machine direction. It is a single layer fabric.

3.1.1. Resistivity of belts:

Resistivity property is one of the parameters that effect our tests. Overall resistivity of a fabric depends on its components. The resistivity of polyester is about $10^{-16} \Omega^{-1} \text{m}^{-1}$, polyamide is about $10^{-15} \Omega^{-1} \text{m}^{-1}$, and conductive polyamide is about $2 \times 10^4 \Omega^{-1} \text{m}^{-1}$. The difference between normal and conductive polyamide is very large.

Polymer properties are not the only factor on fabric resistivity. The percentage of each compound is also important, especially when a conductive yarn is used. Conductive fabrics have one conductive monofilament yarn in machine and cross direction for every 8 monofilaments.

3.1.2. Structural Variables:

Two main causes for charge generation are contact and friction. Friction depends on the number of contacts between materials. As contacts increases, charge generation is greater. So, the parameters that affect this number are:

- Warp and weft yarn density
- Number of layers

Our test fabrics were single layer, 1.5 layers and 2 layers. The increase in number of layers means that there will be more contact points, more friction.



Figure 29: Pictures of some fabrics that were tested; a) Webmaster™ G1340D, b) Webmaster™ F325 and c) SpiralTuf™ SW-70

Additional to these 3 fabrics; another model, which is 100% PET woven fabric, Guardian was tested.

The most different structure that was tested was SpiralTuf SW-70. It is formed by spirals. That means there are no warp yarn along the fabric and weft yarns were hold together by spirals. Figure 30 shows a detailed picture of its structure.

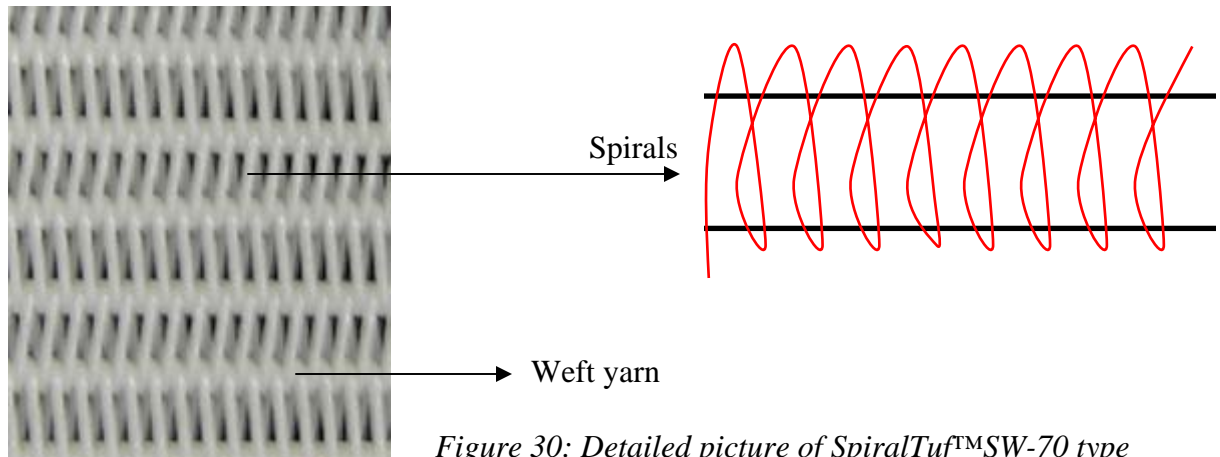


Figure 30: Detailed picture of SpiralTuf™SW-70 type belt

3.2. Machine Used for Testing

For our tests a system that allows fabric transport through the rollers was needed. The spunbond machine in NCRC Partners' Laboratory was used.

Machine properties:

- Belt speed can be changed from 0 to 1000 feet/min. In our tests the speed range was between 100 and 300 feet/min. The 300 feet/min is a similar to commonly used in industry.
- Tension can be adjusted by changing the position of the back roller of the machine. As there is no digital tension device on the machine, tension is

measured by a hand-held tension device. Tension was changed 3 times at 300 feet/min for every fabric.

We found that tension across the width of the fabric was not uniform. For this reason the measurements were made for middle, left and right areas separately, and then **4** **3** **2** compared.

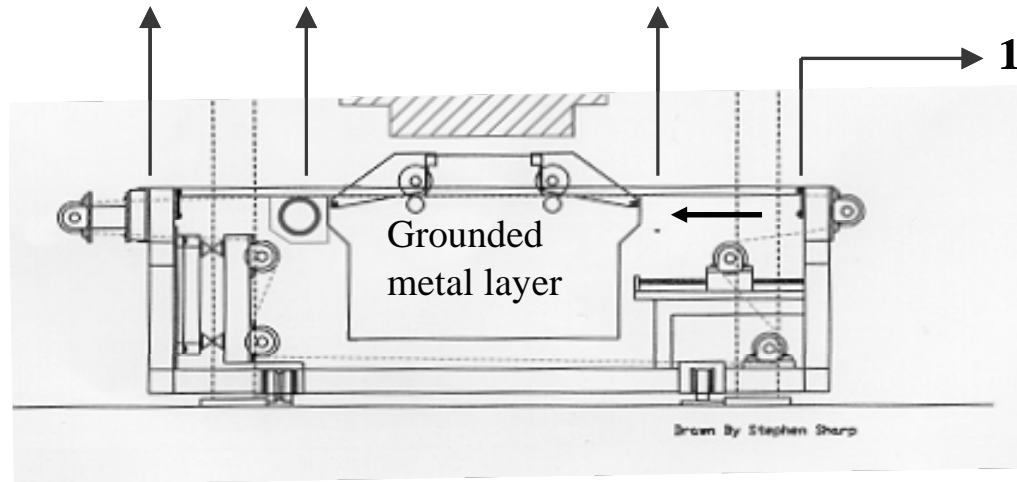


Figure 31: The areas that electrostatic charge was measured

Figure 31 shows the points that were tested on fabrics. Additional to the 3 areas that were cross direction, 4 different areas through the machine direction were used for testing. By doing this, it is easy to see the effect of the grounded metal layer and it also illustrates charge generation properties during fabric transport.

3.3. Data Loggers

- Temperature and humidity are measured by data loggers. As four probes were used, 4 data loggers were used during testing in front of each probe. These Veriteq S2000 data loggers can measure humidity and temperature changes and

save these data. It has capacity of 21,500 data sample and can measure at least in every 10 seconds.

The accuracy for humidity is +/- 2% and for temperature is 0.15 C0. These values were sufficient for our tests.

There is no control on temperature and humidity in Partners' Laboratory. For this reason tests should be done in cold and warm weather. Humidity changes were done by spraying water on the belt.

- Measurements were made in 4 different areas along the fabric (as shown in figure 36) and 3 different areas (middle, right and left) across the fabric width. To see the effect of time, charge density was measured in different areas. As fabric moves from one place to another, without touching any machine parts, it has a tendency to generate charge according to its material structure. Also, by measuring static potential before and after machine parts, we investigated the effects of grounded and ungrounded machine parts that are in contact with the web.

3.4. Charge Decay Setup

Charge decay tests were done to find a relationship between static potential on fabrics during production and their charge decay rates. For this test the Electro-tech Systems model 406D static decay meter was used.

In this test method fabrics were mounted between 2 electrodes and charged with negative and positive 5000 volts. The amount of charge that is on the fabric depends on the time that fabrics are under charge and fabric properties.

All materials have different resistivity properties. If materials have low resistivity that means less time is needed for the fabric to decay the charge on it.

There are two kinds of resistivity for webs, bulk and surface resistivity. The instrument that was used is for surface resistivity.



Figure 32: The charge decay test instrument –ETS Model 406D-

Style	Mesh	M.D. Diam.	X.D. Diam.	F.S.I.	Air Perm.
1.5 Layer					
WebMaster™ F325	75 X 26	0.014" Polyester	0.016" Polyester	57.5	660 cfm/ft²
		0.014" Conductive Polyamide	0.016" Conductive Polyamide		
			0.028" Polyester		
Double Layer					
WebMaster™ 812	74 X 40	0.014" Polyester	0.028" Polyester	42.3	655 cfm/ft²
		0.014" Conductive Polyamide	0.016" Polyester		
			0.016" Conductive Polyamide		
Single Layer					
Taurus 200P - AS	23 X 11	0.030" Polyester	0.031" Polyester	22.5	820 cfm/ft²
		0.030" Conductive Polyamide	0.031" Conductive Polyamide		
WebMaster™ G1340D	50 X 16	0.020" Polyester	0.031" Polyester	43.7	600 cfm/ft²
		0.020" Conductive Polyamide	0.031" Conductive Polyamide		

Table 3: Belt properties

In addition to the fabrics that were used during test on the spunbond machine, 3 different fabrics were tested on the charge decay instrument to see the effect of structure on charge decay times. These fabrics were 100% woven polyester and they are not being produced. The difference is in their fabric structure. Table 3 shows some of the properties of these fabrics.

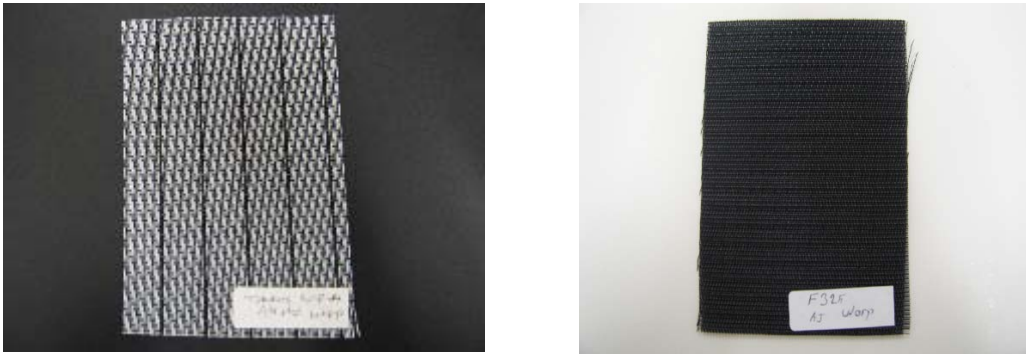


Figure 33: Taurus and Webmaster™ F325 types of fabrics

The definition of F.S.I., which is in the table, is ‘fiber support index’. This is used by the papermaking industry and describes the contact area between fabric and paper. The other differences are number of layers and the diameter of monofilaments. Charge decay time shows significance difference between different fabrics.

In charge decay tests it was assumed that there is only one value for the resistivity independent of the field applied. But we have to say that resistivity increases with decreasing field strength. The resistivities were usually determined at one field strength. Some fabrics can not be charged up to 5000 volts in the time required because of high resistivity. So, the values found for charge decay time is only the time for that specific amount of charge.

What happens during charge decay?

The problem with charge decay is the measurement system. There is a fieldmeter in the middle of fabric and it measures only the area under it. But as the charge on the fabric is not equally distributed, we can not be sure that this charge decay represents the whole of the fabric.

Another problem occurs when conductive monofilaments. Charge on a conductive fabric will be dissipated more quickly than regular fabrics. But this kind of information is only useful while using a certain amount of conductive monofilament on the structure. Otherwise during charge decay some charge will be left between conductive monofilaments. Decreasing the distance between monofilaments in the structure will help dissipation of charge because of the required space that electron should pass to move on a conductive monofilament.

3.5. Handheld Electrostatic Fieldmeter

At the beginning of this research, we wanted to test different kinds of fieldmeters to be sure about test requirements. We started from the basic fieldmeter which is a handheld electrostatic fieldmeter. The specifications of this type of instrument are:

- Easy to read and use
- Lightweight and compact
- Digital and bar graph displays
- Can measure up to +/- 20kV
- Accuracy +/- 10%
- Operates at 10-40°C



Figure 34: Handheld fieldmeter –Simco Model FMX-002-

The disadvantages of this fieldmeter are:

1. Hard to keep the distance between web and fieldmeter constant

The distance between web and fieldmeter effects the test results. Fieldmeters calculate the static potential on a web by using the distance to that web. If the web has a -15kV charge with the distance 1", which means fieldmeter should give -7.5kV at 2" of distance. As the distance is kept by holding the instrument over the web, it is very hard to provide the same amount of distance every time during measurements. Even 0.1" difference between two tests will give different values.

2. There is no output to download data on a computer

Static charge on a web shows fluctuations. The results do change in every second. So, taking the data in a computer and calculating the averages, standard deviations is needed.

3. Sensitivity is not sufficient

Our tests required very sensitive instruments to see every little change on static charge generation. By using a handheld fieldmeter, there are some limitations about sensitivity. This will effect especially average and standard deviation values.

3.5.1. Measurements with Handheld Fieldmeter

The most important advantage of this type of instrument is that the position of the fieldmeter can be changed easily and measurements can be done very fast even in hard-to-reach areas. Using other type of fieldmeter can require much time and it is also hard to set-up the probes.

The measurements were done on the front and back side of the machine (figure 35). "Front" is the side just before the calendaring process. We tested the effect of the roller

on charge generation at different speeds by doing measurements before the roller, on the roller and after the roller.

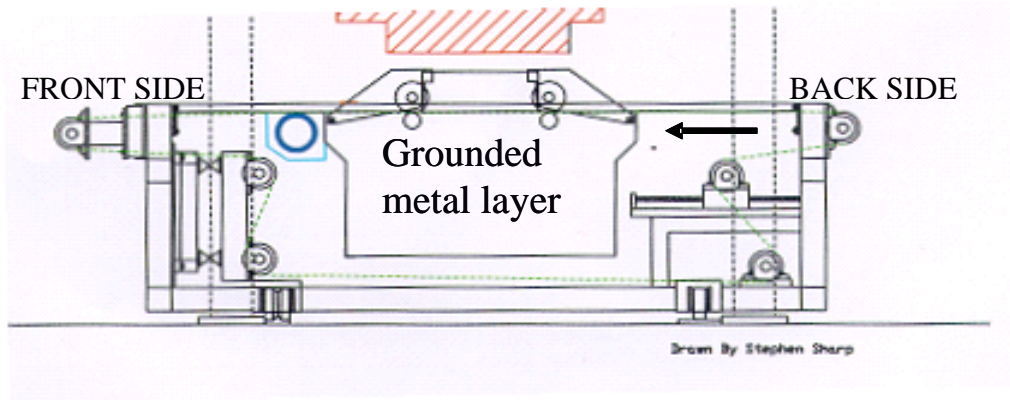


Figure 35: Spunbond machine

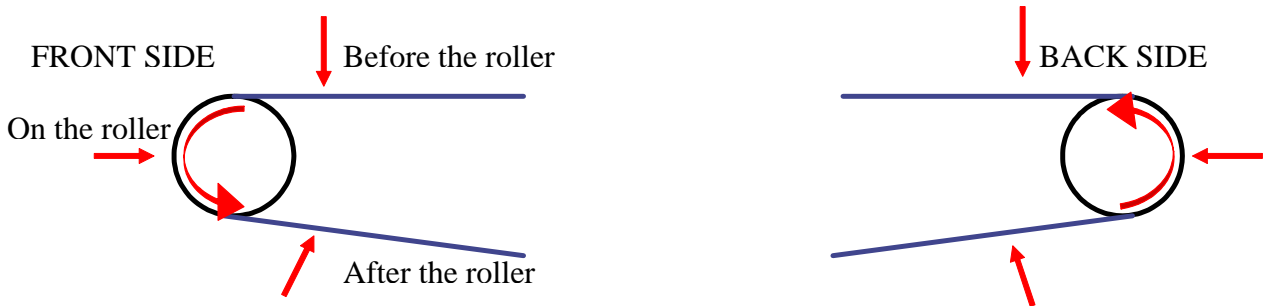


Figure 36: The areas that measured by using the handheld fieldmeter

3.6. One-Probe Electrostatic Fieldmeter

The second step was to use a one-probe fieldmeter to see the differences between previous tests which were done by using the handheld instrument. The model that is used was Monroe Electronics SE0054. The specifications of this fieldmeter are:

- Range $\pm 20\text{kV}$
- Sensitivity 10V/cm
- Probe type: 1036-F
- Probe operating environment: $-30\text{--}100^\circ\text{C}$



Figure 37: The probe that was used, Monroe Electronics, model 1036F

- Easy for hard-to-reach environment
- Recorder output

Mounting this probe on a belt at a distance of 1 cm provided better results than the fieldmeter. Sensitivity is higher, and it is easy to see the data on instrument. There is an output device on it, so the results can be downloaded to a computer. That helps to get more accurate results.

There are two disadvantages of this instrument:

1. Basically probe measures the field on the belt under it. But the results can be affected by areas close to the measuring circle as shown in figure 38. 'A' shows the reason for error in results are shown when no conductive layer is used.

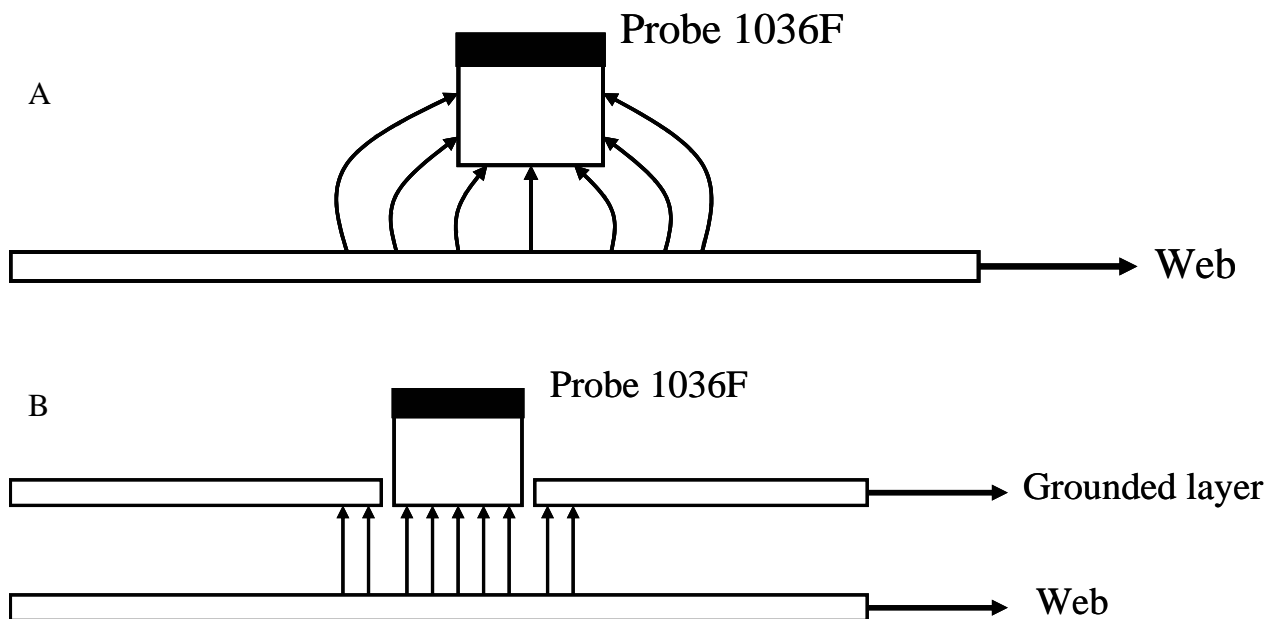


Figure 38: Measurements with one probe fieldmeter with (A) and without (B) conductive aluminum layer

Figure 38-B shows more clearly the way decreases error. For this reason, using a conductive metal layer is required. Mounting the probe in the middle of conductive

surface decreases error rate. But it is very hard to mount as the gap between probe and metal layer is very small. These two shouldn't touch each other during measurement.

The grounded metal layer that was used was an aluminum layer which has 1 mm thickness.

2. Static charge changes time by time because of the effects of some parameters; measurements should be done at different areas at the same time. For this reason, a multi-probe instrument should be used. The other disadvantage of using this one-probe instrument is the limits of measuring different areas.

Static potential on different areas at machine direction also tested with this instrument. As some parameters (humidity, temperature, friction, etc.) changes every time; it is a big possibility that the results had errors. Figure 39 shows the areas that one-probe instrument was used to do tests.

3.6.1. Measurements with One-probe Fieldmeter

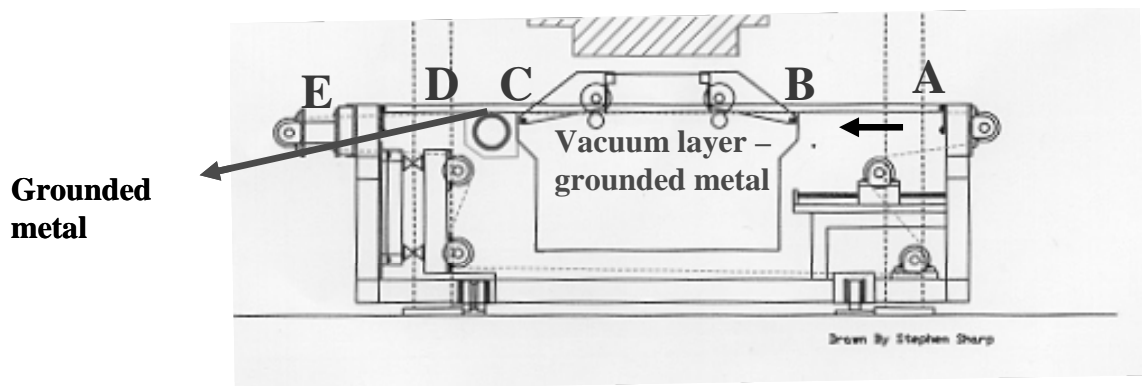


Figure 39: The areas that were tested with one-probe instrument on spunbond machine

The effects of experimental parameters (separation, grounded layer which is in touch with fabric, transporting, grounding metal layer that is not in-touch with fabric) can be seen from the results. Before running the tests, these results were expected:

- Area 'A' (figure 39) should have the highest charge because of the separation
- Area 'B' should have lower charge than 'A' because of charge dissipation to the air
- Area 'C' should have the lowest charge as it is the first point after grounded metal layer. Most of the charge on belt should move to the grounded layer.
- Area 'D' should have higher charge than 'C' because of fiber-to-fiber friction.
- Area 'E' should have higher charge than 'D' because of friction.

3.7. Multi-probe Fieldmeter

This type of fieldmeter was used to overcome the limitations of the one-probe model. This instrument allowed us to see the changes at the same time for different areas, better illustrating the effects of different experimental parameters.

The probes that were connected to it were the newest model and these provide less error during measurements. Here are the specifications of this fieldmeter:

- Analog outputs: +/- 10kV
- Sensor range: +/- 20kV
- Accuracy better than 1%
- Probe type: 1036-E
- Number of probes: 4
- Probe operating environment: -30-100°C



Figure 40: Probe type and Monroe model-177 fieldmeter

- Speed of response: 250 ms

3.8. How Does It Work?

To use the multi-probe instrument on the spunbond machine, some mounting parts were needed. Figure 41 shows the mounting parts that were manufactured. These are:

- 4 metal probes to put sensors on. By using grounding cables the error rate was decreased
- 4 wooden bridges to mount metal plates
- Data acquisition card to get the data from fieldmeter and download it onto a computer



Figure 41: Mounting parts

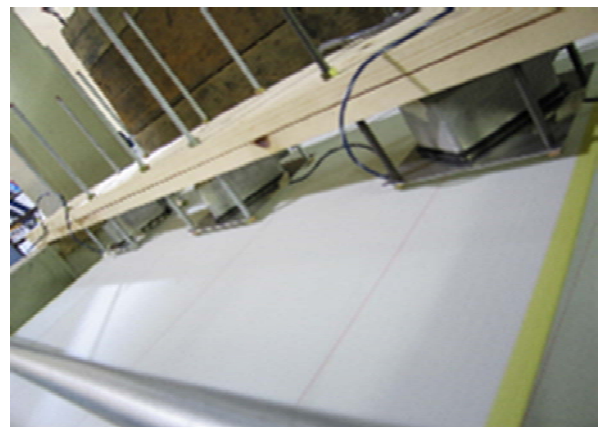
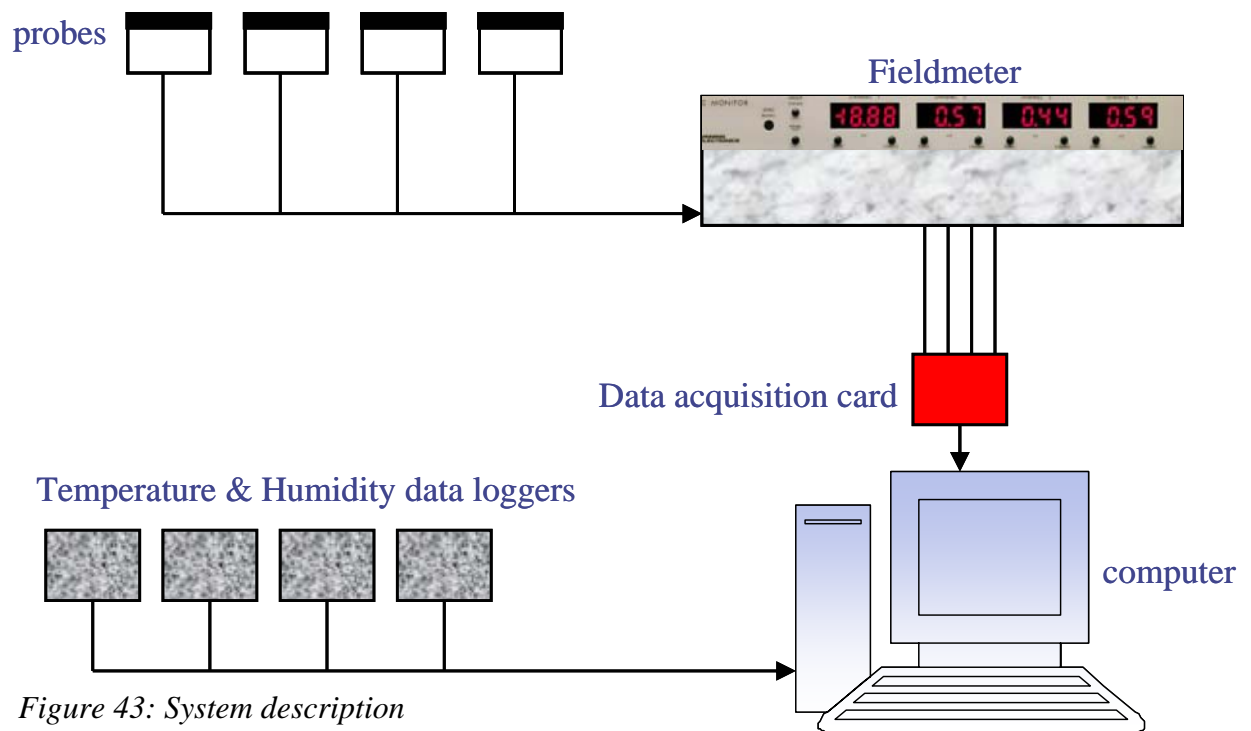


Figure 42: Some pictures taken during a test



The figure above shows the connections of the system elements. 4 probes are connected to the fieldmeter and by using a data acquisition card results can be downloaded. Temperature and humidity data loggers are connected to computer to compare the results from these loggers and fieldmeter.

4. Results and Discussion

4.1. Charge Decay Tests

Charge decay tests were made as a quick method to measure charge generation properties of a belt before running it on a machine.

Basically, (+) and (-) 5000 volts was applied on 7.6*12.7 cm (3*5 inches) samples. Depending on the fabric properties and charging time, the amount of charge that the fabric can hold shows differences. Also, instrument can only charge fabric up to 3 minutes. After 3 minutes, it stops automatically, so some fabrics never reach +/- 5.000 volts.

Tables 4 and 5 show the results for (+) and (-) charge.

Table 4: Decay times at (+) charge

(+) Charge	Warp Direction	Weft Direction
Fabric type / Decay time	(Sec.)	(Sec.)
Taurus 200P	0.12	1.2
G61-G2X	>100	>100
WebMaster™812	0.01	0.01
WebMaster™F325	0.01	0.01
WebMaster™G1340D	0.01	0.01
G1340D not-antistatic	8.28	10.75

WebMaster™ series of belts have 15% conductive polyamide in their structures. For positive charge these belts have very low charge decay times.

The benefit of using conductive polyamide can be seen from the two last rows of the table. Non-conductive G1340D has 8.28 seconds and conductive G1340D has only 0.01 seconds of charge decay time.

The results for non-conductive belts show differences according to their structure. In terms of structure, belt mesh size, warp and weft density, number of layers are important parameters. Figure 45 shows decay times more graphically.

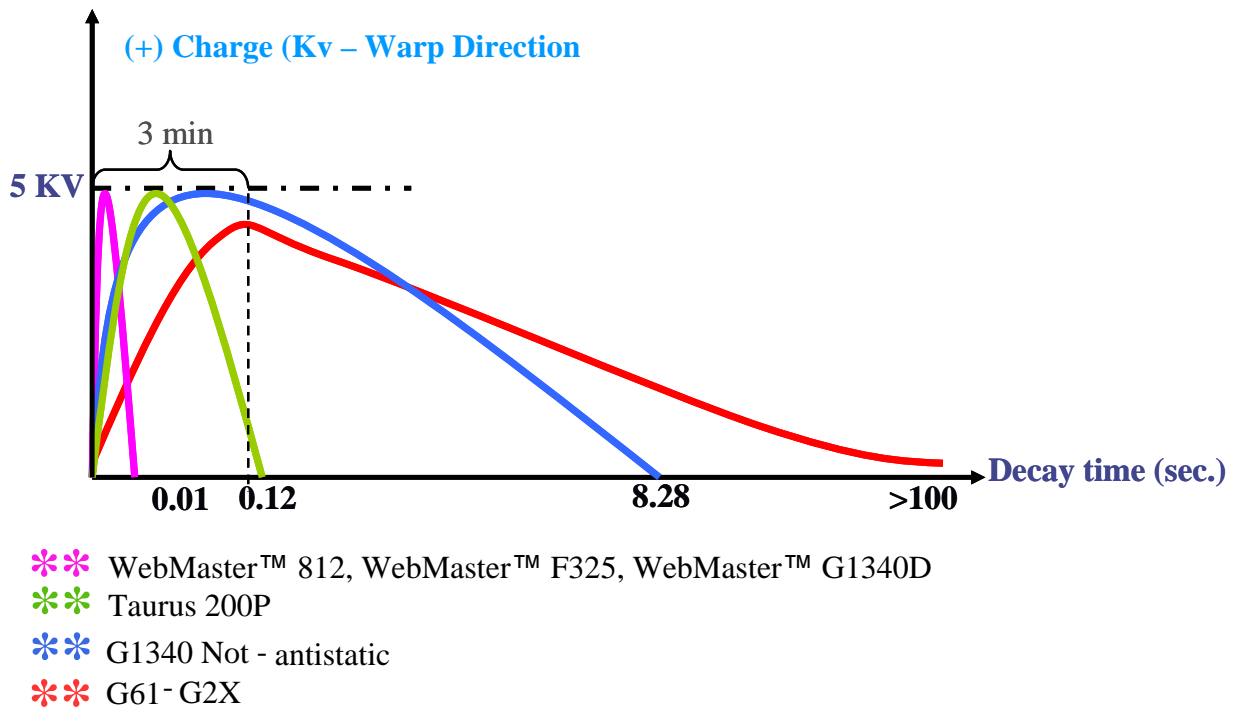


Figure 44: Belt decay times

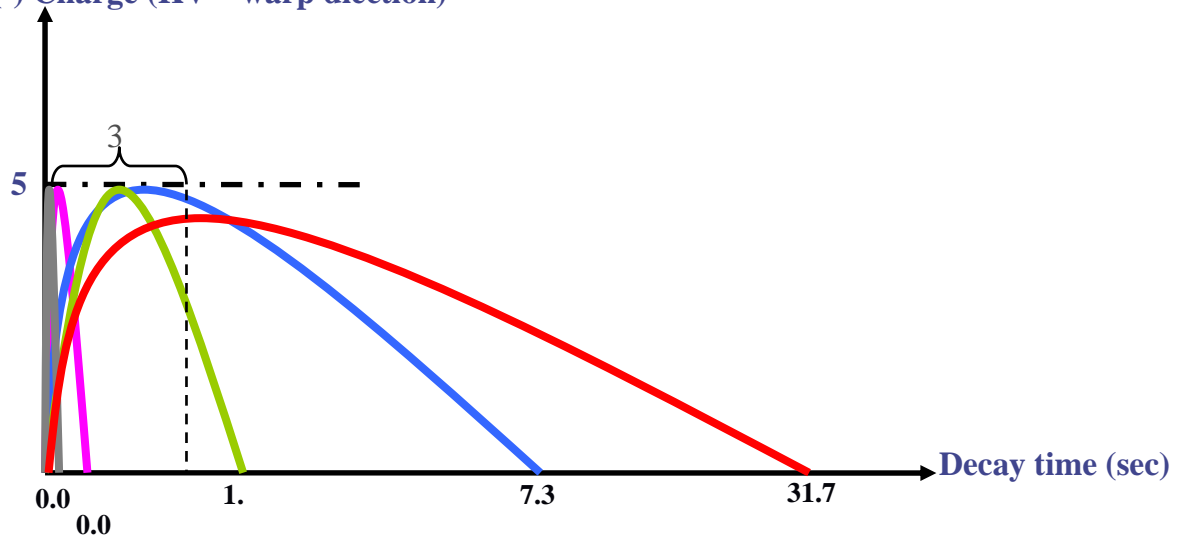
Results for negative charge are pretty much the same as positive ones. Belts which have conductive monofilament have very low decay time. Table 5 and figure 45 shows the results of charge decay times with a negative charge.

Figure 46 are the results for SpiralTuf™ type of belt. As explained in the experimental section, this belt does not have warp yarn in its structure. It is formed of weft yarns which are connected by spirals.

Table 5: Decay times at negative charge

(-) Charge Fabric type / Decay time	Weft Direction (Sec.)	Warp Direction (Sec.)
Taurus 200P	0.14	1.6
G61-G2X	54.11	31.71
WebMaster™812	0.01	0.01
WebMaster™F325	0.01	0.01
WebMaster™G1340D	0.00	0.00
G1340D not-antistatic	11.17	7.31

(-) Charge (KV – warp diection)



- *** WebMaster™ 812, WebMaster™ F325, WebMaster™ G1340D
- *** Taurus 200P
- *** G1340 Not - antistatic
- *** G61- G2X

Figure 45: Charge decay times for negative charged belts

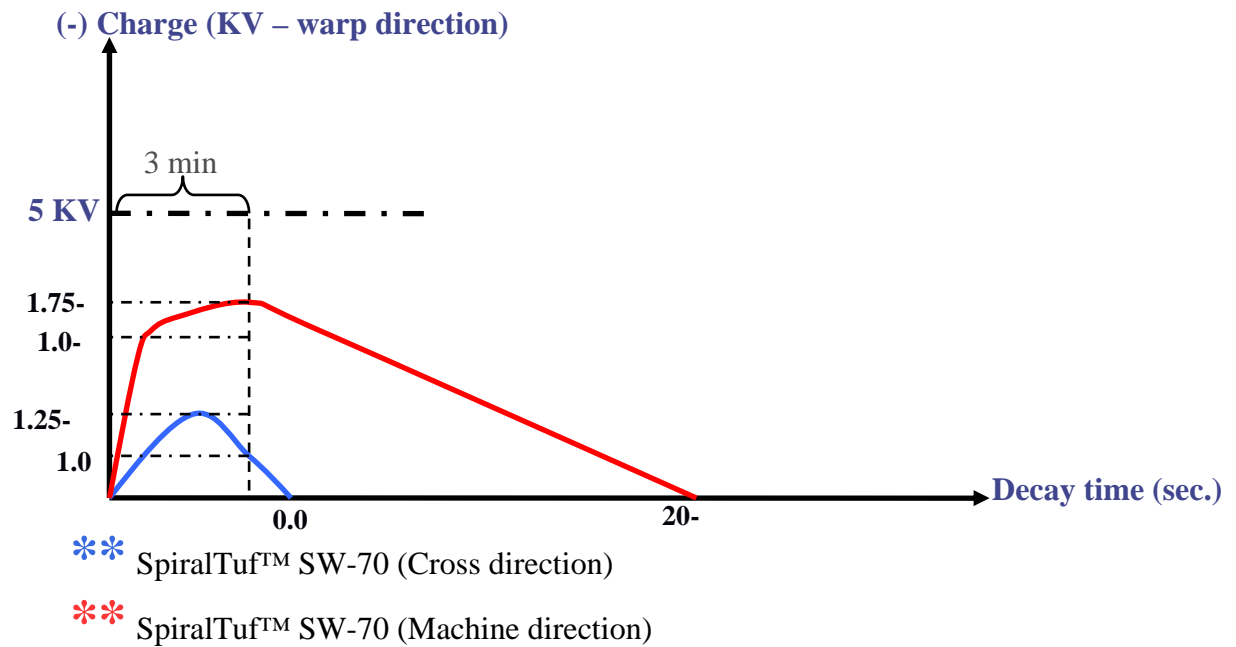
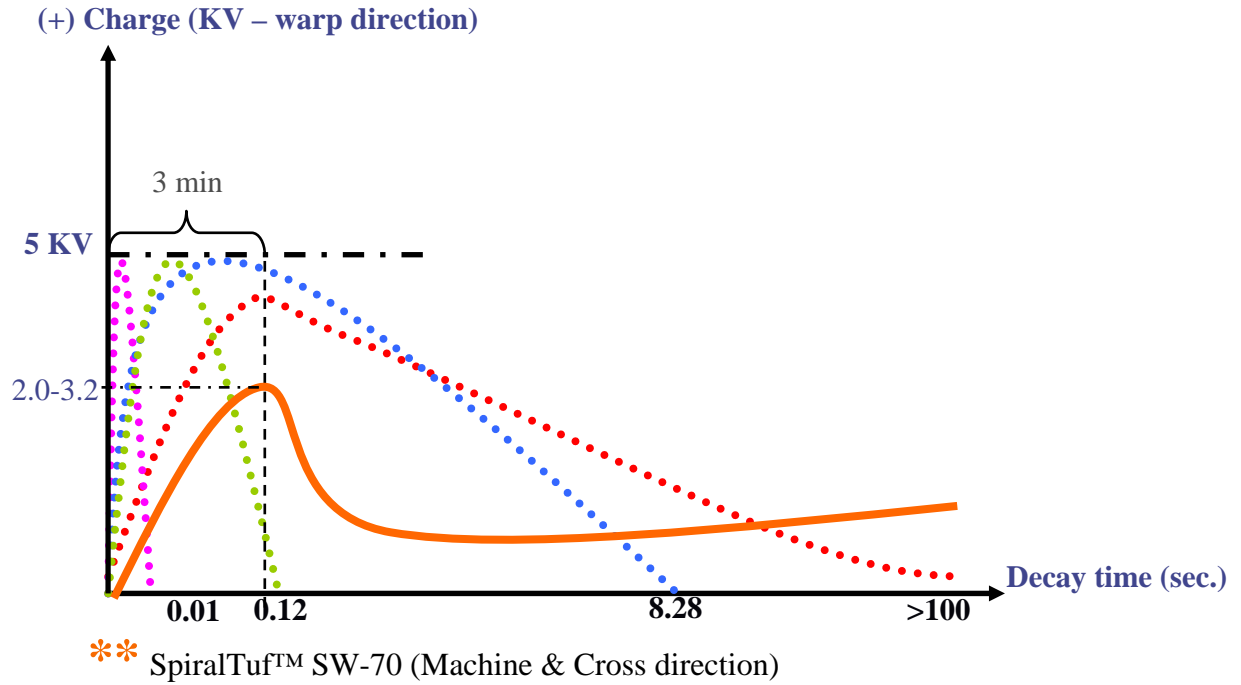


Figure 46 and 47: Charge decay times for SpiralTuf™ SW-70 type of fabric

Figure 46 is the result for positive charged SpiralTuf™ type belt. As there is a time limit to charge the belt (3 minutes), it could only be charged to about 3 KV. The interesting situation is that after the first few seconds, the charge on the belt seems to increase. The

reason for this behavior is the structure of the belt which is the only thing that is different than other non-conductive belts.

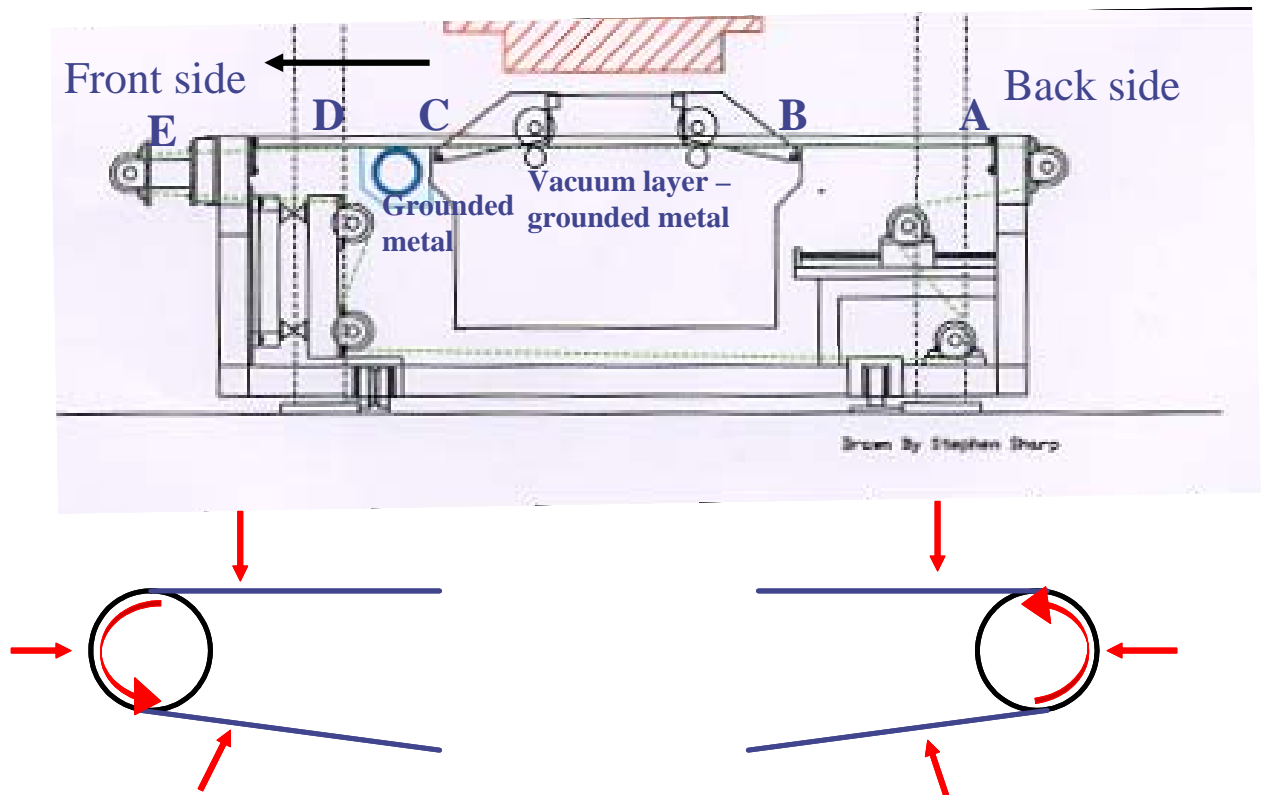
For positive charged SpiralTuf™ SW-70 type belt, it was charged up to 1.75 KV. As the amount of charge is very low, charge decay time is much lower than expected.

Because of the spirals and lack of warp yarns in belt's structure, charge stays in the structure.

4.2. Tests with Handheld Fieldmeter

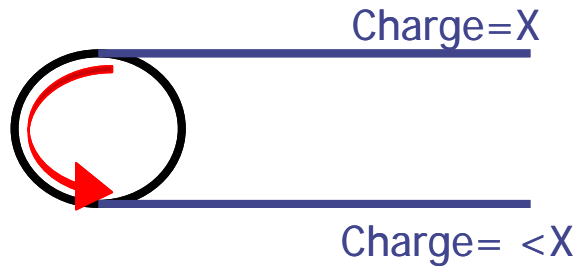
The first instrument that was used a handheld (SIMCO) one. The specifications, advantages and disadvantages were explained in experimental section. We started doing tests on the back and front side of the machine to see the effect of roller and belt transport. Table 6 shows charge generation values at 50, 100 and 150 feet/min.

Figure 48: The spunbond machine that was used for testing



Expectations before running tests:

- Low decay time will result in good charge dissipation time during contact



- Charge generation will be less
- Charge on belt may increase through the fabric transport from back to front side

Table 6: Electrostatic field measurements with handheld instrument

Conductive Belt/ Charge (KV)	Front side	Charge (KV)	Back Side	Charge (KV)
	Before cylinder	0.1-0.3	Before cylinder	0.4-1.0
50 FEET/MIN	After cylinder	0.2-1.0	After cylinder	0.04-0.2
	On the cylinder	0.02-0.08	On the cylinder	0.01-0.03
	Before cylinder	0.4-0.7	Before cylinder	1.5-2.0
100 FEET/MIN	After cylinder	0.6-1.2	After cylinder	0.15-0.32
	On the cylinder	0.18-0.42	On the cylinder	0.15-0.40
	Before cylinder	1.4-2.6	Before cylinder	1.4-2.6
150 FEET/MIN	After cylinder	0.15-0.4	After cylinder	0.15-0.4
	On the cylinder	0.15-0.35	On the cylinder	0.15-0.35

Results show that ‘before cylinder’ values are higher than ‘after cylinder’ values for a conductive belt. It means that some amount of charge was dissipated from belt. It can be assumed that the total amount of charge (charge on cylinder and belt) was divided into two parts. Some charge was taken by cylinder, so the charge on the belt after cylinder was lower. Figure 49 and 50 show these values more clearly for back and front side.

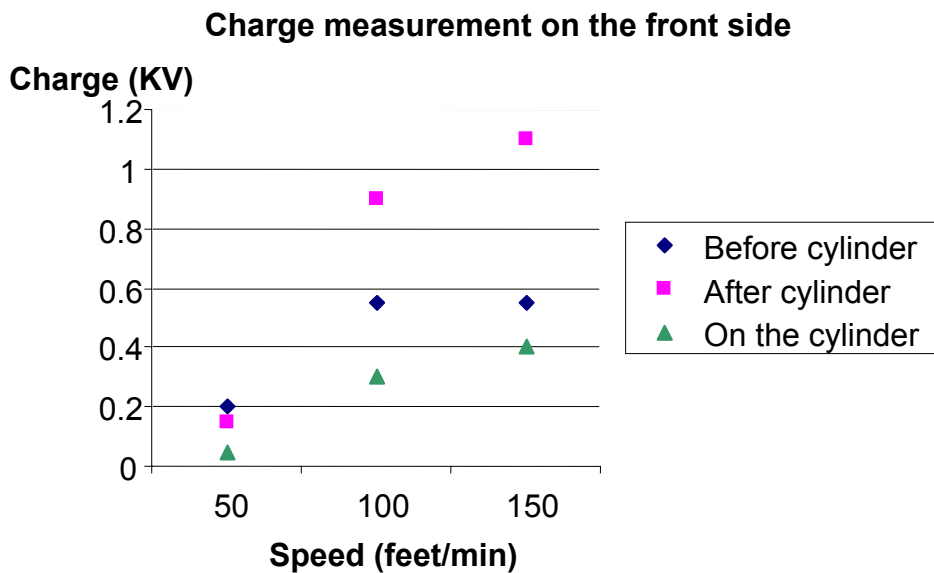


Figure 49: Charge on the front side

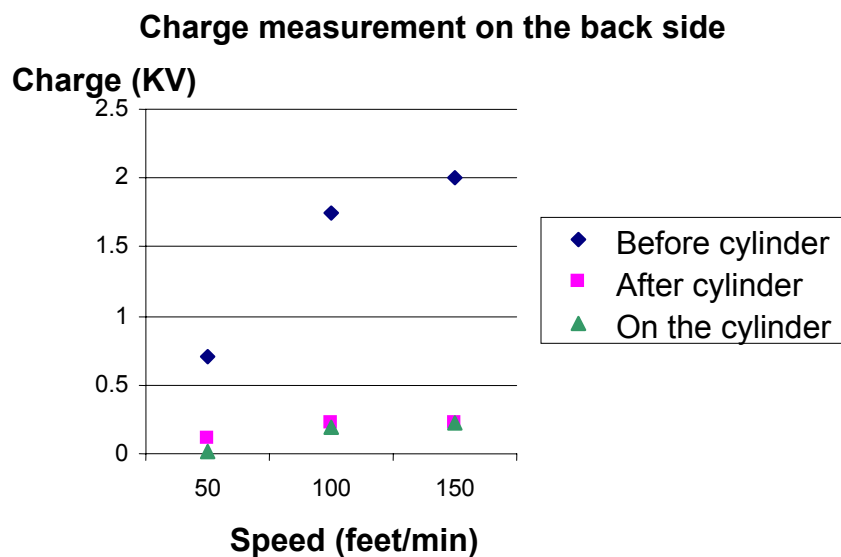


Figure 50: Charge on the back side

4.3. Tests with One-probe Fieldmeter

A one-probe instrument was borrowed from Monroe Electronics. Five different areas were measured to see the effect of cylinders, grounded metal layer, and belt transport at 50, 100 and 150 feet/min on three different areas cross the belt (right, middle and left areas).

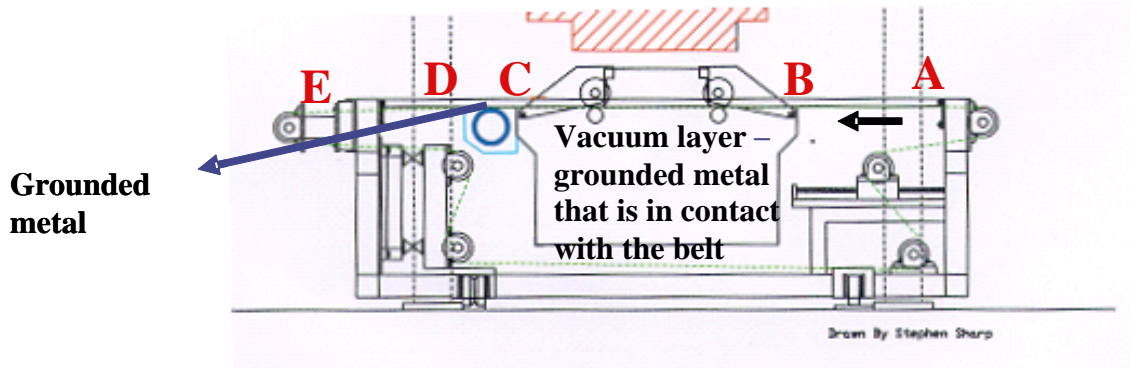


Figure 51: Measure areas on spunbond machine

Three different belts were tested; these were a conductive belt, a non-conductive belt and spiral weave.

Expectations before running tests:

- Charge generation at area A should be the highest because of the separation of belt and cylinder.
- Charge will decrease at area B; some charge on belt will dissipate through the air
- Area C should have the lowest charge. Most of the charge should be transferred to the grounded metal layer.

Tables 7, 8 and 9 show the results for three different types of fabric. It can be easily seen that the conductive belt generates very low charge. Non-conductive types of fabric generate much higher charge than conductive ones and the spiral type generated the

highest charge. The spiral belt has the highest decay time. Expectations above can not be seen for conductive belts.

Table 7: Charge generation on a conductive belt

Conductive Belt / Charge (KV)	Area	A	B	C	D	E
50 FEET/MIN	Right	0.13	0.12	0.12	0.12	0.12
	Left	0.13	0.11	0.12	0.14	0.13
	Middle	0.22	0.14	0.18	0.37	0.31
100 FEET/MIN	Left	0.18	0.13	0.14	0.15	0.18
	Middle	0.24	0.30	0.48	0.48	0.49

Table 8: Charge generation on a non-conductive belt

Guardian™ / Charge (KV)	Area	A	B	C	D	E
50 FEET/MIN	Right	3.45	2	0.2	1.93	1.5
	Middle	6.3	4.15	0.65	4.6	3.88
	Left	5.9	3.4	0.8	4.35	3.3
100 FEET/MIN	Right	4.15	3.2	0.43	3.3	2.4
	Middle	6.6	4.6	0.63	4.95	4
	Left	6.25	4	0.75	4.85	4
300 FEET/MIN	Right	5.35	4	0.87	3.35	3.55
	Middle	7.75	6.2	1.05	6.2	5.5
	Left	6.8	4.25	1	5.35	4.5

Table 9: Charge generation on a spiral type of belt

SpiralTuf™ belt/ Charge (KV)	Area	A	B	C	D	E
50 FEET/MIN	Right	1.62	1.03	0.48	4.9	3.2
	Middle	3.8	1.3	0.53	8.3	2.6
	Left	3.8	1.58	0.66	5.45	3.2
100 FEET/MIN	Right	5.3	3.1	0.51	7.1	4.55
	Middle	7.1	2.75	0.66	8.25	4.35
	Left	5.6	2.4	0.6	6.05	3.95
300 FEET/MIN	Right	10.6	6.15	0.97	9.1	6.9
	Middle	>14	7.8	0.98	>14	7.1
	Left	>14	8.2	1.15	10.5	8.2

Using a conductive layer, which is in contact with the belt, helps dissipation of charge.

For every type of belt, area C has the lowest charge. It can be also seen that as speed increases, charge generation increases because of the higher friction values between monofilaments and separation. Also, there will be less time for electrons to move to the cylinder during contact. So, more charge will remain on the belt. Figures 52 and 53 show the effect of speed on the conductive belt (Albany International) more clearly.

Like the measurements with the handheld instrument, the conductive belt generates very little charge. SpiralTuf™ type of belt generates the highest charge. For speed at 300 feet/min and over, we couldn't even measure the exact charge because of the limitations with the test instruments. The maximum output is 14 KV.

Areas A and D have the highest charge because of the separation of belt-roller and belt-conductive metal layer.

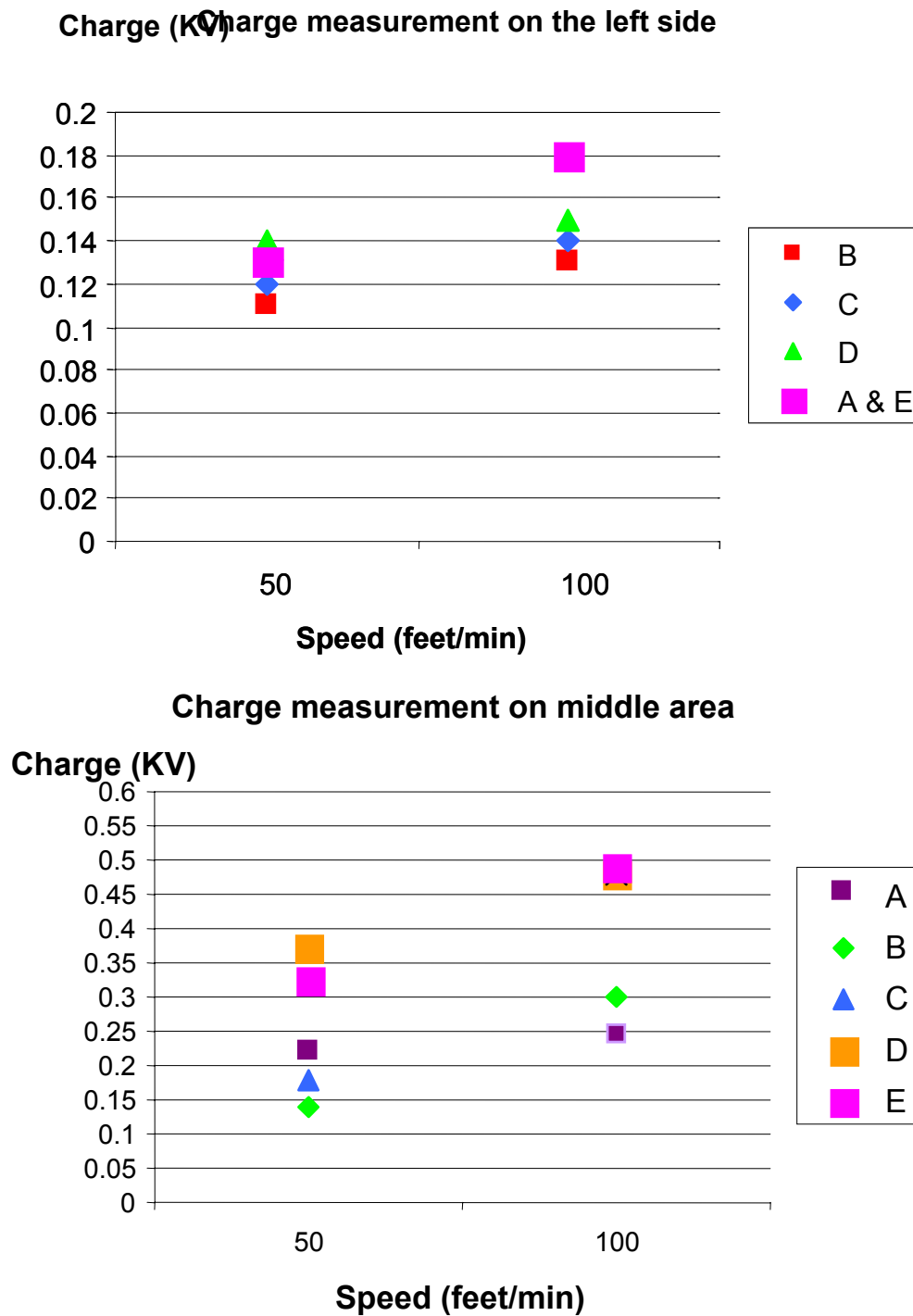
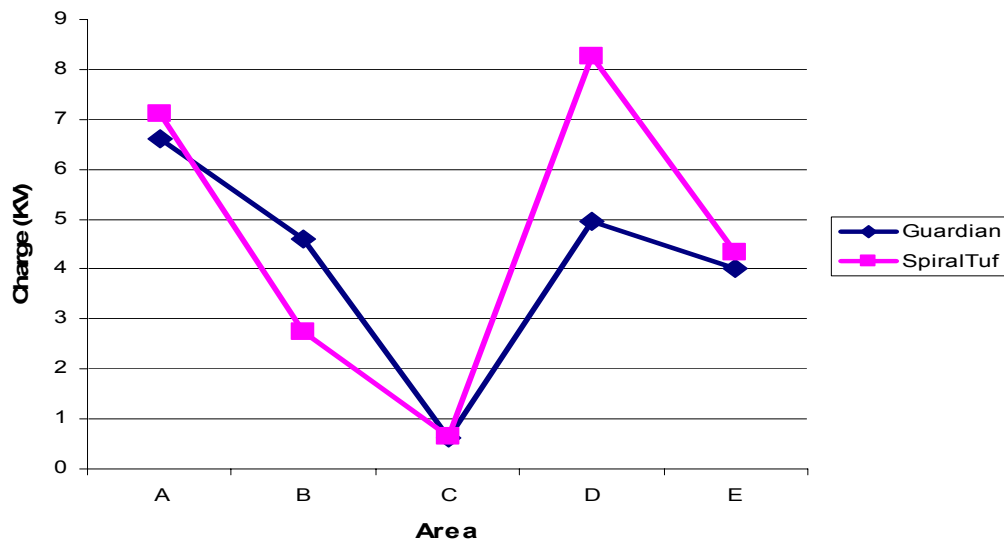


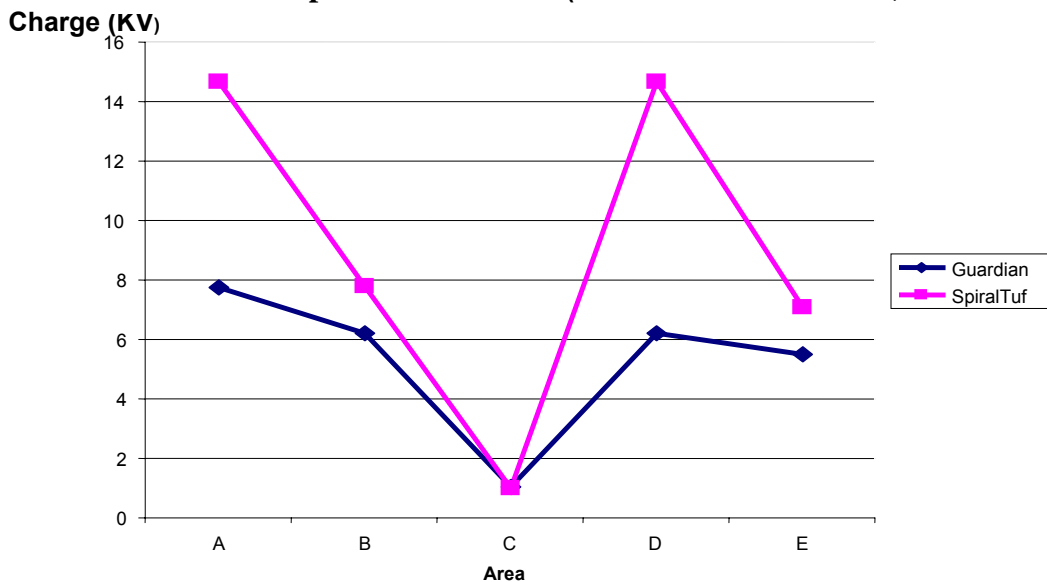
Figure 52, 53: Effect of speed on the conductive belt (One type of Albany International belt)

On the spunbond machine areas A and D have the highest charge generation values because of the separation. Area B has lower charge than A, because some charge was dissipated through the air. We have to keep in mind that every structure has limited charge generation values. So, if a material is highly charged, extra charge will be dissipated. Figures 54, 55 and 56 show the changes of charge generation values at different areas.

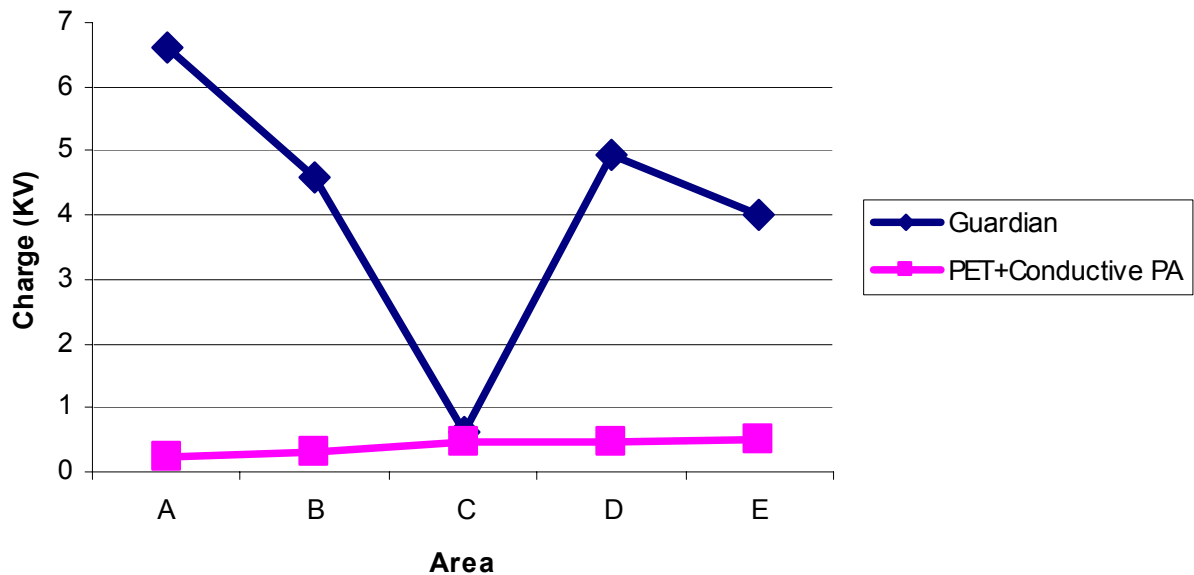
Guardian™ vs SpiralTuf™SW-70 (100 feet/min- middle area)



Guardian™ vs SpiralTuf™SW-70 (300 feet/min -middle area)



Guardian (100%PET) vs. PET+Conductive PA (100 Feet/min -middle area)



Figures 54, 55 and 56: Comparison between Guardian™ (woven 100% PET), SpiralTuf™ SW-70 and a conductive belt

The first two figures above are pretty similar. Only the conductive belt shows difference as it generates so little charge. Every kind of belt has less than 1 KV of charge at point C, which is just after a grounded conductive layer.

The reason for charge increase at area D is the separation of the metal layer and the belt. Then until area E, charge on the belt dissipates into air.

As speed increases, there won't be any changes about the behavior of belts. Figure 60 shows charge generation values at 300 feet/min.

4.4. Tests with Multi-probe Fieldmeter

Multi-probe fieldmeter (Monroe Electronics, model 177) was purchased to do measurements on different areas at the same time. The 4 new probes that were purchased have less error than the previously used. They can be worked with in tough areas and conditions (at high temperature and humidity).

Measurements were done on 3 different areas at cross direction and on 4 different areas at machine direction. Parameters that were tested were:

- Belt structure
- Speed
- Tension
- Humidity
- Contact area
- Spraying water

4.5. Effect of Speed



Figure 57: Measurement of right, left and middle areas

Previous tests showed that speed has a direct effect on charge generation. By using three different probes at cross direction we obtained charge generation values at the same time. This type of information is very important as the charge

on a textile material changes with time (the amount of friction, humidity and temperature values can not be controlled. Unless the measurements are not made at the same time, some of these parameters may change and can affect charge generation values).

The picture in figure 57 was taken during one of our tests. In the figure, the conductive layers and the cables that were used to ground the layers can be seen. Figures 58-63 show the charge generation values of different type of belts at different speeds.

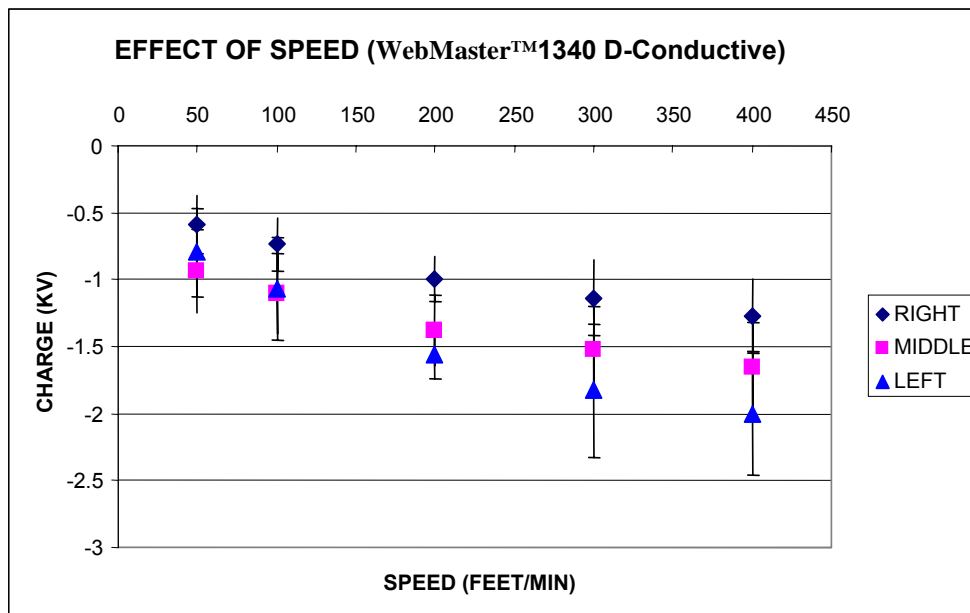
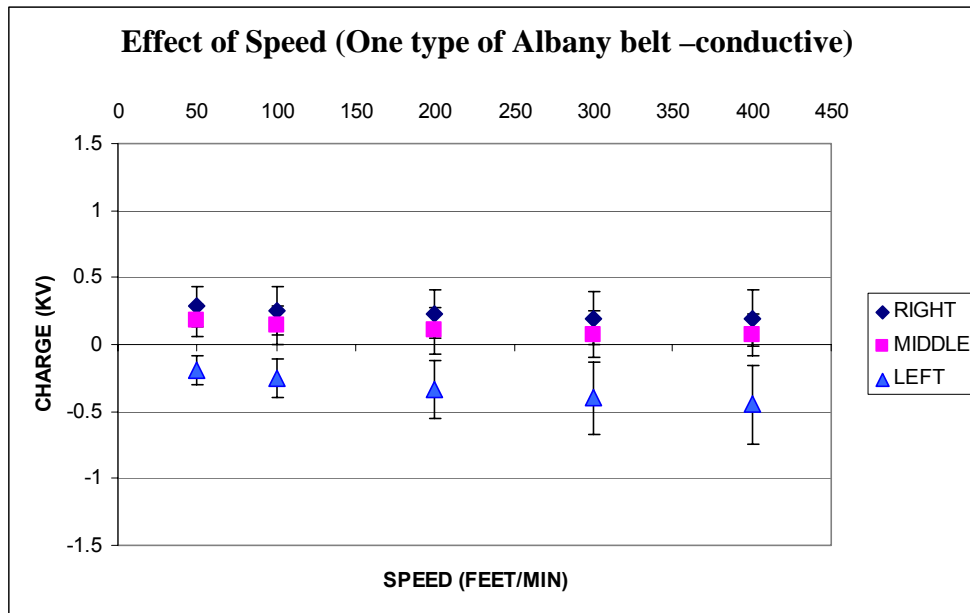


Figure 58 and 59: Results of conductive belts

Conductive belts generate little charge compared to non-conductive ones. The interesting point here is the results for an Albany used belt. Some polymer particles were on it and because of this, charge on belt can find a way to dissipate. These polymers are also the reason for positive and negative charge values on the belt.

WebMaster™1340D is a brand new conductive belt and it generates less than -2KV of charge which is less than non-conductive ones.

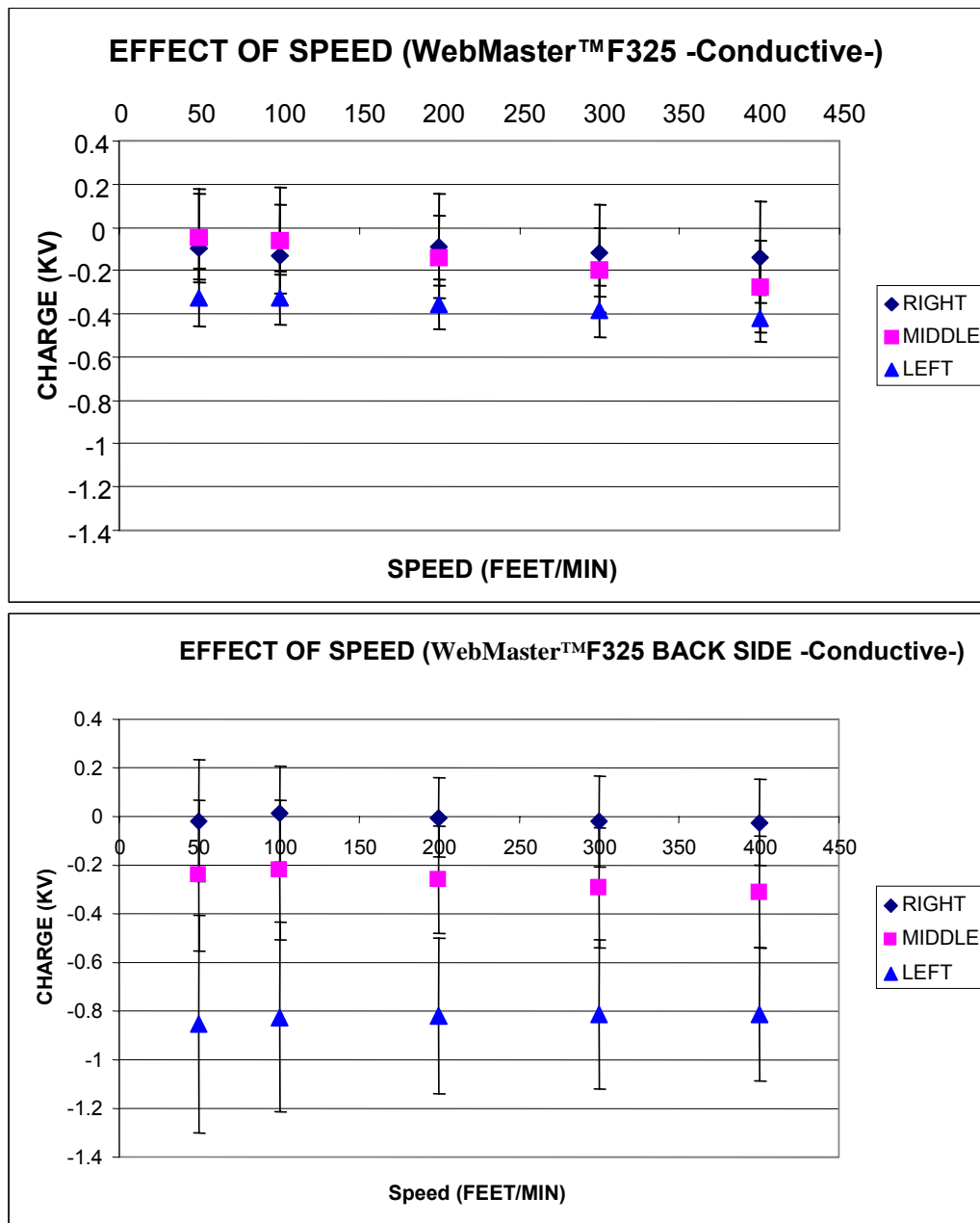


Figure 60 and 61: Results of conductive belt type WebMaster™F325 front and back side

‘Contact area’ is an important parameter as it is one of factors increasing friction. As contact area increases, there will be more friction, hence more charge generation. For this reason, WebMaster™F325 was tested on both sides.

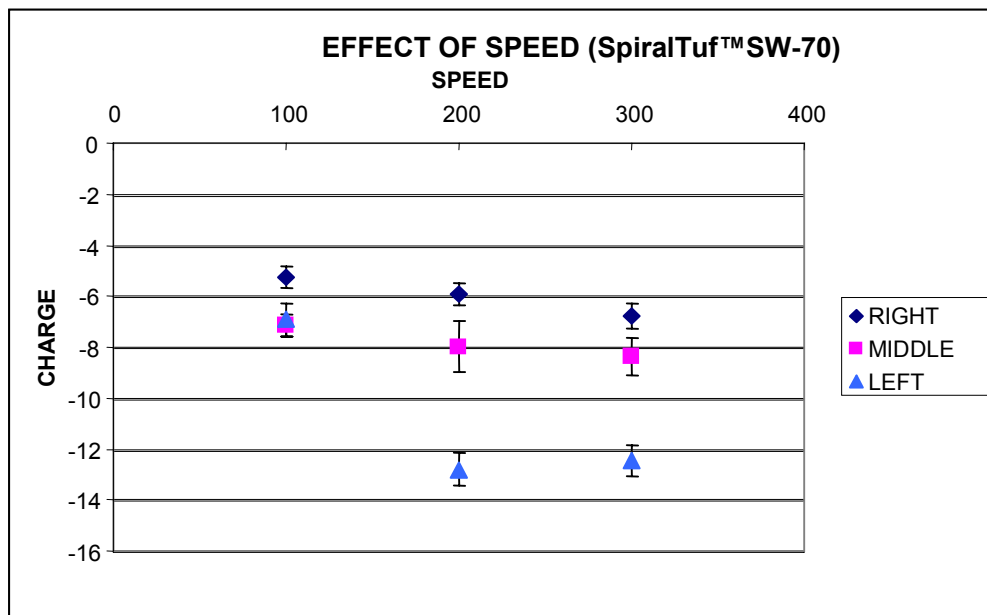
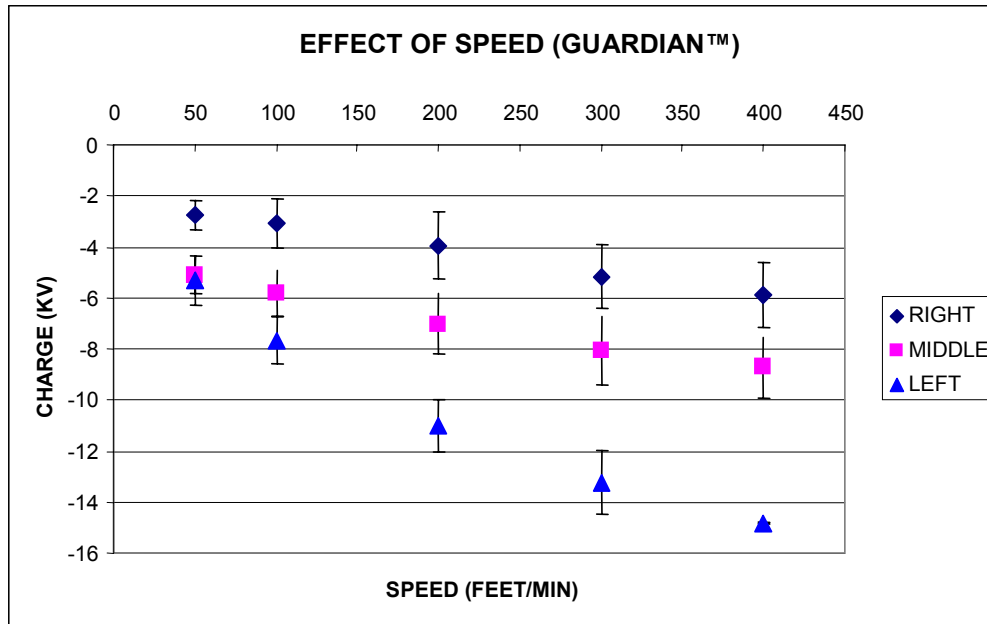


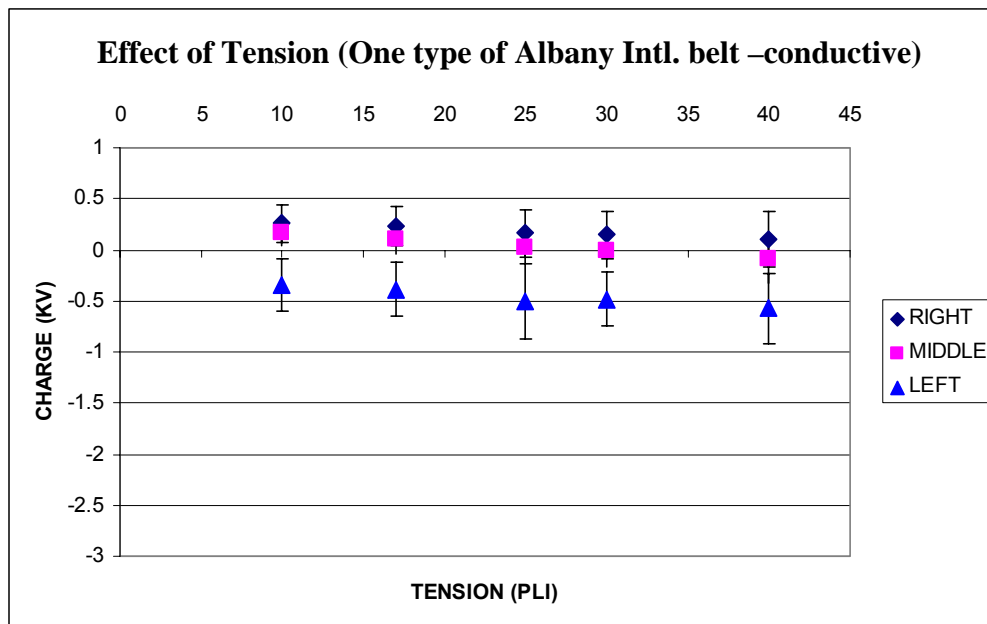
Figure 62 and 63: Effect of belt structure

Figures 62 and 63 show the charge generation on two belts that was formed of 100% polyester with different structures. SpiralTuf™ generates more charge because of its structure (non-conductive). Charge on this belt can not dissipate because of the absence of straight warp yarns. The charge is hard to measure at more than 300 feet/min because of the limited output range of the fieldmeter.

4.6. Effect of Tension

During this research, we determined out that tension is another important parameter for charge generation. For every type of belt, static potential were measured at 5 different tension values (10, 17, 25, 30, and 40 PLI). By looking at figures 64 to 69, it can be clearly seen that tension is more influential that speed changes.

Another important point is the three areas that were measured. For every different speed and tension values, the left area generates the highest charge and right side the lowest. The reason for this will be explained after this section.



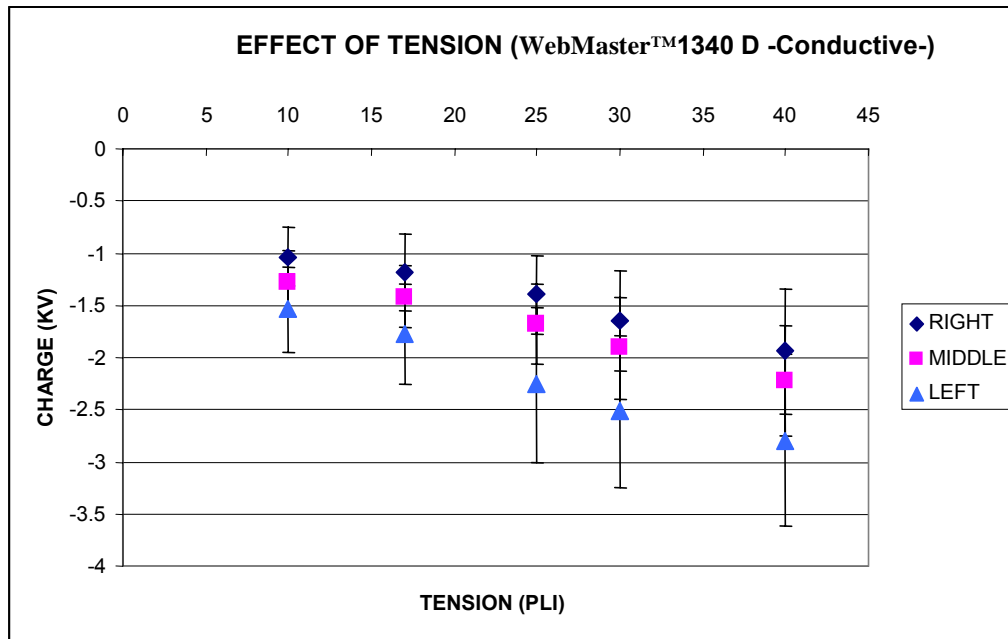
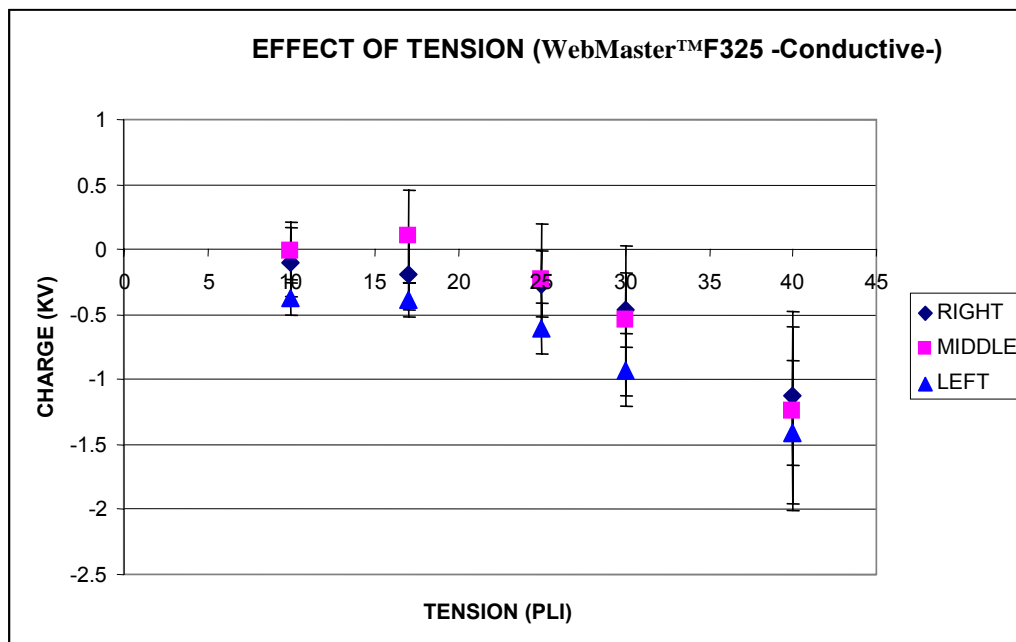
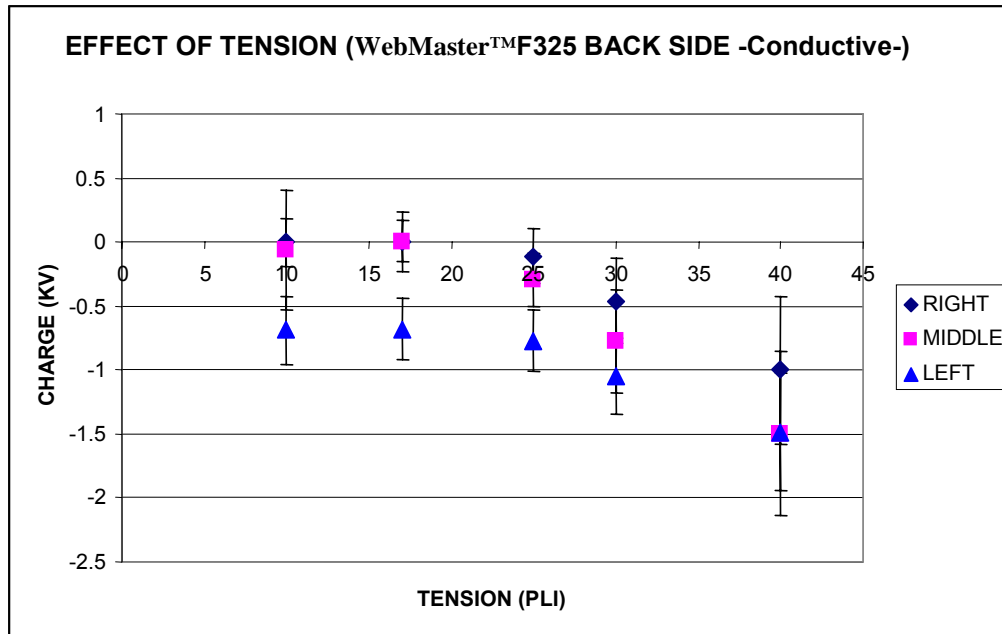


Figure 64 and 65: Comparison of used and new belts

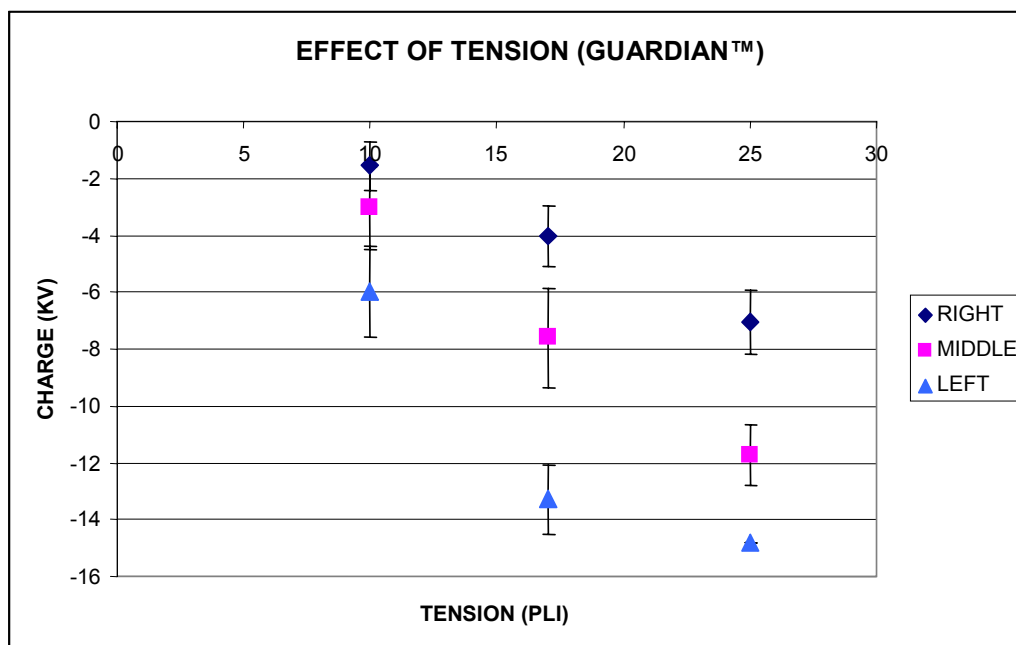
As in ‘effect of speed’ results, the used belt generates positive and negative charges, but new conductive belt generates more static charge as tension increases. The highest charge generation was at 40 PLI, which was -2.8 KV for the left area.





Figures 66 and 67: Effect of contact area

Contact area is the factor that increases friction. To see the effect of this, a conductive belt, WebMaster™F325, was tested. The results are pretty similar. But there is also not much difference in contact area values of front and back side of this belt.



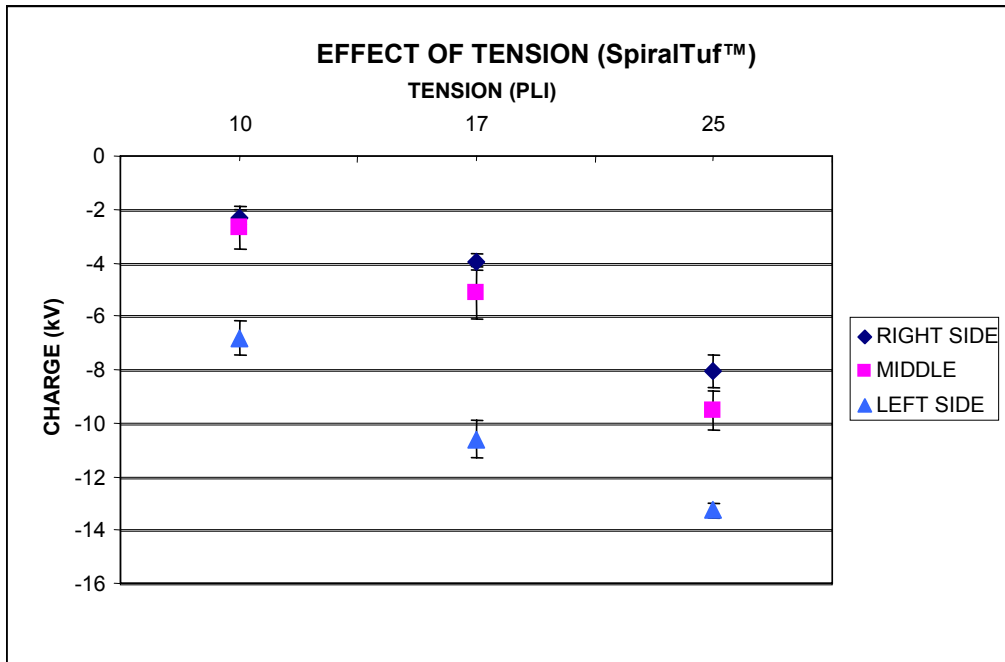


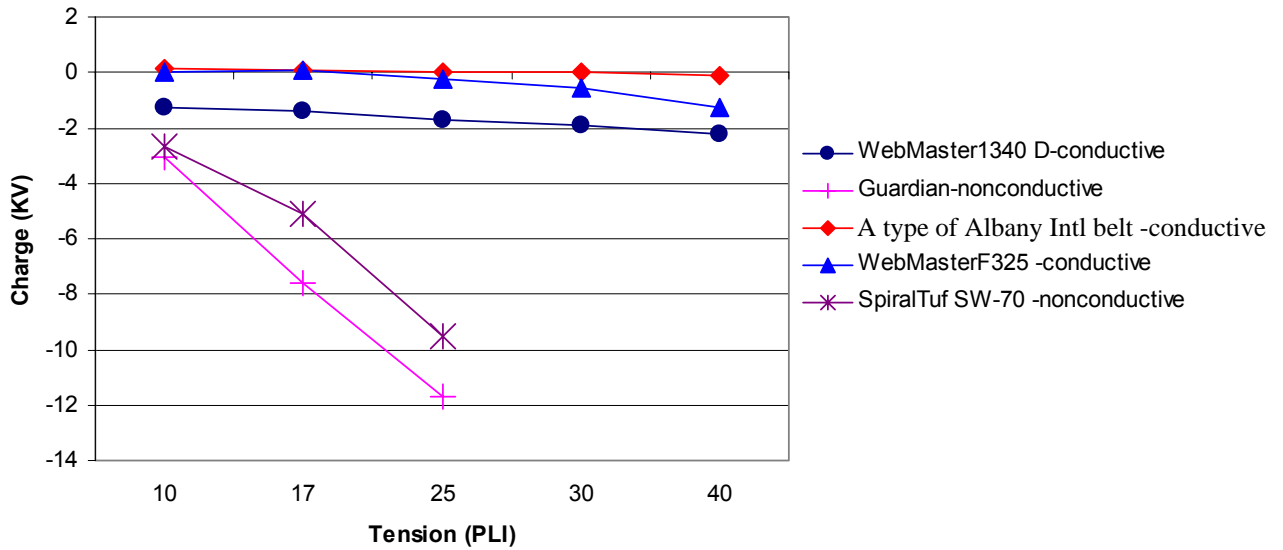
Figure 68 and 69: Effect of belt structure

The SpiralTuf™SW-70 type belt generates the highest charge as tension increases. Tension values more than 25 PLI could not be measured because of the limited output range of the fieldmeter. This problem can be solved by increasing the distance between web and probe. But data at the longer distance would not be comparable with that from the previous test.

4.7. Comparison of Belts

Comparison of belts can be seen in figure 70 and 71. The belts which have conductive polyamide generate the lowest charge. Non-conductive ones (Guardian and SpiralTuf) generate the highest charge and it wasn't able to measure these belts at over 25 PLI. The values shown below are 'middle areas' of the belts. Guardian type of belt seems to generate the highest charge in figure 70 but the average of three areas of SpiralTuf is the highest.

Comparison of Belts -Effect of Tension



Comparison of Belts -Effect of Speed

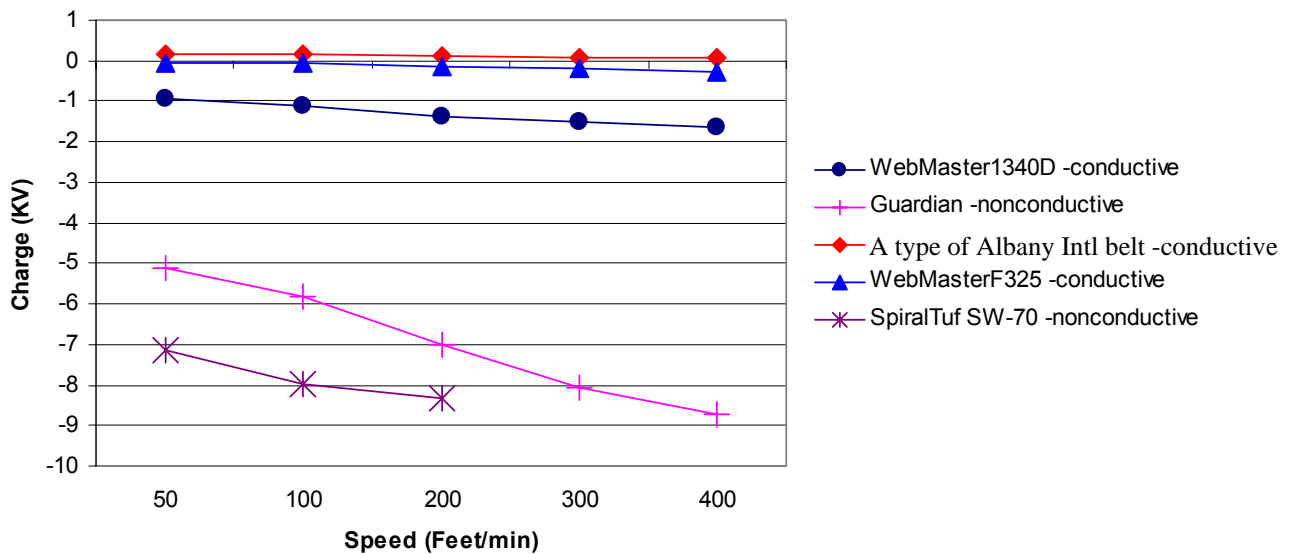


Figure 70 and 71: Comparison of belts

WebMaster types of belts have about 0.01 seconds charge decay times and non-conductive types (SpiralTuf™ SW-70 and Guardian™) have the highest decay times (over 100 seconds).

4.8. Tension at Cross Direction

As mentioned earlier, tests show that tension is the most influential parameter in charge generation. It can be clearly seen that left side generates the highest charge and right side the lowest. To understand the parameters that effect charge generation, the reason(s) for this situation had to be understood.

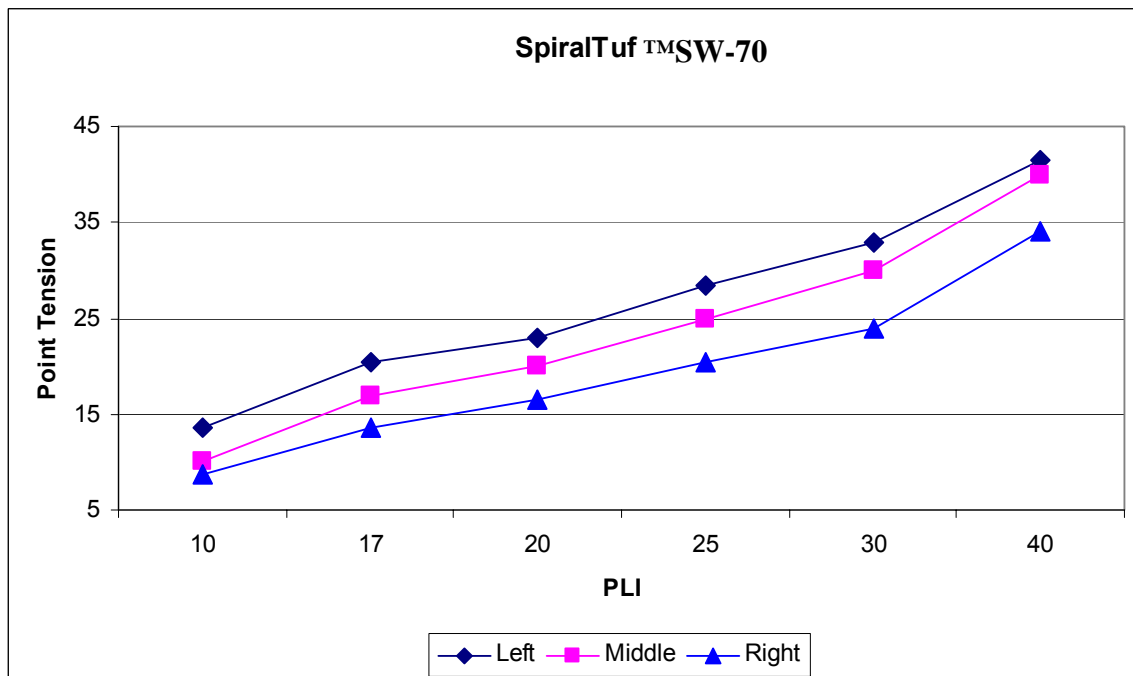
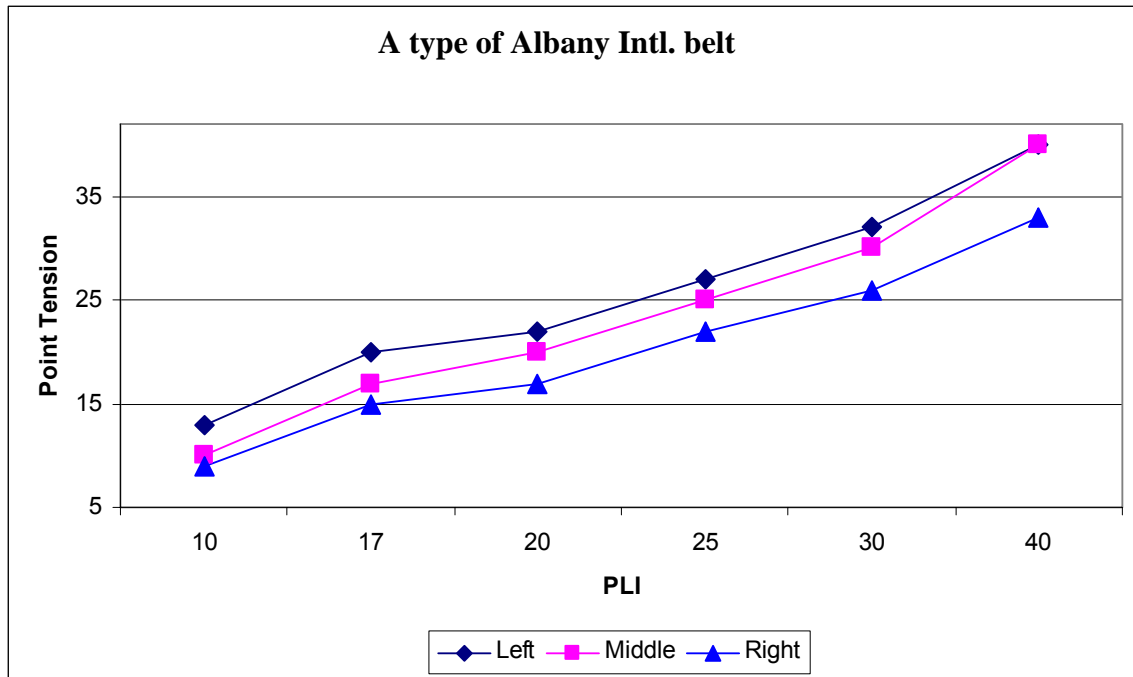
The charge measurements were made on three areas. The speed was same at these areas, but not the tension? Table 10 shows the results for tension when different types of belts were used.

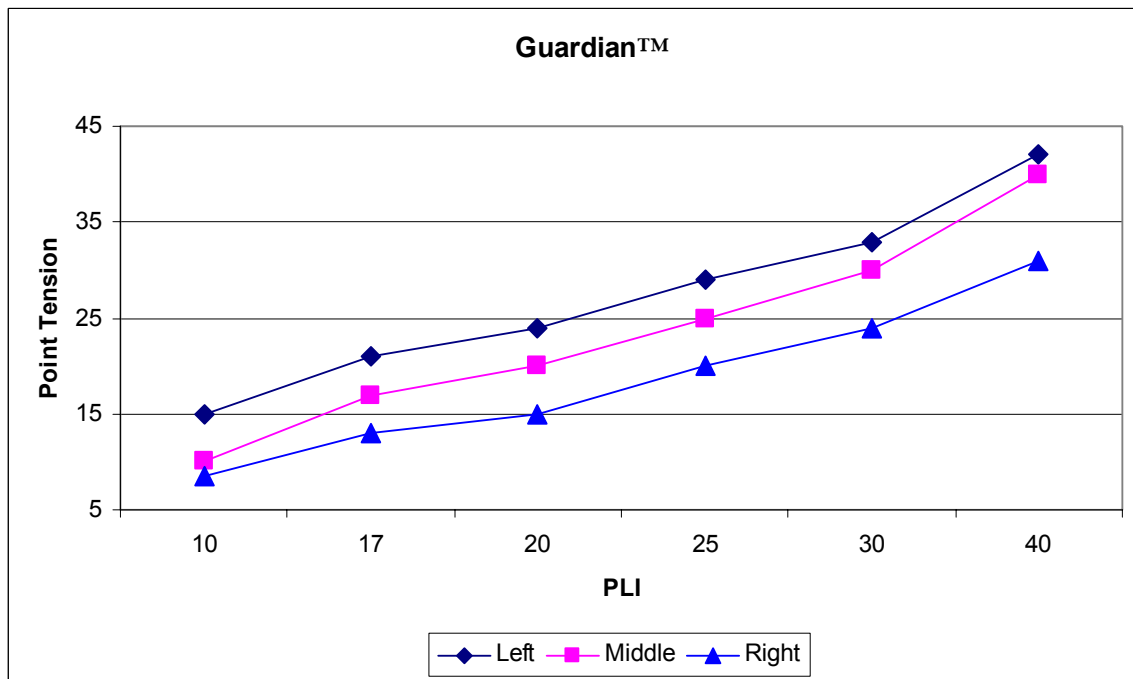
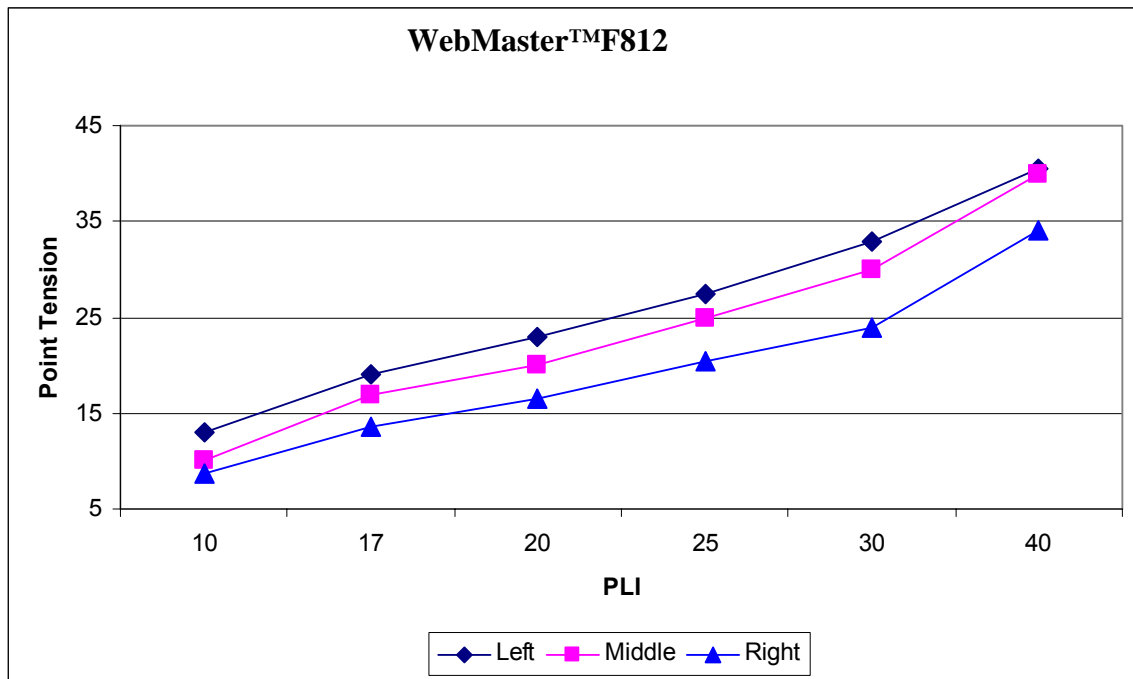
Area/Tension(PLI)		10	17	20	25	30	40
A type of Albany Intl. Belt	LEFT SIDE	13	20	22	27	32	40
	MIDDLE	10	17	20	25	30	40
	RIGHT SIDE	9	15	17	22	26	33
SpiralTuf™	LEFT SIDE	13.5	20.5	23	28.5	33	41.5
	MIDDLE	10	17	20	25	30	40
	RIGHT SIDE	8.7	13.5	16.5	20.5	24	34
WebMaster™ F812	LEFT SIDE	13	19	23	27.5	33	40.5
	MIDDLE	10	17	20	25	30	40
	RIGHT SIDE	9	14	17	21	26	34
Guardian™	LEFT SIDE	15	21	24	29	33	42
	MIDDLE	10	17	20	15	30	40
	RIGHT SIDE	8.5	13	15	20	24	31

Table 10: Point tension values at different tensions

These tests were done at five different tension values but all results show that left side always has the highest tension and right side has the lowest. Tension difference is the only different parameter on these three areas. It is caused by two cylinders that are

responsible for keeping the belt at constant area. The right and left sides of these cylinders can move up and down independently. The machine belts used tend to move to left side of the machine. So, left side of cylinders move up and keep the belt steady. That increases tension of that area. Figures 72-75 show tension values of these areas more clearly.





Figures 72-75: Tension values of belt at cross direction

Comparison of right, middle and left areas can be seen in figure 76 and 77. Figure 76 shows static charge values on different areas at 25 PLI, and figure 77 shows static charge on conductive and nonconductive belts at different tensions. The charge on belt slightly increases through the left side of it. This increase is much higher for nonconductive belts.

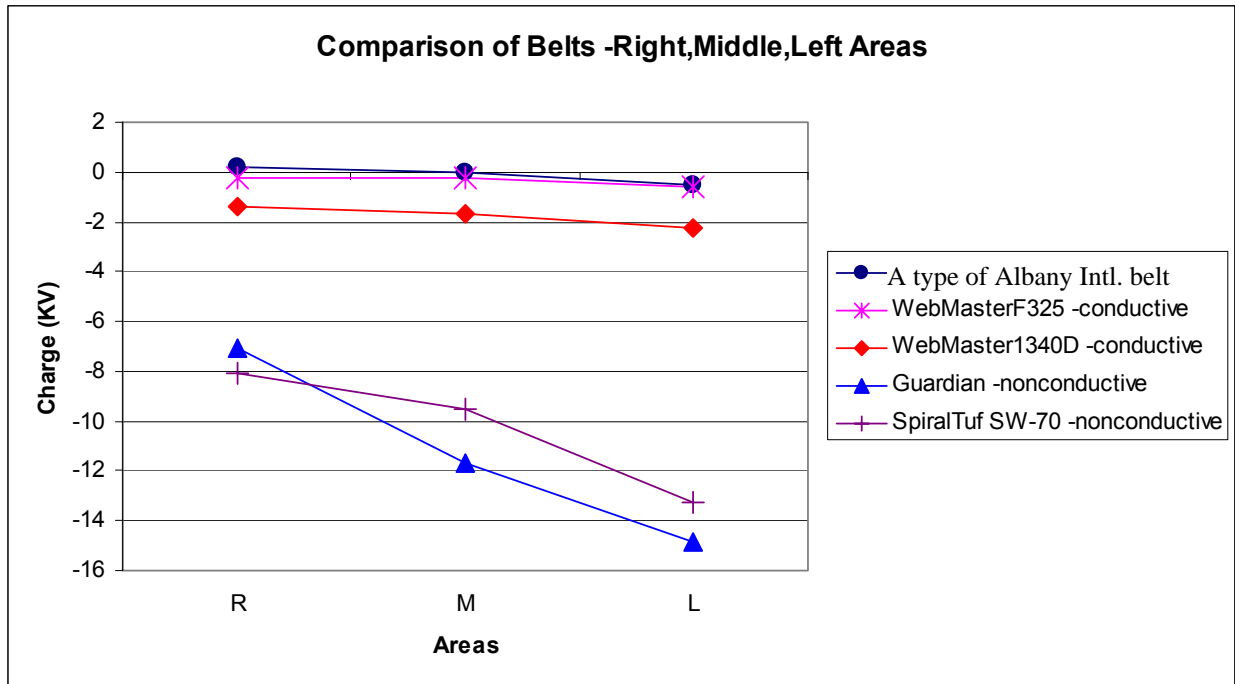
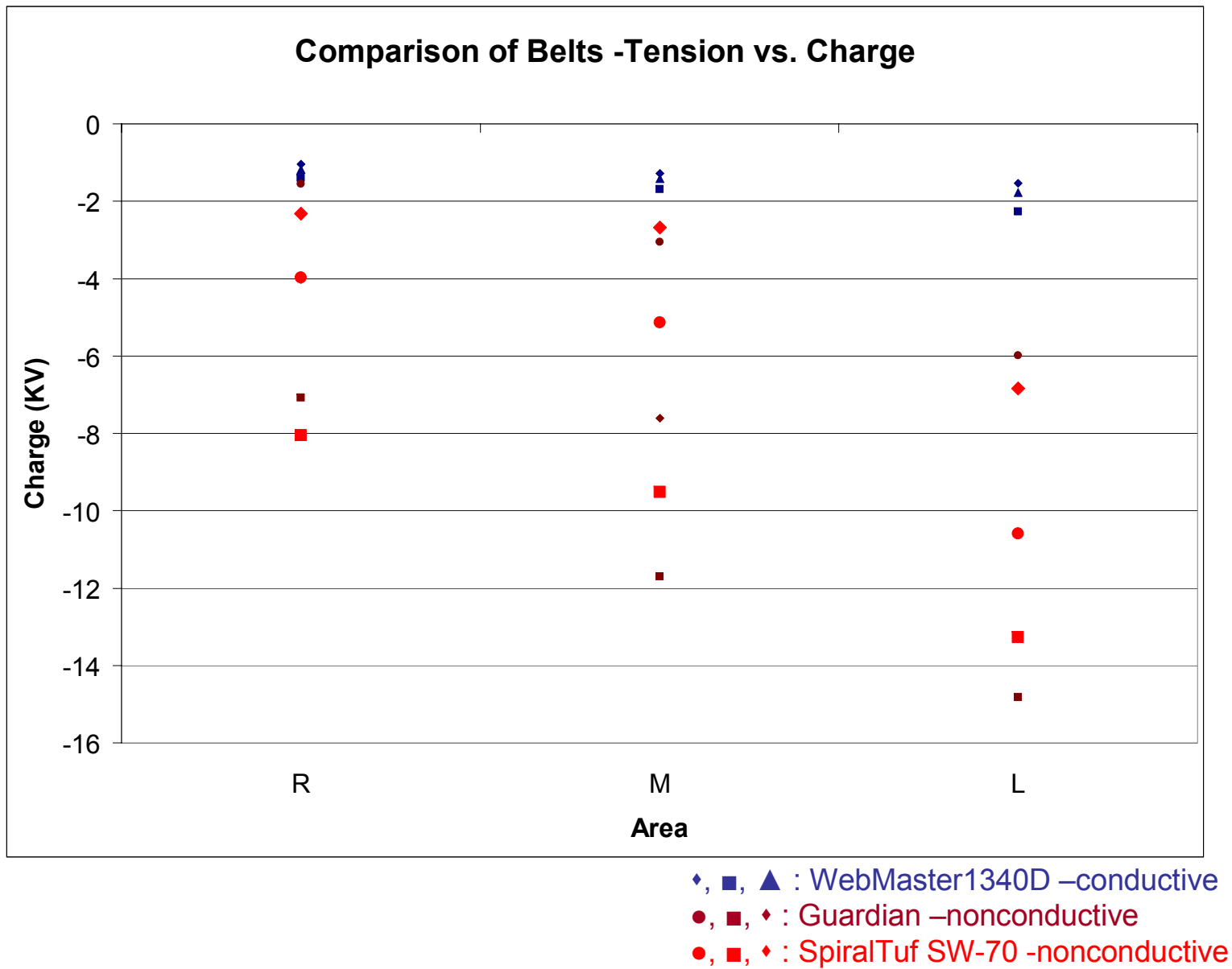


Figure 76: Comparison of belts

Figure 77: Comparison of belts at 3 different tension values
(conductive vs. nonconductive)



4.9. Effect of Relative Humidity

In industry, humidity is the first parameter that is used to decrease static charge during production. Raising humidity increases the amount of water in the air and this helps dissipation of static charge because water is a conductor. There will be more water molecules close to material.

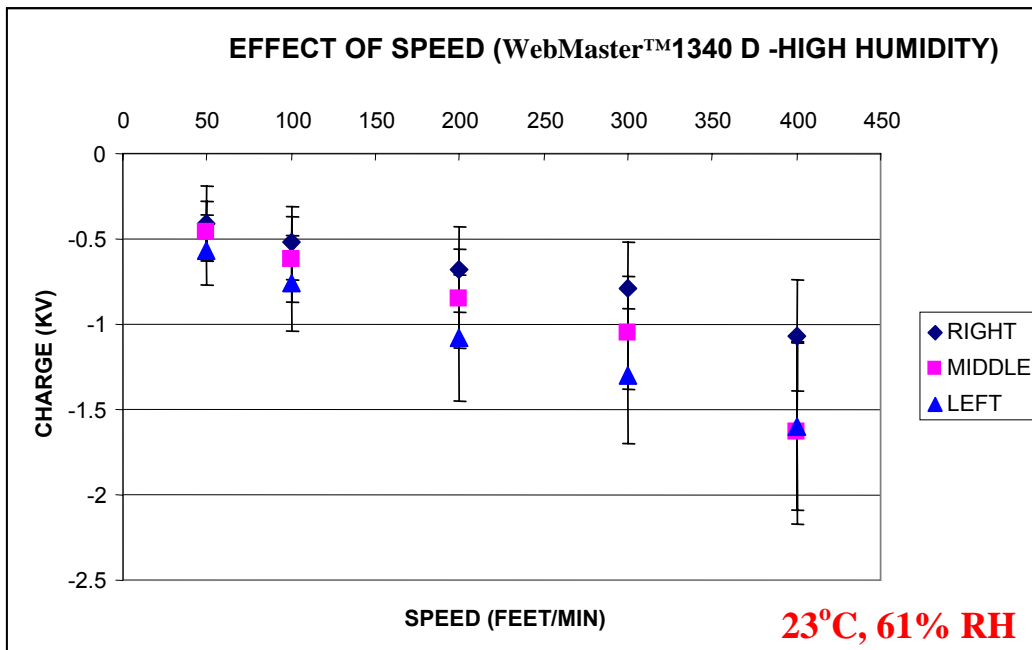
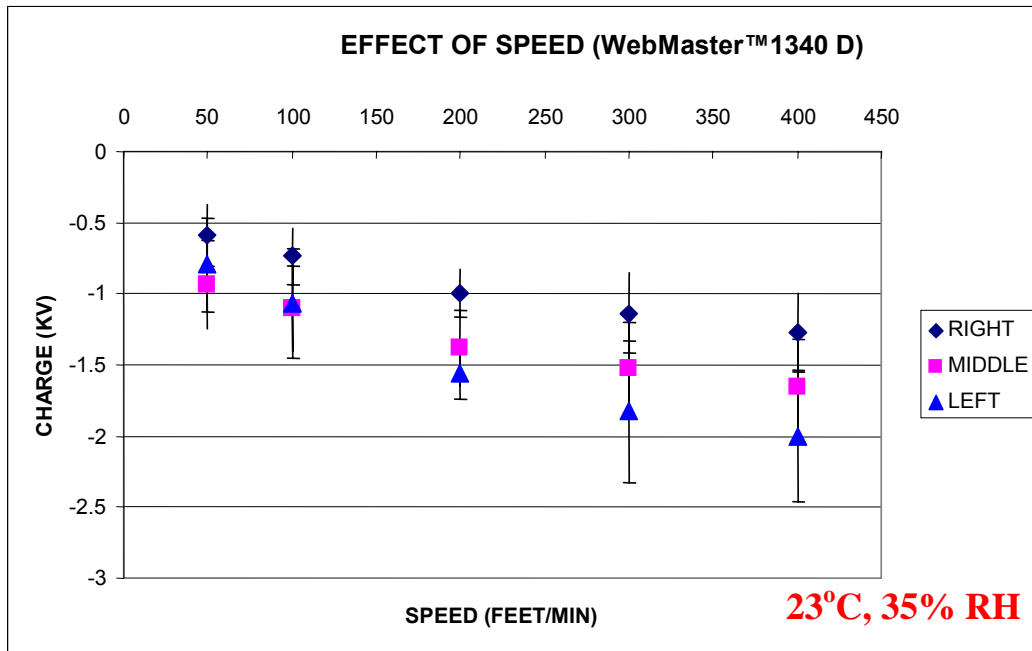
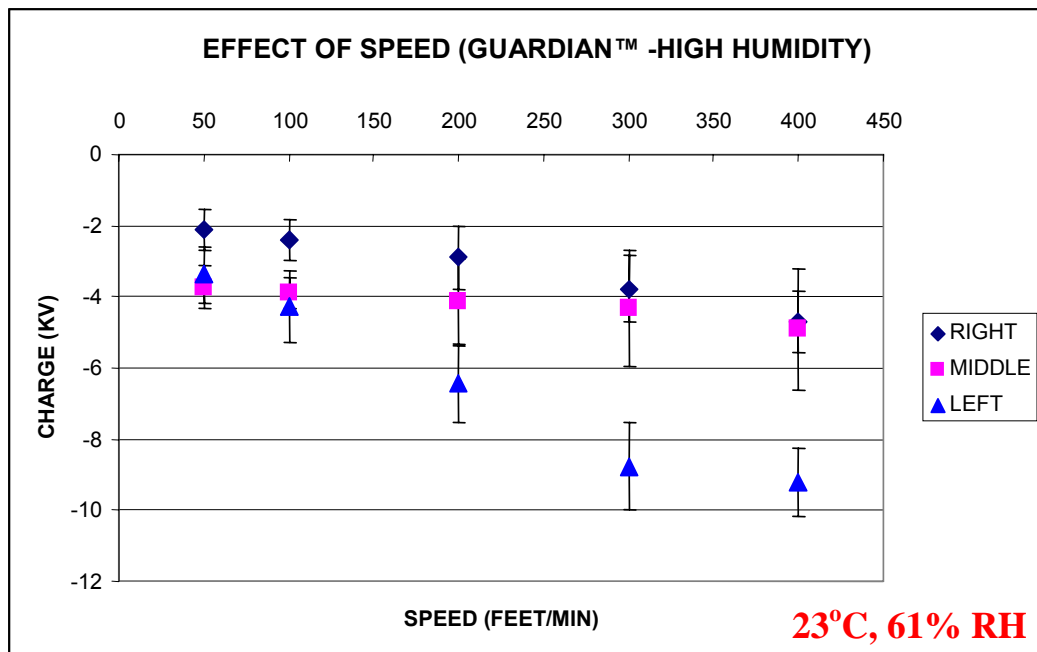
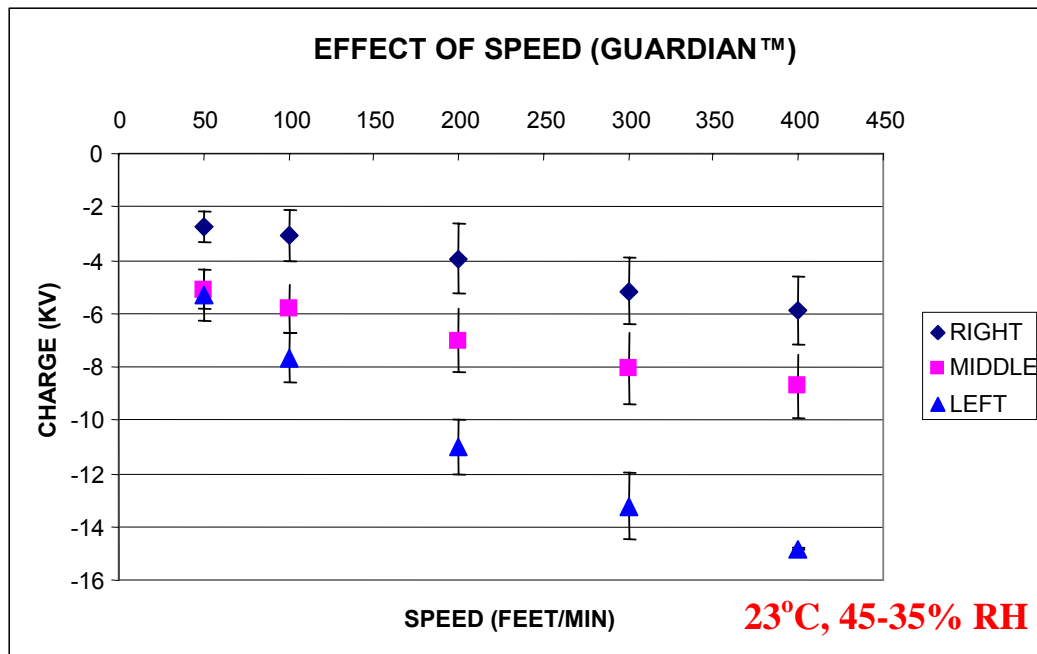


Figure 78 and 79: Charge generation for a conductive belt at low and high humidity

In NCRC Partners' laboratory there are no temperature and humidity control devices. Because of this we had to do our test in low and high humidity. Figures 78-83 show the charge generation comparison of conductive and non-conductive belts.

At 300 feet/min, on WebMaster™1340D conductive belt -1.5 KV of charge was



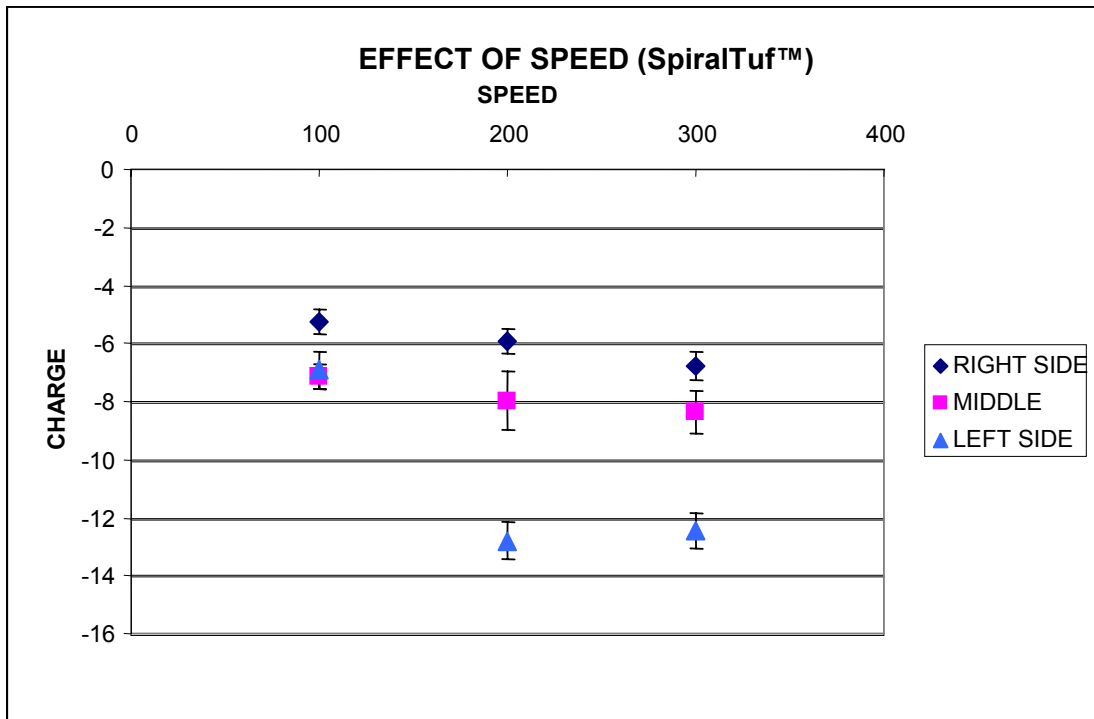
Figures 80 and 81: Effect of humidity on a non-conductive belt (Guardian™)

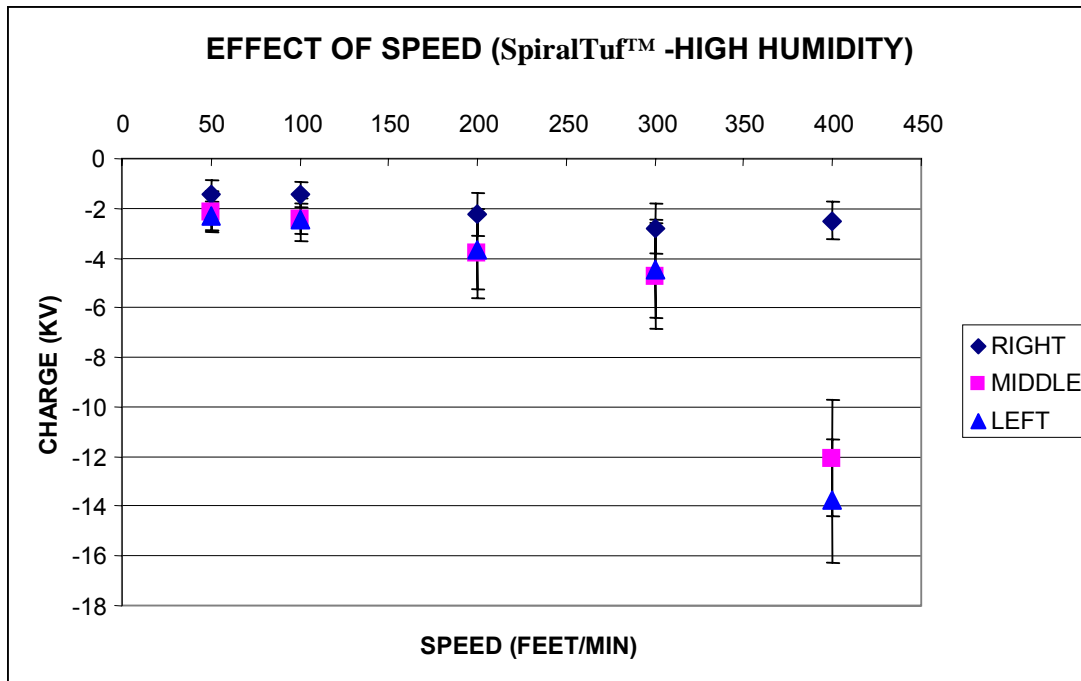
generated at low relative humidity. As humidity was increased to 61% generation of charge was only -1KV at the same speed.

For a non-conductive belt, the effect of humidity can be seen more clearly.

Figures 80 and 81 are the results for Guardian™ type of belt. At 300 feet/min it generates -8KV of charge, but as relative humidity increases to 61%, generation of charge decreases to about -4KV.

SpiralTuf™SW-70 generates the highest amount of charge and increasing humidity is an important parameter to dissipate charge for this type of belt. From the effect of speed figures, left side of SpiralTuf™SW-70 generates more than -14 KV at over 300 feet/min. But as seen in figure 83, charge generation is about -5KV of charge at this speed.





Figures 82 and 83: Effect of humidity on SpiralTuf™ SW-70 type belt

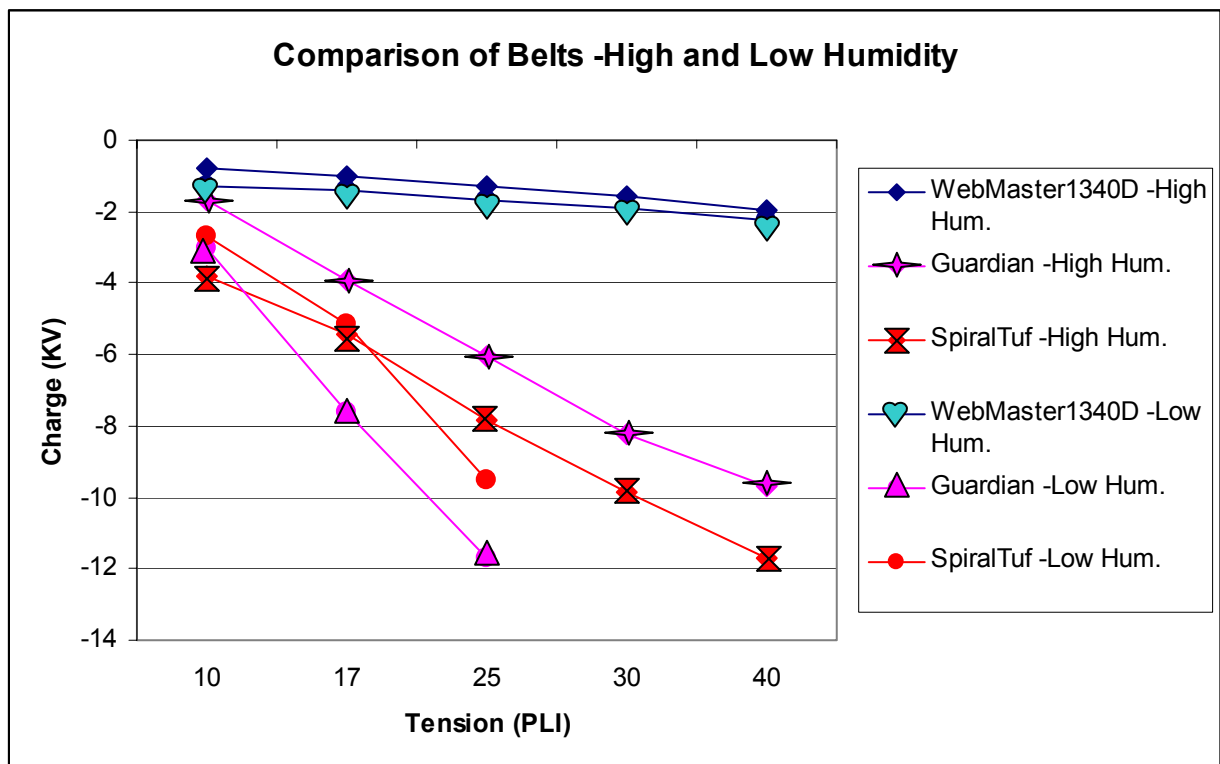


Figure 84: Comparison of belts –High and low humidity

Increasing humidity can be a good way to dissipate static charge especially on non-conductive belts. Charge values of different belts are shown in figure 84, increasing humidity also helped us to do our tests with higher tension values than low humidity tests.

4.10. Effect of Friction Bar

Effect of friction tests were done by using a PVC tube on the belt (Albany International).

This was done by 3 situations:

- Situation #1: PVC tube was rolling on the fabric at constant area just before electrostatic sensor, no force was applied.
- Situation #2: PVC tube was on the belt, steady state, no force was applied.
- Situation #3: PVC tube was on the belt, force applied

The results are shown in table 11. The interesting point here is using a non-conductive PVC tube helps charge to dissipate. The friction between tube and belt in first situation is the lowest, so this situation generates the lowest charge. As friction increases (as in situation 2 and 3), generation of charge increases. But in all situations, charge on belt is less than original one. That means some amount of charge is taken by tube and dissipated to air during contact with the belt.

As force applied (situation #3) there will be more friction and the charge on the belt will be more than situation #2. This shows that friction and the amount of friction are important parameters on charge generation. This information also helps us to understand the effect of tension on charge generation values. As tension increases there will be more force that causes friction and this will increase static charge generation.

		Av. Charge (KV)	Std. Dev.
Before Cylinder		-0.231	0.032
After Cylinder	Situation #1	-0.031	0.029
	Situation #2	-0.128	0.033
	Situation #3	-0.211	0.016

Table 11: Effect of friction

4.11. Effect of Spraying Water

To see the charge dissipation on the belt water was sprayed to belt (SpiralTuf™SW-70) at a certain distance with 45° angle. Table below shows results.

	Before Spraying (right, middle, left)			After Spraying (right, middle, left)		
Average (KV)	-4.6	-8.9	-14.1	-0.08	-0.51	-0.76
Std.Dev.	0.55	0.52	0.49	0.19	0.32	0.96

Table 12: Effect of spraying water

The left side generates the highest charge as expected. Water is a conductor and it is a good way to dissipate the charge on materials as contact with a grounded object is not possible for every condition. So, water can be used if it is certain that it won't cause any problem with the material and the machine used.

After spraying water the left side still generates the highest charge and the right side generates the lowest.

4.12. Surface Resistivity

This test was done to find a relationship between surface resistivity values and charge generation of a belt. So, this kind of test can be used as a quick method additional to

charge decay test. But, the results showed fluctuations. For this reason, the averages were put in table 13.

As in charge decay tests, non-conductive belts have the highest surface resistivity values and SpiralTuf™SW-70 has about $5.7 \times 10^{10} \Omega$ of resistivity.

The reason for fluctuations might be the movement of electrons. Electrons are not steady in the system and when they find an easier-to-move way, they change their direction. So, electrons always try to move in the structure. When they move fast (it means they found an easier way to dissipate), the resistivity will be low. But especially for a structure of fabric there are monofilaments and air gaps which are easy-to-move and hard-to-move areas in the structure that an electron should go through.



Figure 85: Surface resistivity instrument

Fabric Type	Resistivity (Ω)	Charge generation (KV)-middle areas at 300 feet/min-
Guardian™	2.5×10^{10}	-8.0
WebMaster™1340D	1.8×10^{10}	-1.5
WebMaster™F325	1.9×10^{10}	-0.2
SpiralTuf™SW-70	5.7×10^{10}	-8.3

Table 13: Surface resistivity values of different belts

5.0. Recommended Test Procedure

The equipments that were used for this project were:

- A fieldmeter (4 probe)
- 4 conductive metal layer
- 4 grounding cables
- 4 wooden bridges
- 1 data acquisition card
- Temperature and humidity data loggers
- Computer
- Software for fieldmeter and data loggers
- 4 cables to connect probes to the data acquisition card

Measuring static potential at cross direction

The recommended procedure:

1) Connect three metal layers to one wooden bridge. The metal layers should have a sensing surface area which is exactly as big as sensing surface of the probe. The thickness should be as thin as possible to decrease the error rate. The size of this layer should be at least 2-3 times bigger than radius of the sensing surface. There should be small holes at each corner to mount it with screws.

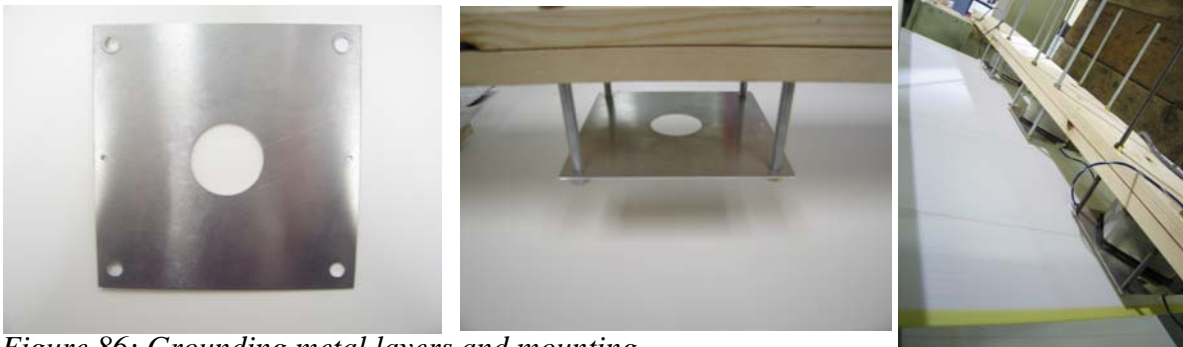


Figure 86: Grounding metal layers and mounting

- 2) Put the sensors on these metal layers and mount it onto the machine. Keep the distance at 1 cm between metal layer and surface. This distance can be increased but to compare the results with the results in this project, all parameters should be same. However, in literature it is said that by increasing the distance by 2cm, the result should be divided by two to get the same result as in '1 cm' distance, it is not true. Results at 2 cm are not two times higher than the results at 1 cm.
- 3) Connect the probes to fieldmeter and use cables to connect fieldmeter and data acquisition card.

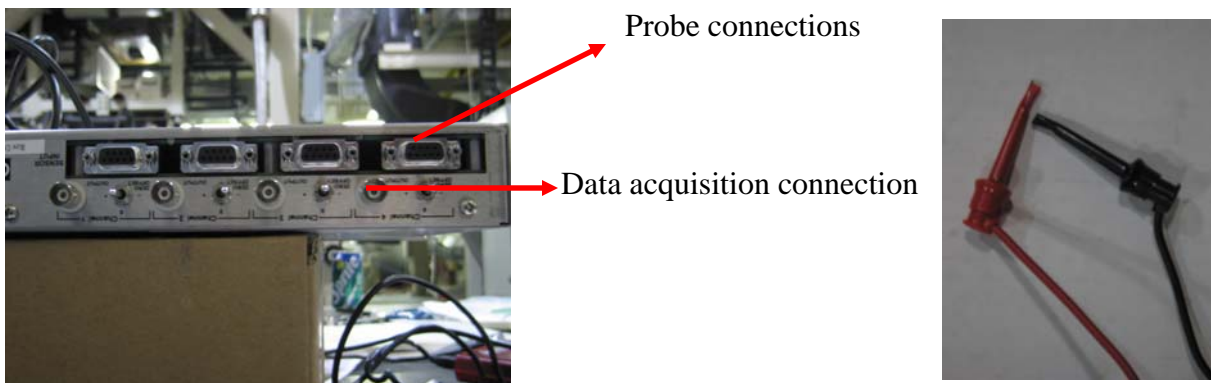


Figure 87: Connecting probes and data cables

- 4) Connect the cables to data acquisition card. 4 probes can easily be connected to 1 data acquisition card. The card has 'AI0 to AI7 and four ground (GND) connections. Red cables are for AI and black ones are for GND connections. This can be done by 2 different methods. Figure 87-b shows an easier connection. Red cables are connected to AI sections and one black cable is connected to GND. This shouldn't be used with testing of nonconductive belts because of the output limitations. Connection figure 88-c can be used with any type of belt. Red cables are connected to AI0, AI2, AI4 and black cables are connected to GND1, GND3 and GND5.

To download the data onto a computer, software is needed. If figure 88-b is used, on the software '0SE, 1SE, and 2 SE should be used. If figure 88-c is used, '0-1 diff, 2-3 diff, 4-5 diff' should be used. During all tests multiplier should be 1.000 to have KV.

By using the configure section, the required data can be saved in exact file. Program won't save the data unless 'Write to File' is clicked.

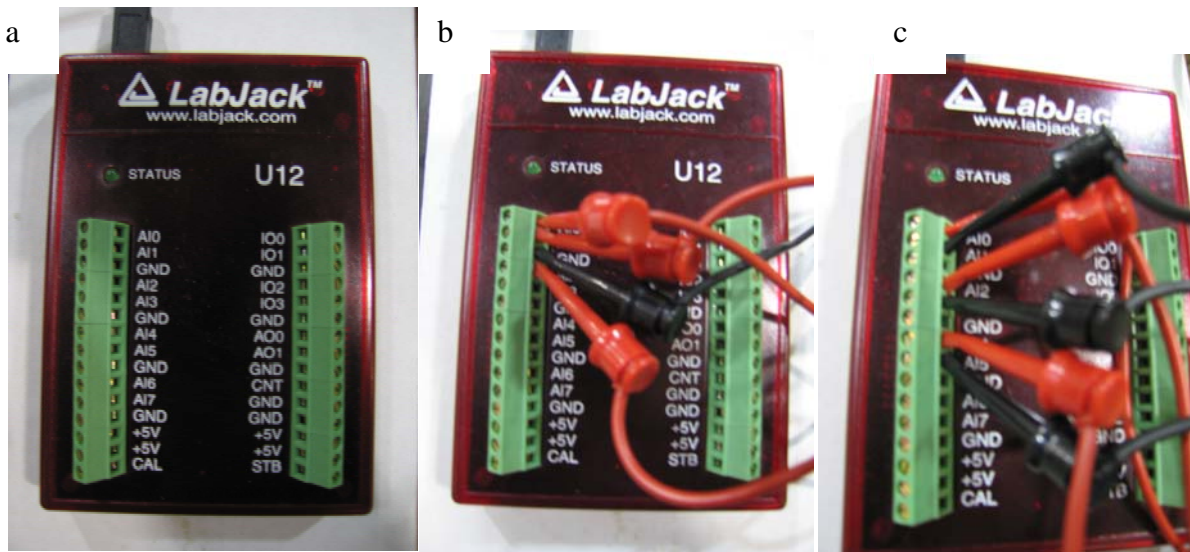


Figure 88: Connecting cables to data logger

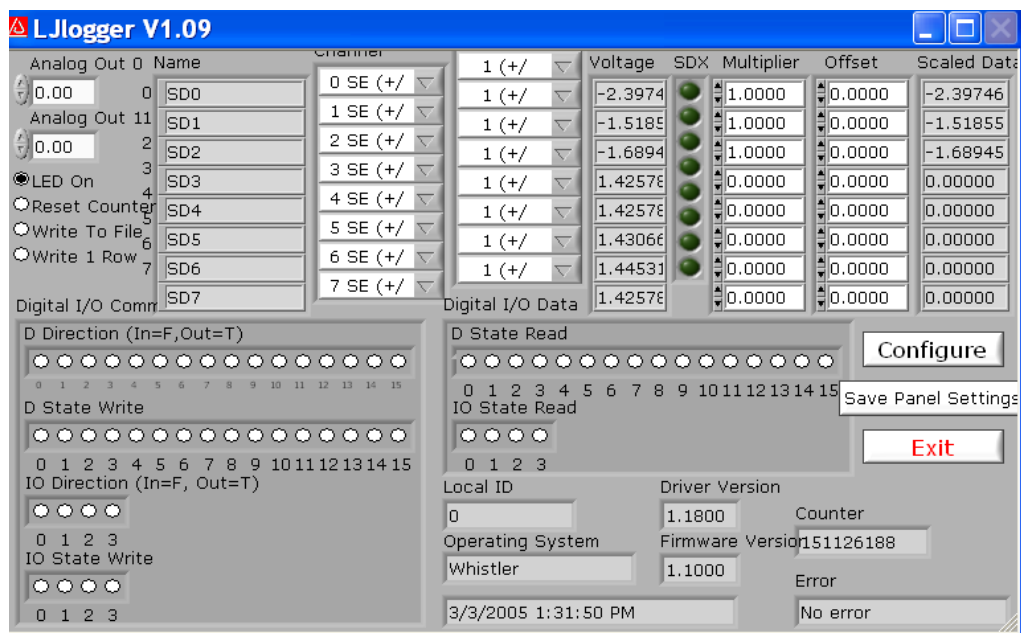


Figure 89: Fieldmeter software

5) Connect the humidity and temperature data loggers to computer and change the data time to 10 seconds. That means it is going to record the data in every 10 seconds. After the test, it is easy to compare the results with the fieldmeter data as they both records time.

After recording, by using the software the data can be downloaded onto a computer. This software also provides the graphs of temperature and humidity changes to see the changes easily. Figure 89 is a sample picture of this graph.

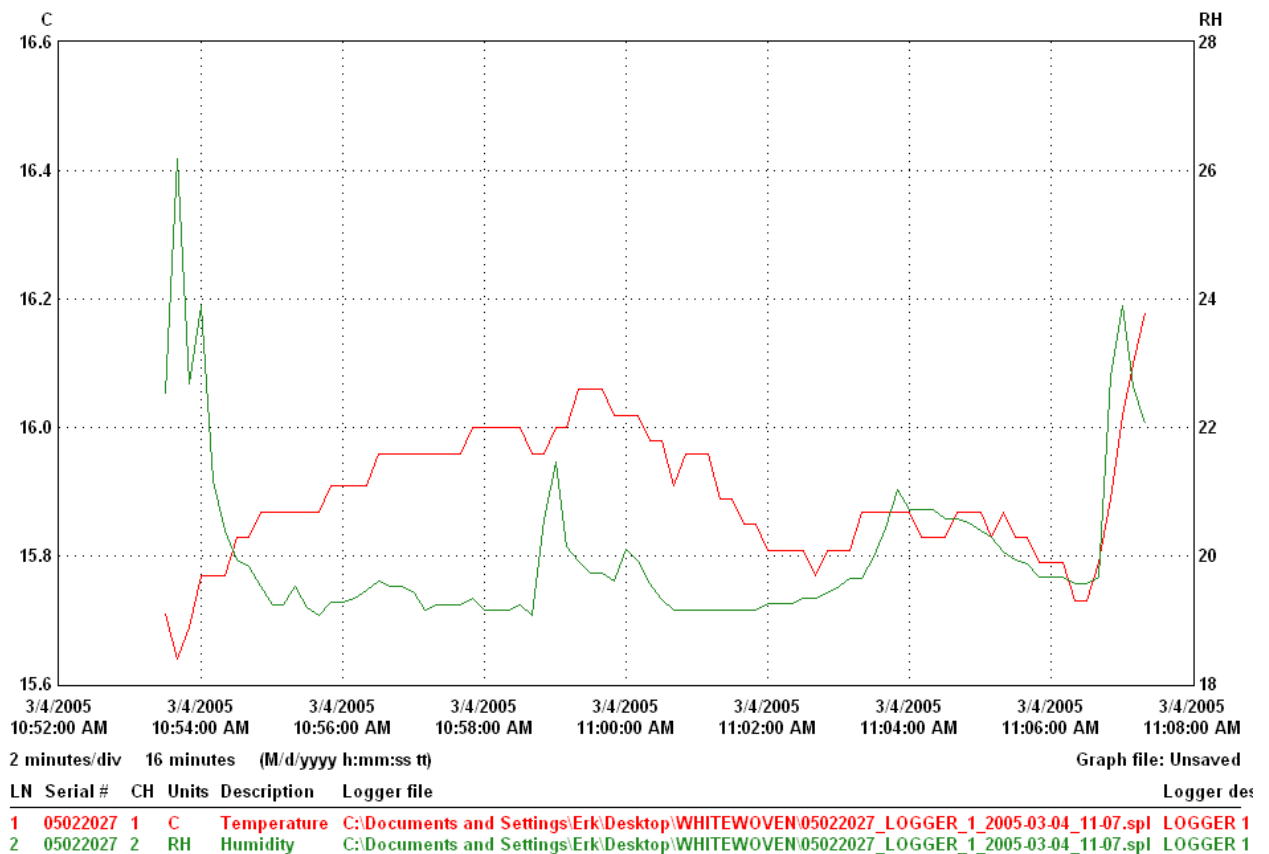


Figure 90: Data logger software

6) Measure the tension of the belt. In our tests the tension was kept at 20 PLI by using a hand held tension meter. This can be also used while belt is running.

Figure 91: Hand held tension meter



Conclusions

1. Belts that have conductive polyamide in their structure have very short charge decay times. Depending on the belt structure (belt thickness, mesh size, warp and weft density, polymer type), decay times of non-conductive belts show different results. Especially for non-conductive belts, the properties are very important. For conductive belts, it does not make so much difference (less than a second). The importance of belt structure can be clearly seen with SpiralTuf™SW-70 type of belt. It is formed of spirals and there aren't any warp yarns through the belt. This makes it harder for static potential to dissipate as there are big gaps between weft yarns. Charge decay test can be used as a quick method for assuming charge generation properties. Belts which have low charge generation time, generates less charge on a spunbond machine
2. Charge on belt shows variations in machine direction. Cylinders, grounded metal parts of the machine, transporting of the belt are some of the parameters. It can be understood that separation is an important parameter and increases with speed. As speed increases, more charge will be generated on the belt. So, the areas just after separation points have the highest charge values.
3. Friction and contact are two main reasons for charge generation and there are many touching point between warp and weft yarns in belt's structure. They are always in contact and generating charge all the time. So, after reaching its minimum amount, charge starts to increase.
4. Speed is another important parameter effecting charge generation. For every type of belt, as speed increases, charge increases. One reason for this is there will be

less time for charge on the belt to dissipate and another reason is during separation, some electrons will start to jump onto a cylinder. This will increase the charge just after cylinders. Another reason is friction between cylinders and speed increases the number of friction points.

5. Tension has a tremendous effect on charge generation. As it increases, for every type of belt, charge on the belt increases. As tension increases there will be more friction force between yarns and machine parts. There is a possibility of increasing contact area as tension increases.
6. Tension on belt varies in the cross direction of a machine. As tension is an important parameter, different tension at different areas will be a reason for different amount of charge on belt at cross direction. This may have an effect on web density at cross direction.
7. As water is a conductor, humidity helps charge to dissipate. Increasing humidity will create a water layer on the belt and charge on it can find one of the best ways to dissipate.
8. Surface resistivity test can also be used for a quick method for predicting belt behavior on a moving belt. But as the structure has air gaps, resistivity values can show fluctuations. But it can be seen from the results that belts with conductive layers show lower resistivity values. Using static decay test method is much better than surface resistivity test in terms of predicting the belt behavior.

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