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Some effects of irradiating cotton yarn in the plasma of an electric discharge

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To the Graduate Council:

I am submitting herewith a thesis written by John R. Barrett Jr. entitled "Some effects of irradiating cotton yarn in the plasma of an electric discharge." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

C. W. Bockhop, Major Professor

We have read this thesis and recommend its acceptance:

R. B. Stone, C. H. Shelton

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

November 24, 1959

To the Graduate Council:

I am submitting herewith a thesis written by John R. Barrett, Jr. entitled "Some Effects of Irradiating Cotton Yarn in the Plasma of an Electrical Discharge." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

C W Bockhop
Major Professor

We have read this thesis
and recommend its acceptance:

R. B. Stone

C. H. Shelton

Accepted for the Council:

Dale Wantling
Dean of the Graduate School

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SOME EFFECTS OF IRRADIATING COTTON YARN IN THE PLASMA OF AN ELECTRICAL DISCHARGE

A THESIS

Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

by

John R. Barrett, Jr.

December 1959

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Jan, my wife, who waited to have our first-born until the typing was completed.

DEFINITIONS

AEdl-10A. Laboratory identification of cotton mixture irradiated and tested in this study.

Bobbin. A spool or reel used to hold yarn or thread.

Breaking strength, strength at rupture, tensile strength or ultimate strength. The maximum resultant internal force that resists rupture in a tensile test.

Chart. A term identifying values determined from individual break recordings on the ruled paper as marked by the Uster tester.

Coefficient of variation, Cv. An expression of the sample standard deviation as a fraction of the sample mean usually presented as per cent.

Count. An indication of linear density expressed as the number of eight hundred forty yard hanks of yarn in a pound.

Dial. A term identifying values determined from the accumulative counters of the Uster tester.

Elongation. The deformation in the direction of load caused by a tensile force generally expressed as per cent of the tested length.

Grips, chucks. The devices used to firmly hold the yarn through which force is applied while testing.

Irradiation. Exposure to radiations.

Linear density. Weight for a given length of yarn.

Parameters. Quantities assigned arbitrary values, as distinguished from variables.

Plasma. The positive column of an electrical discharge through air at low pressure.

Ply. The number of single yarns twisted together to form a plied yarn.

Radiation. The process by which energy is emitted from molecules and atoms owing to internal changes including the combined processes of emission, transmission and absorption of the energy.

Salvage. The broken cotton yarn after testing.

Single yarn. The simplest strand of textile material suitable for operations such as weaving, knitting, etc.

Standard deviation, s. The average quadratic deviation of a single observation from the arithmetic mean.

Tenacity. Breaking strength expressed in force per unit linear density.

Tex. A unit of linear density expressed as the weight in grams of one thousand meters of yarn.

Twists. The turns about its axis, per unit of length, observed in yarn.

Uster. A constant rate-of-load continuously operating yarn strength and elongation testing machine.

Warp. The yarn running lengthwise in a woven fabric.

Yarn. A general term for continuous strands of textile fibers twisted in a form suitable for knitting, weaving or otherwise intertwining to form a textile fabric.

CHAPTER I

INTRODUCTION

General Statements

The importance of cotton in this country may be realized from the monetary value of the crop. It is the principal cash crop in most of the Southern states and ranks high in several Western states. On a national basis in 1954 cotton was second only to corn in farm value of leading crops.

The per capita use of cotton compared with other fibers in the United States has decreased from 80.6 per cent in 1940 to 68.5 per cent in 1954. Rayon, acetate and other synthetics have increased from 9.7 per cent in 1940 to 24.9 per cent of all fibers used in 1954 (20)*. Some have expressed concern over the possibility of synthetics replacing cotton to a large extent.

In recent years reports have indicated improvements in the physical properties of various plastics from nuclear irradiation. Results of research described in these reports suggested the possibility of improving the physical properties of cotton by similar irradiations, thereby making cotton more competetive with synthetics. Gilfillan and Linden (10) exposed mercerized cotton yarn to gamma and neutron irradiations. They concluded that gamma irradiation seriously weakened cotton fibers. In their research, neutron irradiation weak-

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*Numbers in parentheses refer to the appended references.

ened cellulosic fibers to such a degree that it was impractical to test them. All the yarns investigated were injured but they state that their work "does not prove that it is impossible to improve the strength properties of yarns by irradiation, but suggests that if such an improvement is possible, it will be found at lower doses than those used here."

Purpose of the Study

The purpose of the study described in this thesis is to show some of the effects on cotton yarn of irradiation with the plasma of an electrical discharge through air at low pressure.

Review of Literature

Gilfillan and Linden (11) used electrically produced beta rays to irradiate cotton yarn in the absence of appreciable amounts of water vapor and atmospheric oxygen. They concluded that the presence of water vapor and atmospheric oxygen during irradiation had little or no effect on yarn strength and that the dosages of irradiation employed significantly reduced the strength of cotton yarns.

Harmon (12) irradiated textile cords in a Cobalt 60 gamma ray source at room temperature. In general, the effect of high-energy gamma radiation, over the range covered in this study, was to worsen the physical properties of the cords evaluated.

Teszler, Wiehart and Rutherford (25) exposed unscoured and unbleached Deltapine cotton yarn to gamma and neutron radiations.

Their work showed that the dyeing characteristics of the samples were altered by either neutrons or gamma rays. Filter paper which received a dosage of $3.3X10^8$ roentgens became completely water soluble in the studies of Lawton et al. (16). Blouin and Arthur (4) reported on the effects of Cobalt 60 gamma radiation on some of the physical and chemical properties of purified cotton irradiated in atmospheres of oxygen and nitrogen. Their work indicated an increase in solubility in water and in dilute alkali, a decrease in tensile strength and small but unusual changes in moisture regain.

Pan et al. (19) investigated changes in the chemical and physical properties of silver lap, yarn and fabric made from raw cotton resulting from limited dosages of beta radiation with cathode rays under various conditions. Their results showed that the tensile strength of the yarn decreased with increasing dosage. At low levels the strength tended to increase to a maximum before it started to decrease. The low level irradiated yarn tested slightly stronger than the control.

Theory of the Discharge

An electric discharge in a gas at pressures of a millimeter or so of mercury, depending on the gas, causes luminous regions of varying intensity along the path of the discharge (24). Beginning at the cathode these regions are denoted: Ashton dark space; cathode glow; cathode, Crookes or Hittorf dark space; negative glow; Faraday dark space; positive column; anode glow and anode dark space.

The major part of the voltage drop across a discharge tube occurs in the cathode dark space and depends on the gas and the work function of the cathode material (24,26). Electrons emitted from the cathode by ion bombardment are accelerated by the cathode fall of potential gaining the energy necessary to maintain the discharge by production of positive ions.

The positive column is a typical plasma having approximately an equal number of positive ions and electrons in large concentrations (24). The positive column may be lengthened by increasing the electrode spacing; thus, adequate space is available in which to expose materials to the plasma. In the plasma the electrons diffuse more rapidly than do the ions (24) and the walls of the tube gain a negative charge. Positive ions from the plasma move to the walls and recombine with electrons. Material placed near the edge of a discharge tube would be subjected to both ionic and electronic bombardment and to the effects of light and heat energy, which are also generated in the plasma.

The positive column may contain alternate light and dark regions. These are called striations and the potential drop across the dark area is greater than that across the more luminous areas. The voltage gradient of an unstriated positive column is uniform with the temperature gradient corresponding to the voltage gradient (24).

Two types of longitudinal oscillations may occur in plasmas (24). Electrons may oscillate about a mean position and transmit energy either by moving as a group or by velocity modulation of faster moving electrons passing through the oscillating region. These oscillations are in the order of kilomegacycles. Ionic oscillations may also occur at frequencies comparable with supersonic sound waves.

The discussion just presented is on the general theory of the discharge used to irradiate the yarn for the study described in this thesis.

Preliminary Studies

Stone describes the research which lead to this study in "Effects of Exposing Cotton to Gas Plasmas, A Progress Report" (23). Plasma irradiation had made corn and soybean seeds more water absorptive. During experiments with several other types of seed some interesting effects were discovered. Irradiaticn made short fibers of lint remaining on the cotton seeds after ginning water absorbent.

Cotton fibers, which had no processing other than ginning, were rough, stiff and water absorbent after irradiation. Analysis indicated that the wax on the fibers had been degraded but not removed, that the rate of wetting had been increased and that the cellulose of the outer wall of the fiber had been weakened by the irradiation treatment. Electron-micrographs showed broken surface areas of treated cotton fiber (23).

Irradiated yarn had a more rapid rate of water absorption than the control, also, there was indication that the breaking strength had increased. Breaking strength and elongation data from single strand breaks of Deltapine-15 ten count yarn broken on an Instron tester are shown graphically in Figures 1 and 2, with point data tabulated in Table I.

Pressley type flat bundles (3) were irradiated in the plasma, brought to control conditions and broken on a Stelometer at one-eighth inch gage length. The results showed no change in tenacity due to irradiation. Elongation was reduced but this is attributed to slippage in the leather jaws. The appearance of the salvage from the testing was changed. The irradiated fibers generally broke in the center of the gage spacing and when removed remained compactly together where the control broke irregularly and fell apart when touched.

Yarn properties had been affected by irradiation in the plasma. Due to the limited number of breaks in preliminary work, the variation between individual breaks, the fact that little elongation information had been obtained and due to some question as to techniques in irradiating and breaking the yarn it was decided that a thorough study be made which would show the effects of plasma irradiation on cotton yarn. Yarn strength and elongation were the two main qualities to be used in measuring the effects of the irradiation treatment.

Number of Breaks

The number of breaks needed for significant results was next determined by statistically analysing previous yarn tests. Cochran and Cox states:

> Whatever the source of the experimental errors, replication of the experiment steadily decreases the error associated with

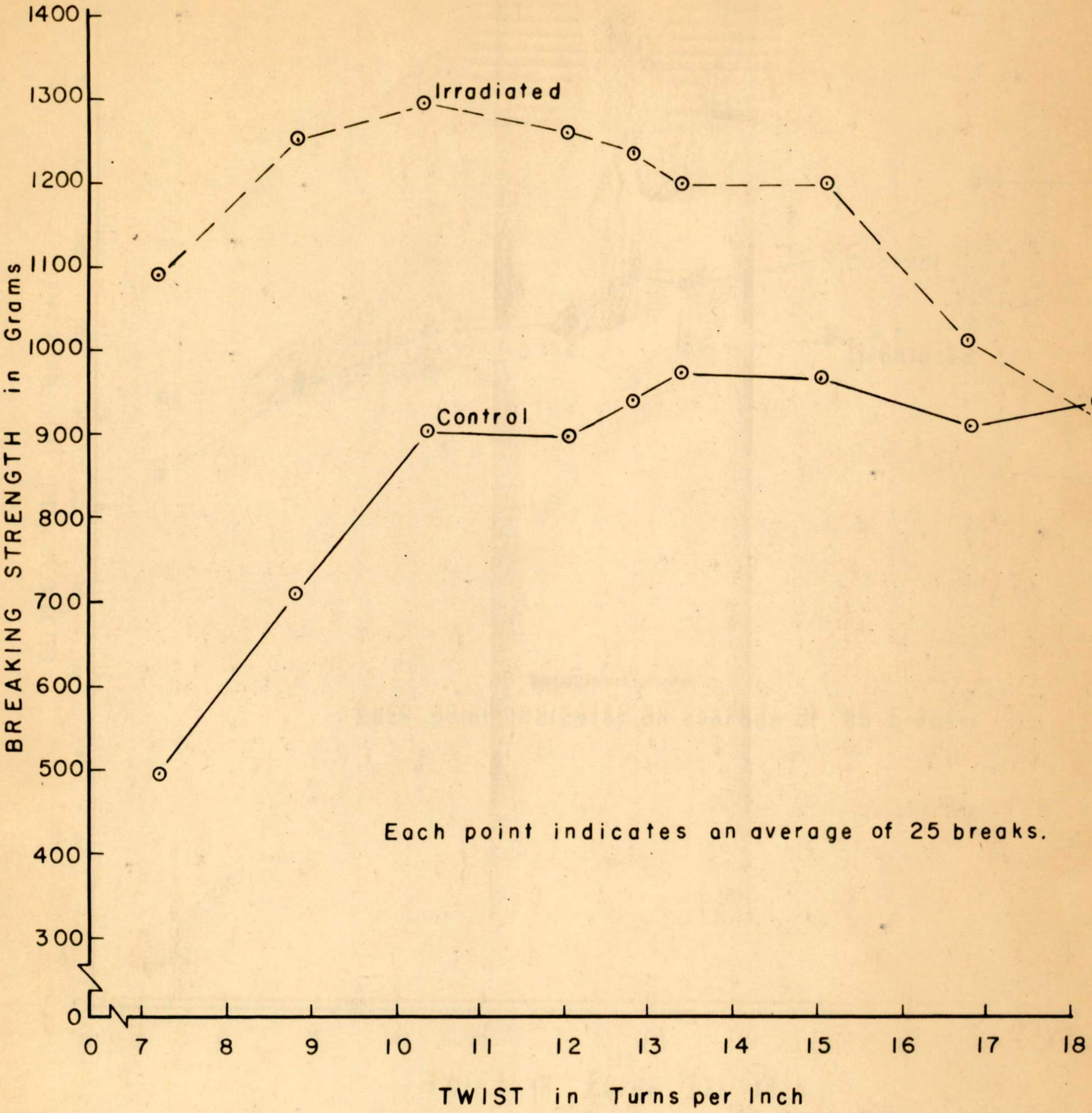
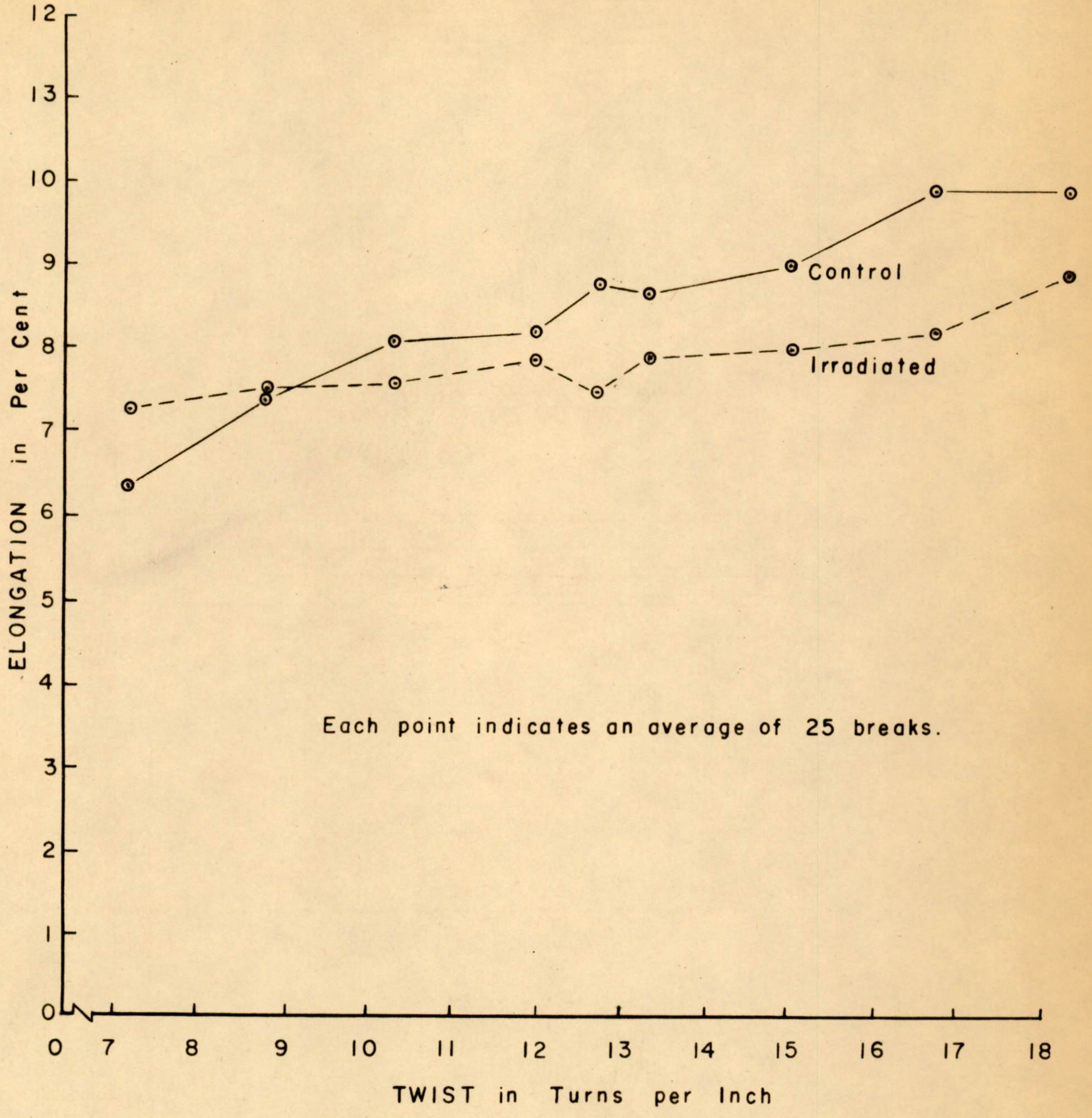


Figure 1. Breaking strength versus twist for control and irradiated Deltapine-15 ten count yarn.



Each point indicates an average of 25 breaks.

Figure 2. Elongation versus twist for control and irradiated Deltapine-15 ten count yarn.

TABLE I

BREAKING STRENGTH AND ELONGATION DATA FROM SINGLE STRAND BREAKS OF DELTAPINE-15 #10 YARN BROKEN ON AN INSTRON TESTER

Twist In Turns/Inch	Control[a]		Irradiated[a]	
	Breaking Strength In Grams	Elongation In Per Cent	Breaking Strength In Grams	Elongation In Per Cent
7.14	493	6.4	1088	7.3
8.76	702	7.3	1248	7.5
10.30	900	8.1	1286	7.7
11.98	896	8.3	1254	7.9
12.76	932	8.9	1233	7.6
13.34	964	8.8	1200	8.0
15.05	950	9.1	1191	8.1
16.77	901	10.0	1007	8.3
18.34	923	10.0	914	9.0

[a] Each value is an average of 25 breaks.

> the difference between the average results for two treatments, provided that precautions (such as randomization) have been taken to ensure that one treatment is no more likely to be favored in any replicate than another,...(7)

With this in mind an estimate of the number of breaks, or replications, necessary to show statistically a significant difference in breaking strength of control yarn as compared to irradiated was needed. Since confounding of variables emerged as a problem in the use of an analysis of variance type comparison, necessary variables being twist in the yarn and treatments at the various twists, it appeared that the best way to show that yarn qualities had definitely been affected was to use the statistic "Student's" t (22) to test the hypothesis that the mean breaking strength of the irradiated yarn was to be no different from the mean breaking strength of the control yarn. With the rejection of this hypothesis it could be said that the means, irradiated as compared with control, would be different. This could be done on a point to point basis through a range of twists.

In planning the study described in this thesis a system explained by Cochran and Cox (7) to determine an estimate of the number of breaks necessary to show significant differences between the control mean breaking strength and the irradiated mean breaking strength was used.

By using the twenty-five breaking strength observations previously made on Deltapine-15 ten count yarn, and grouping the top four points in the control curve, data from one hundred breaks was available for determining the number of breaks required for a given probability of obtaining a significant difference in means.

By assuming 103.6 grams, the standard deviation calculated from one hundred breaks of Deltapine-15, as the true standard deviation the following results were obtained: twenty-six breaks would give ±100 grams, one hundred breaks would give ±50 grams and 471 breaks would give ± 25 grams as significant for the means to be different at the 95 per cent level. Samples of the calculations involved in determining this are found in Appendix A. It was thought that the assumed standard deviation was considerably larger than would be encountered in actual testing.

Scope of the Study

From examining the work previously done on Deltapine-15 ten count yarn, and after consultation with Mr. C. B. Landstreet and Dr. Smith Worley, Crops Research Division, Spinning Laboratory, USDA, ARS, the decision to make four hundred single breaks of ten count, or sixty tex, yarn over a range of twists was reached.

The range of twists was from as low as could be spun to well over the peak strength point (15). This turned out to be from about 7.5 to eighteen turns-per-inch.

To make some twelve thousand individual breaks on an Instron tester would take about three man-months. It was decided that if a way could be devised to allow use of a Uster continuous break tester that much time could be saved in breaking the yarn. Since about one yard of yarn is used in each break by the Uster, some four hundred yards of irradiated yarn would be needed for testing at each point along the range of twists. Preferably this length of yarn was to be in one piece. This turned out to be impractical and the yarn was irradiated in one hundred yard lengths.

If the Uster was to be used, a machine would have to be developed to irradiate yarn as a continuous process. The machine developed to irradiate cotton yarn in a continuous length will be discussed in detail in the next chapter of this thesis.

In general, the scope of the study described in this thesis is: the development of an apparatus to irradiate with plasma a continuous length of cotton yarn, the use of the apparatus and the Uster to obtain breaking strength and elongation data to show the effect on cotton yarn of the irradiation and to compare treatments used in efforts to explain the effects caused by the irradiation, and the analysis and presentation of data collected.

General Methods and Procedures

The irradiation methods and equipment for obtaining glow discharges in gases at low pressure used in irradiating cotton yarn for the study described in this thesis were essentially the same as in "Low Energy Irradiation of Seeds," by Brown, Stone and Andrews (5). The apparatus consisted of a tube fitted with electrodes at each end, a vacuum pump equipped for pressure regulation and a variable high voltage source. Adaptation of this system to allow the irradiation of a continuous length of cotton yarn will be described in Chapter II.

Cotton yarn testing equipment and methods were in accordance with the American Society for Testing Materials standards on testing cotton yarn unless otherwise specified.

The machine used in breaking the cotton yarn was a Uster yarn strength tester. This machine is of the constant-rate-of-load class as preferred by ASTM for testing breaking strength of single yarn, single strand method (2). A thorough description of this machine, how it works and how it was used is included in Chapter IV.

The ASTM specifications say that machines shall be operated at such a rate that the yarn breaks within 20 ± 3 seconds from the time of the start of the test (2). Because the data accumulated in this study was to be used for comparison purposes and as an indication of quality control by Crops Research Division, Cotton Spinning Laboratory, Knoxville, Tennessee, it was decided not to adhere to this specification but to use a rate of ten seconds as had been used in other yarn tests run by the Spinning Laboratory.

ASTM standard conditions of cotton yarn were maintained throughout the testing (2). The yarn was in moisture equilibrium with a standard atmosphere having a relative humidity of 65 ± 2 per cent at $70 \pm 2^{\circ}F$. A state of moisture equilibrium was considered reached when two successive weighings a day apart did not differ by more than 0.1 per cent of the total weight.

The data recorded by the Uster machine was analysed on both an individual break and an accumulative basis. Mean elongation, mean breaking strength, frequency distribution of elongation and frequency distribution of breaking strength were all analysed and compared. The exact methods of these analyses and comparisons will be discussed in detail later in this thesis.

CHAPTER II

DESCRIPTION OF THE IRRADIATION APPARATUS

Need for this Apparatus

In order to have a more uniform irradiation process and to utilize the Uster continuous break tester for accumulating enough data in a reasonable length of time to show definitely that cotton yarn was affected by the plasma of an electrical discharge through air at a low pressure, an apparatus to subject yarn to this plasma in a continuous length was needed. The complete apparatus is shown in Figure 3.

Bobbin Holding Chamber

An evacuated holding chamber, Figure 4, made from cloth laminated and impregnated with plastic was used to hold the yarn. This chamber was a tube fifteen inches long, 2.380 inches outside diameter, 2.025 inches inside diameter, fitted with a cap at the yarn exit end and a square T-section as a cap for the bobbin holding end. Direct application of vacuum on the chamber indicated no objectionable leaks or out-gassing of the plastic material.

A regular warp bobbin attached to a spindle used for ring spinning with the base of the spindle pressed through a number 10 1/2 black rubber stopper was used to hold yarn in place in the chamber, Figure 5. Ethanol extraction prior to irradiation made the yarn so rough that it would not slide evenly over the end of a warp bobbin. This necessitated

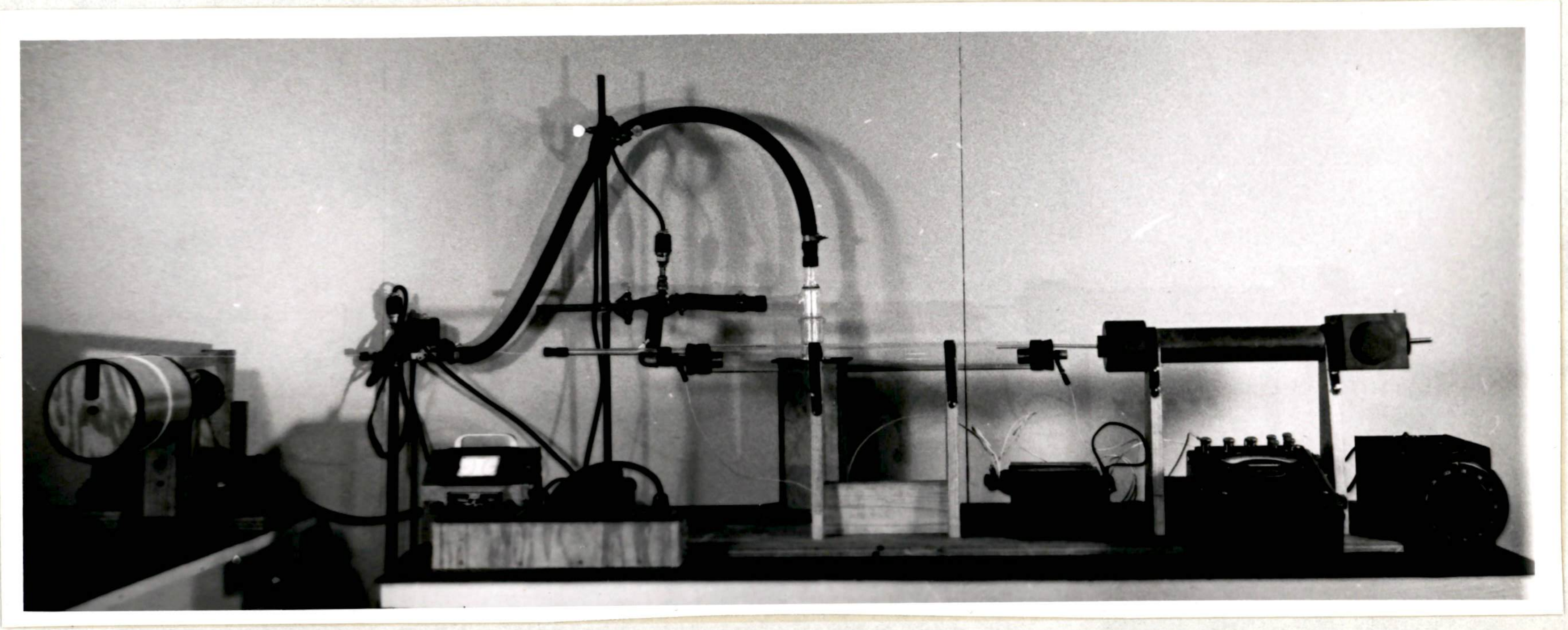


Figure 3. The complete irradiation apparatus.

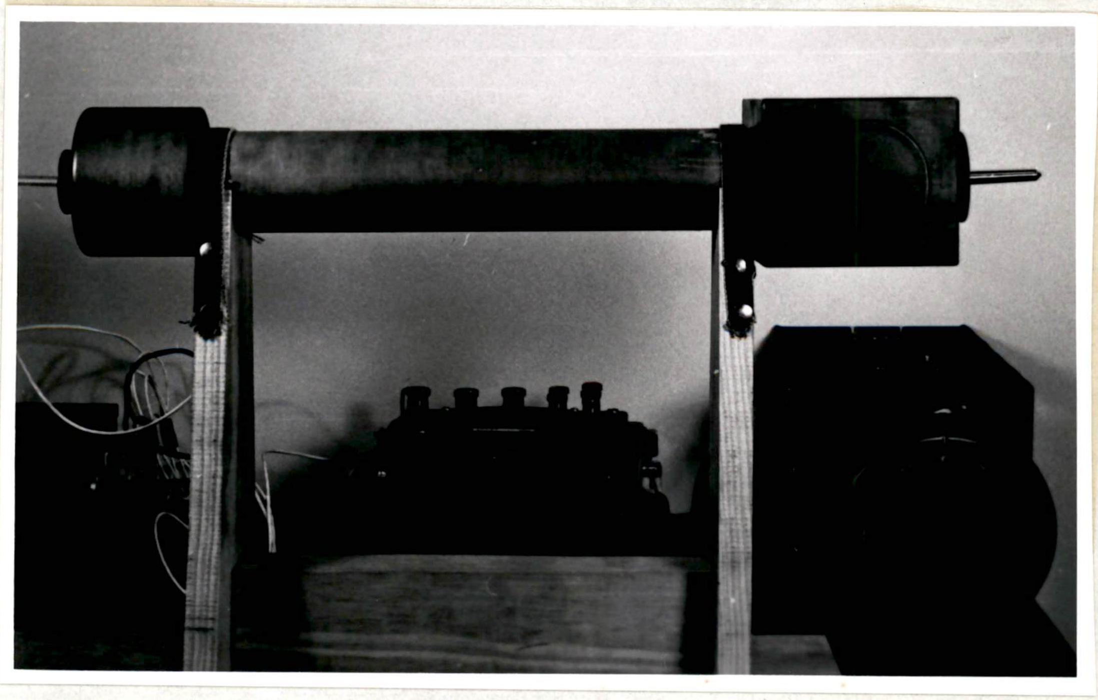


Figure 4. Bobbin holding chamber.

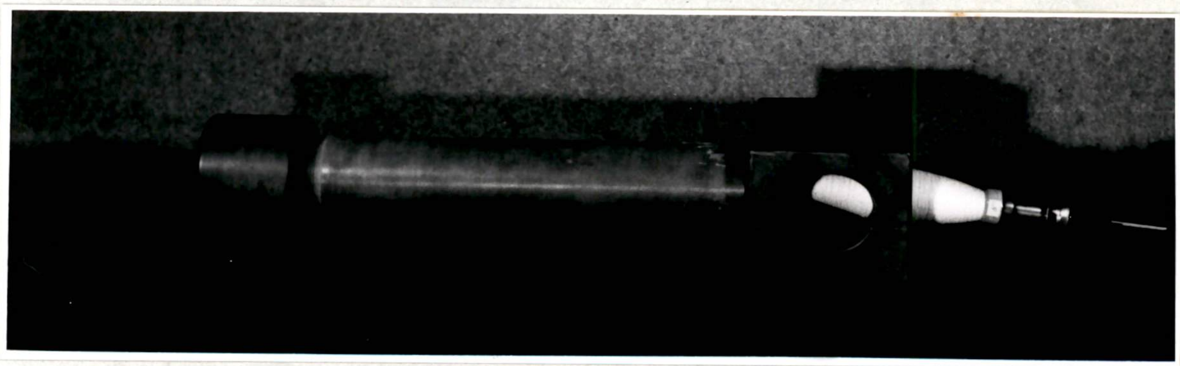


Figure 5. Bobbin holding chamber showing placement of warp bobbins.

the use of another type of holding bobbin two inches long and made on the order of a sewing thread spool, Figure 6. It would hold approximately two hundred yards of yarn as compared to twelve hundred yards held by the warp bobbins.

A packing of cotton fiber was used near the exit end of the holding chamber to keep an excess of yarn from being pulled from the warp bobbin when vacuum was initially applied to the system. Cotton fiber used for this packing was the same as used in spinning the yarn.

The yarn was fed through a section of one-eighth inch polystyrene tubing extending from inside the holding chamber to half way through the rubber stopper that was used as electrode support at the entrance end of the irradiation chamber, Figure 7.

Black rubber stoppers were used to hold the spindle, the spool support wire and the polystyrene tubing. These stoppers fitted into tapered machined holes in the holding chamber with no evident vacuum loss.

Irradiation Section

The irradiation chamber, Figure 8, consisted of a 2.009 inch outside diameter, 1.827 inch inside diameter hard glass tube twenty-four inches long. This tube was fitted with iron electrodes supported by number 10 1/2 black rubber stoppers. The yarn was fed through the upper portion of the stoppers through tubing into the plasma of the discharge. The path of the yarn through the plasma was approximately

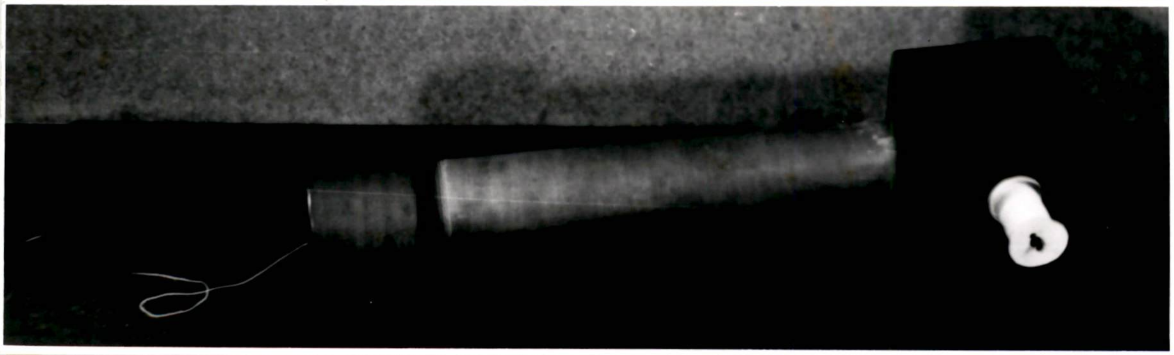


Figure 6. Bobbin holding chamber showing placement of spool type bobbin.

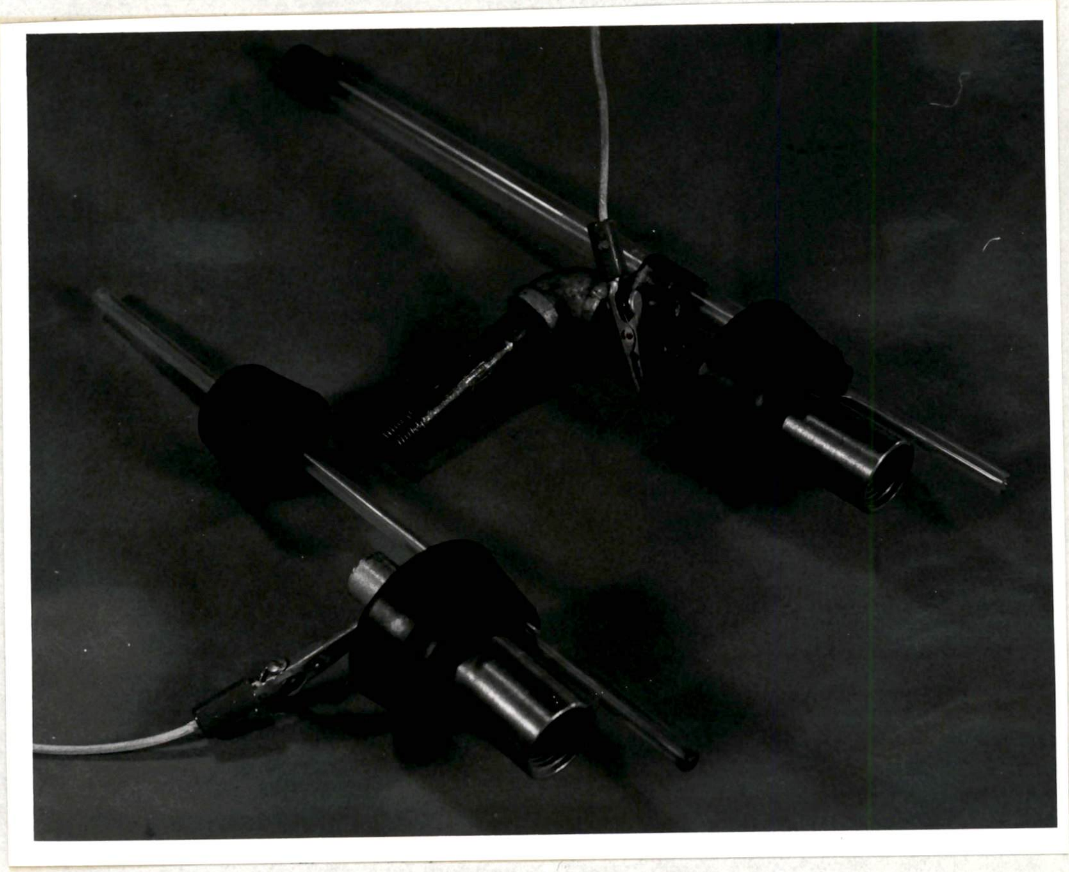


Figure 7. Electrodes and assembly.

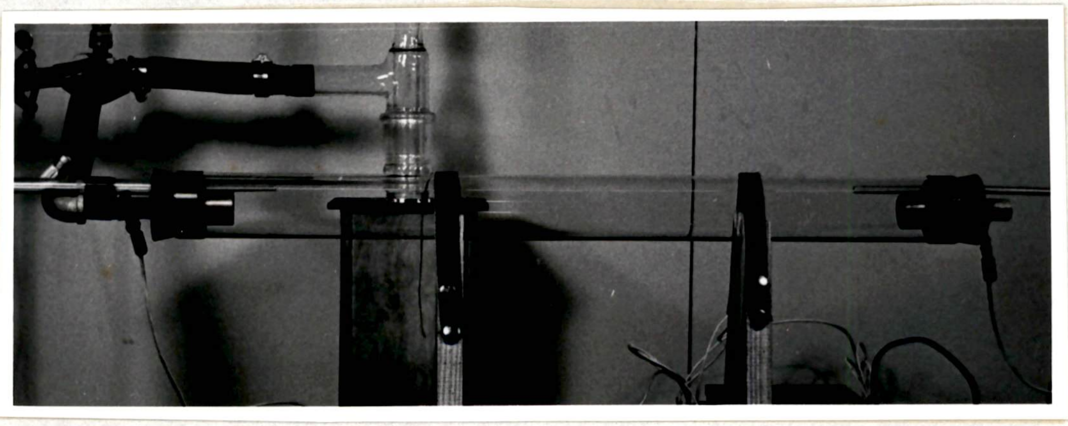


Figure 8. Irradiation chamber.

one-fourth inch from the tube wall.

The electrodes, Figure 7, were made of one-half inch iron pipe sleeves, machined and polished to one inch outside diameter, 1 3/8 inches long. A one-half by one-fourth inch iron reducer was placed in each sleeve and machined even with the end of the sleeve. A one-fourth inch nipple was placed in each reducer and extended through the center of the rubber stoppers used as supports. The nipple at the yarn entrance end was capped. The nipple at the yarn exit end was fitted with a hose connected to the vacuum system. These nipples also were part of the electrical system used to transmit current to the electrodes. The electrodes were spaced 20 1/2 inches apart.

A one-eighth inch fire-polished glass tube 3 1/4 inches long was butted against the polystyrene tube half-way through the support stopper at the entrance end of the irradiation chamber. Another similar tube was used at the exit end extending half-way through the support stopper. These tubes were used to guide the yarn past the electrodes and the cathode dark space (26) into the plasma of the discharge, to hold the yarn in position in the tube and to limit the actual distance through which the yarn was irradiated to eighteen inches.

A three-eighths inch polystyrene tube ten inches long was butted against the one-fourth inch glass tube half-way through the support stopper at the exit end of the irradiation chamber. In the end of this tube was a type of compression fitting that allowed the yarn to move from the evacuated area to atmospheric pressure, Figure 9. This fitting was made by passing the yarn through a section of polyethylene

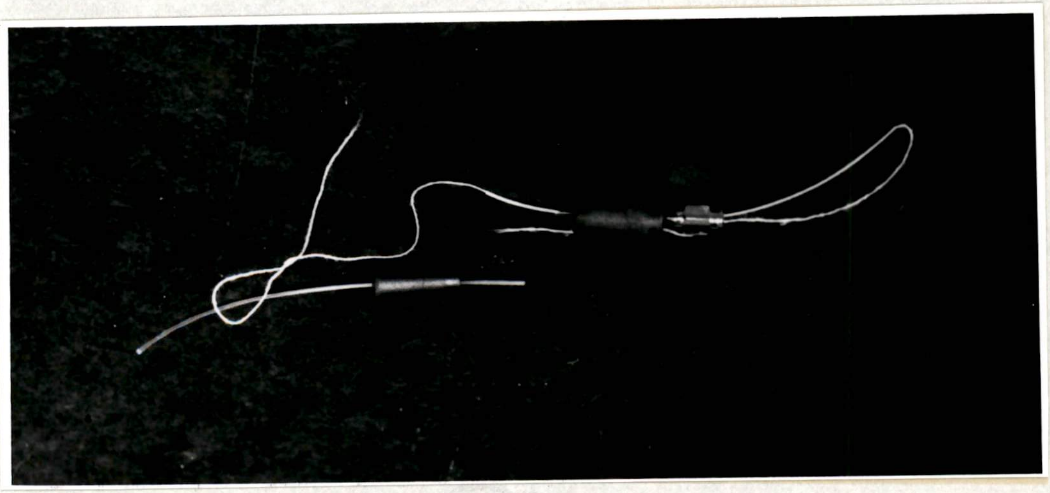


Figure 9. Compression fitting.

tubing, inside diameter 0.030 inches and outside diameter 0.048 inches, approximately four inches long. This in turn was placed through a 00 black rubber stopper which was plugged into the end of the three-eighths inch polystyrene tubing. The leak at this fitting was adjusted by either squeezing the 00 stopper tighter into the three-eighths inch tubing or by stretching out the polyethylene tubing into somewhat of a minute venturi orifice.

To load the compression fitting, vacuum was used to thread the polyethylene tubing, threaded tube was fed through a large hypodermic needle that had been forced through the 00 stopper and then the needle was removed leaving an assembled compression fitting.

Wind-up Device

In the apparatus being described, the yarn was pulled from the bobbin holding chamber, past one electrode, into the plasma of the discharge, past the other electrode, through the compression fitting and wound onto a drum driven by an electric motor geared through two reducers and a bead-chain drive. This wind-up device is shown in Figure 10.

The yarn was wound onto a drum 6 7/8 inches in diameter, ten inches long, with a circumference of 21.6 inches. The cylinder of this drum was aluminum, the ends three-fourths inch plywood. This particular size and shape drum was used because one hundred yards of yarn could be treated and wound up without changing the diameter of the coil enough to noticeably affect the length of time the yarn was irradiated.

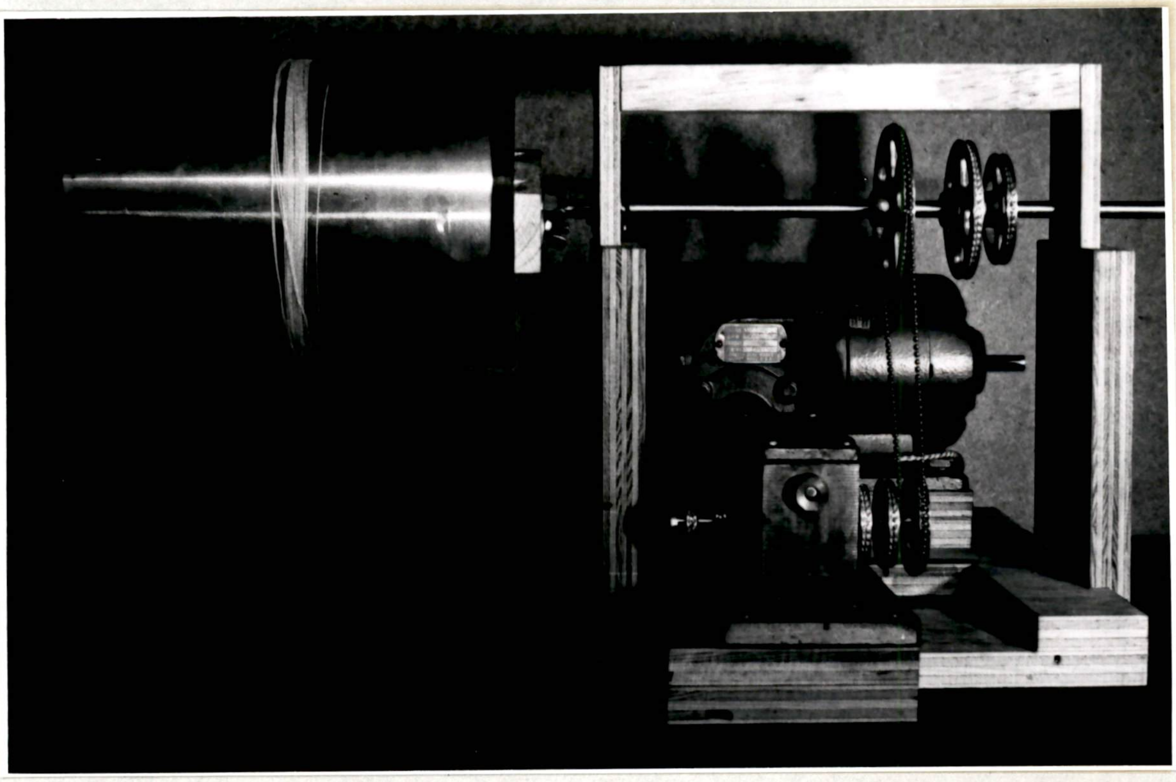


Figure 10. The wind-up device.

Power for the wind-up device was supplied by a General Electric one-twentieth horsepower, 115 volt, sixty cycle, single phase, 1725 revolution-per-minute electric motor. Built onto this motor was a ten-to-one gear type reducer. The shaft of this reducer drove a sixty-to-one gear type reducer. The output of the second reducer was 2.875 revolutions-per-minute.

Power was transmitted from the second reducer to the shaft on which the drum was mounted by number six qualified bead chain and bead-belt sprockets. The time that the yarn was irradiated in the plasma of the electrical discharge was varied by varying the sprocket ratios.

This wind-up device proved flexible and operated satisfactorily. There was sufficient power to pull the yarn with no slippage in the speed reduction system.

Electrical System

A potential was applied between the electrodes to give an electrical discharge. Input voltage to the system was 115 ± 0.1 per cent controlled with a Sorenson AC Voltage Regulator, Model 1000S.

A ten ampere, 50-60 cycle, 0 to 135 volt variable auto-transformer was used to control the power supplied to the high voltage transformers. Two number 721-161 Jefferson Electric Luminous Tube Transformers connected with paralleled primaries and secondaries to double the current output supplied high voltage to the electrodes. Specifications on these transformers were: 115 volt primary, sixty cycles, five thousand volt secondary, thirty milliampere capacity.

A Weston AC-DC Milliammeter Model 370, No. 1674, accuracy 0.25 per cent of full scale, 0 to 75 milliampere range, was used to monitor the current in the high voltage circuit of the system.

The voltage necessary to produce an electrical discharge through the partially evacuated tube is a function of the pressure and kind of gas in the tube (5). Controlling pressure was difficult in this study, but pressure was maintained at 1.5 ± 0.3 millimeters of mercury. At forty milliamperes current in the secondary circuit, operating potential across the electrodes was approximately fourteen hundred volts as measured with a Hewlett Packard vacuum tube voltmeter Model 410B using a capacitive voltage divider Hewlett Packard Model 452A.

Vacuum System

To maintain an electrical discharge the irradiation chamber of this system had to be evacuated and held at low pressure throughout an irradiation treatment.

A Cenco Hyper-Vac number 23 vacuum pump powered by a one-half horsepower Emerson electric motor was used. Iron pipe and rubber vacuum hose connected the pump to the open electrode support nipple at the irradiation chamber. An Alco S115 Solenoid valve allowed easy application and release of vacuum in the system. A freeze trap packed with dry ice and methanol was used to dry the air entering the pump.

Pressure was measured in the connecting system approximately one foot from the treating chamber. A Hastings Absolute Pressure Indicator Model AP 1S with a Vacuum Gauge Tube-type DV-4AM sensingelement was used to determine the vacuum in millimeters of mercury. This pressure indication system was calibrated with a McLeod Gauge. An isolation transformer in the power input to the pressure indicator eliminated interference that might come from the irradiation section.

Effectiveness of the Machine

The effectiveness of any machine, or apparatus, depends upon its ability to do the job it was designed for. In this study the apparatus was designed to irradiate cotton yarn in a continuous length. It was operated satisfactorily for some two hundred hours in determining optimum irradiation levels and in treating yarn used in studying the effects of irradiation with plasma on cotton yarn. Therefore, the apparatus was effective in performing the job it was designed for.

To allow determination of an optimum level of treatment with irradiation, the apparatus was designed to be flexible. Intensity of the discharge and position of the yarn in the plasma could be varied, vacuum could be maintained and varied and time of irradiation in the plasma was variable. From the standpoint of flexibility, the machine was effective.

CHAPTER III

TREATMENT OF THE YARN

Description of the Yarn

Introductory Information

The yarn treated and tested was obtained through, and with the assistance of, personnel from Crops Research Division, Cotton Spinning Laboratory, USDA, ARS, Knoxville, Tennessee.

It was decided that, due to the limited scope of this study, an "average" yarn be used. That is, the cotton fibers were to be of average quality spun into yarn using a standard spinning process. Ten count or sixty tex yarn was selected in order that the yarn be strong enough to stand the manipulations of the irradiation and treatment processes.

Picker-lap (18) was obtained from a quality mill. The cotton used in making this lap was a six bale mix of unknown variety opened and processed into a finished picker-lap. No oil or sizing was added anywhere through the yarn preparation process.

Fiber Analysis

To insure uniformity of raw stock, fiber qualities were checked at the beginning and end of the section of lap used. For each determination four Fibrograph, eight Stelometer and four Arealometer tests were run (3,14). From the Fibrograph the two determinations of mean, or average length of fiber, were 0.95 and 0.87 inches with the upper-half-mean length 1.13 and 1.10 inches. Tenacities (27) at one-eighth inch gage length obtained from Stelometer tests were 1.94 and 1.92 grams per grex. Fineness, obtained with the Arealometer in specific surface area, was 442 square millimeters per cubic millimeter of fibrous material in each case. The Arealometer also was used to determine maturity by means of a roundness factor. The two values obtained were twenty-nine and twenty-eight. All fiber analyses were done by the Cotton Laboratory, USDA, ARS, under the direction of Dr. Smith Worley.

Carding, Drawing and Spinning

The remaining processes in preparing the yarn were done at the Spinning Laboratory. The picker-lap was carded (18,21) to open the cotton more completely, to clean the cotton slightly, to separate out the very short fibers and to produce a continuous untwisted strand of cotton fibers called a sliver.

Next the cotton was drawn. Drawing is the process of progressively passing or sliding fibers by each other, causing a reduction in the size of the strand, but not breaking its continuity (18). In this particular process of drawing, two passes were made through the draw frame. The purpose of drawing is to straighten the fibers parallel to each other and to the direction of the strand and to reduce the size of strand.

Since the drawn sliver for the ten count yarn was strong enough to stand the manipulations of spinning without adding twist in a roving process, the roving frame was by-passed and the sliver taken directly to the four-roll ring-spinning frame (13,18). The purpose of this frame was to reduce the sliver to the required size of single yarn and to insert the desired twists. A single cotton yarn may be defined as a continuous twisted strand of cotton fibers which has received its final attenuation (18).

The final yarn twist and linear density are shown in Tables II and III. For convenience the single strand yarn was called AEd1-10A and is identified throughout this study by its twist. The twist is the mechanical turns-per-inch placed in the yarn at the spinning frame. Figure 11 shows the spun yarn on twelve hundred yard warp bobbins with one bobbin pictured for each of the various twist points.

In the process of irradiating and testing, the yarn was drawn over the end of the warp bobbin once. Every effort was made to maintain twist in the yarn.

Setting Parameters of Irradiation Treatment

After the yarn was spun and the apparatus to irradiate this yarn was developed, the next step was to determine a combination of irradiation time, current, pressure and position of yarn in the tube that would give maximum difference in control as compared to irradiated yarn qualities.

Due to the nature of the compression fitting, pressure was not included as a variable but was maintained at 1.5 ± 0.3 millimeters of mercury. This was the lowest pressure that could be attained without tightening the compression fitting to the point that drag would cause

TABLE II

LINEAR DENSITY DATA FROM SINGLE STRAND IRRADIATED AND CONTROL AEd1-10A COTTON YARN BROKEN ON A USTER TESTER

	Linear Density[a]			
	Tex[b]		Count[c]	
Turns/Inch	Control	Irradiated	Control	Irradiated
7.66	57.53	57.47	10.27	10.27
8.45	58.62	59.52	10.07	9.92
9.07	59.50	58.38	9.93	10.12
9.80	58.67	58.60	10.07	10.08
11.14	58.93	56.91	10.02	10.38
11.95	61.28	60.92	9.64	9.69
12.69	60.51	60.20	9.76	9.81
13.17	60.97	59.99	9.69	9.84
14.89	58.20	58.16	10.15	10.15
16.31	59.36	57.83	9.95	10.21
18.03	61.15	58.85	9.66	10.03

[a] Each value represents yarn used for 400 breaks.

[b] A Tex unit is equal to the weight in grams of 1000 meters of yarn.

[c] Count indicates the number of 840-yard hanks in a pound.

TABLE III

LINEAR DENSITY DATA
FROM SINGLE STRAND AEdl-10A COTTON YARN
TREATED BY VARIOUS METHODS AND BROKEN ON A USTER TESTER

Method Of Treatment	Twist In Turns/Inch	Linear Density[a]	
		Tex[b]	Count[c]
Control	8.45	58.62	10.07
Irradiated	8.45	59.52	9.92
Drawn & Evacuated	8.45	59.07	10.00
Ethanol Extracted	8.45	59.60	9.91
Ethanol Extracted & Irradiated	8.45	59.52	9.92
Control	11.95	61.28	9.64
Irradiated	11.95	60.92	9.69
Drawn & Evacuated	11.95	60.62	9.74
Ethanol Extracted	11.95	60.04	9.84
Ethanol Extracted & Irradiated	11.95	59.60	9.91

[a] Each value represents yarn used for 400 breaks.

[b] A Tex unit is equal to the weight in grams of 1000 meters of yarn.

[c] Count indicates the number of 840-yard hanks in a pound.

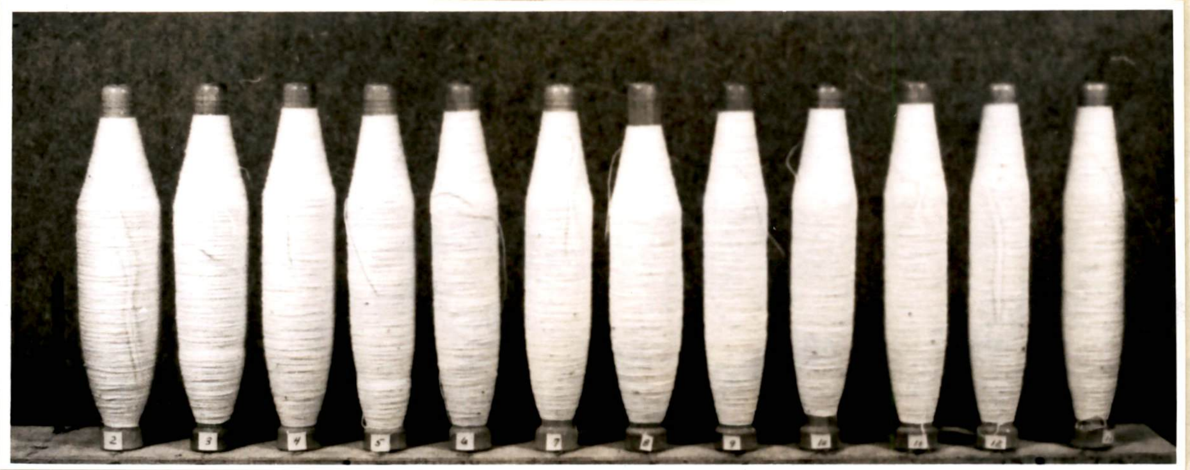


Figure 11. Spun yarn of various twists.

breakage of the yarn. The ± 0.3 fluctuation in pressure was due to variation in the linear density of the yarn. Voltage, which in this type of discharge is a function of pressure (5), was not included as a variable.

Position of yarn in the tube was varied by bending the glass guides at angles. By doing this the radial distance of the yarn path from the center of the tube was varied, starting at the center of the plasma and working outward. It was found that the yarn was charred instantly in the center of the tube and was degraded in all positions except a path one-fourth inch or closer to the pyrex tube wall. Therefore the yarn was irradiated in a path in the plasma eighteen inches long and approximately one-fourth inch from the tube wall.

Current in the high voltage circuit was varied along with the time that the yarn was in the plasma of the discharge. Yarn breaking strength, elongation and linear density were used as measures of the effectiveness of each combination of current and time.

In varying current, fifteen milliamperes or less would not sustain a discharge and fifty milliamperes or greater caused charring and ultimate disintegration of the yarn. Because of this the current was maintained at twenty, thirty and forty milliamperes in determining the optimum level of irradiation.

Any time less than 17.0 seconds was unsatisfactory due to overheating caused by friction or clogging of the compression fitting. Any treatment time over 62.5 seconds resulted in charring and ultimate degradation of the yarn. Length of treatment was varied in steps and maintained at 17.0, 31.5, 41.0, 52.5 and 62.5 seconds in determining the optimum time of irradiation.

Results of the work done in determining the optimum parameters of irradiation treatment are shown graphically in Figure 12 with point values for data tabulated in Table IV. Yarn used in this preliminary work was AEd10-1A of 12.98 turns-per-inch twist. This was the predicted twist to give maximum breaking strength.

Figure 12 shows the general trend in breaking strength with varying time-current combinations. Elongation was not considered a critical factor in determining treatment level. Elongation was reduced but no definite trend was evident as a result of varying irradiation time and current.

At first the variation in tex, or linear density, caused some alarm. Again no definite trend could be determined relating the fluctuations in tex to level of irradiation treatment. The general reduction in tex was thought to be caused by moisture removal due to evacuation and singeing. This yarn was seasoned three days or less in most cases, and, as was determined later, this was not long enough to allow the yarn to return to constant condition with a 65 ± 2 per cent relative humidity and 70 ± 2°F air atmosphere.

In setting the parameters of the treatment, position of yarn in the plasma, pressure and voltage were not variable. The only variable parameters were time of irradiation and current in the high voltage circuit.

Elongation and tex were of little value in setting these two

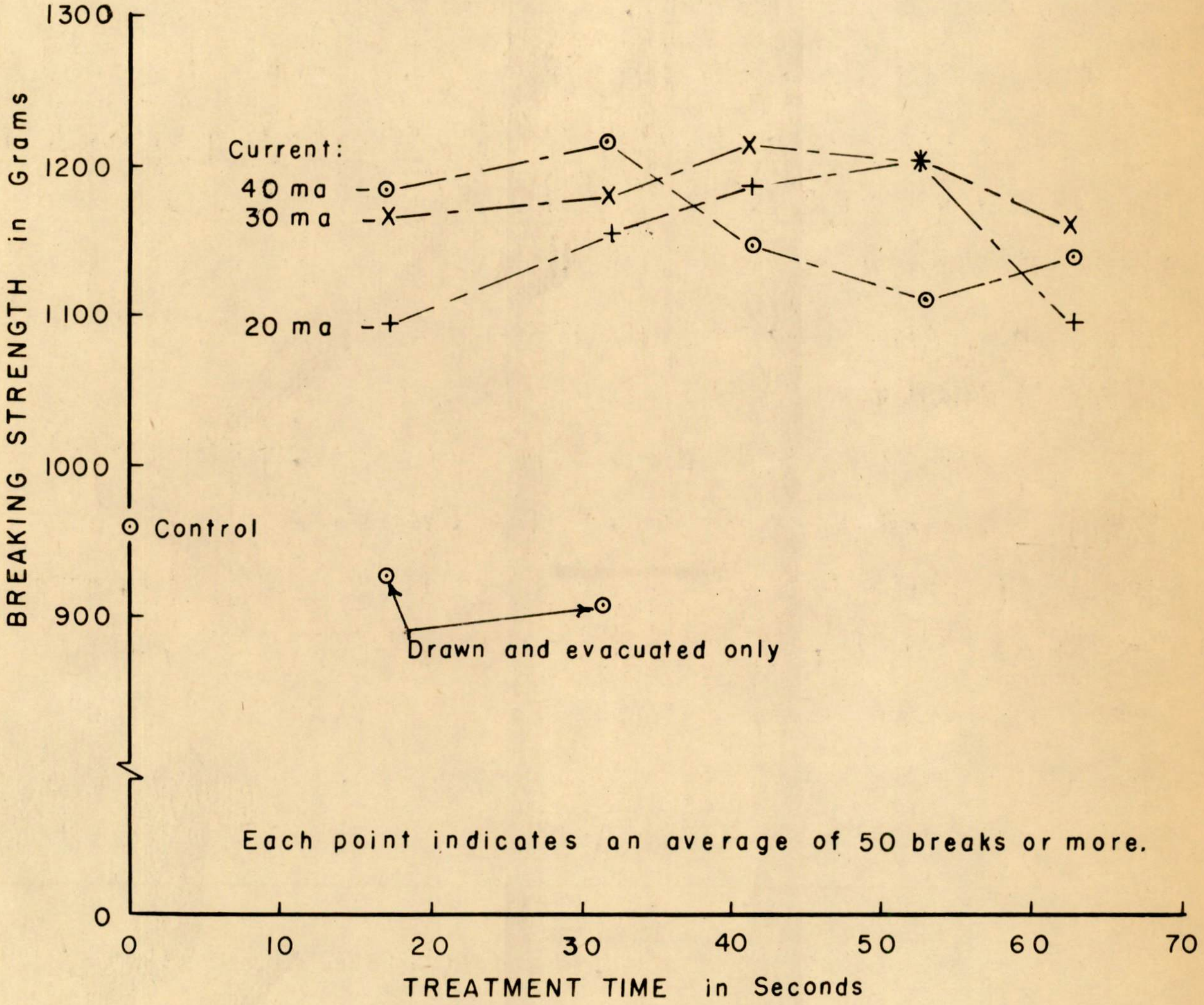


Figure 12. Plot of data used in setting parameters for irradiation treatment of AEd1-10A cotton yarn.

TABLE IV

DATA USED IN SETTING PARAMETERS FOR IRRADIATION TREATMENT OF AEd1-10A COTTON YARN FROM SINGLE STRAND BREAKS ON A USTER TESTER

Current In Milliamperes	Time In Seconds	Tex In Grams/1000 Meters	Breaking Strength In Grams	Elongation In Per Cent
Control	-	58.7	965 (200 breaks)	8.30
Control	-	59.0	954 (200 breaks)	8.05
0	17.0	57.6	926 (165 breaks)	6.95
0	31.5	57.3	902 (225 breaks)	7.30
20	17.0	57.0	1096[a]	7.43
20	31.5	59.1	1156	6.83
20	41.0	56.9	1190	7.10
20	52.5	57.9	1202	7.24
20	62.5	56.1	1102	6.10
30	17.0	57.8	1172	7.10
30	31.5	57.3	1184	6.99
30	41.0	55.4	1232	7.00
30	52.5	57.3	1204	7.24
30	62.5	57.6	1165	6.84
40	17.0	57.0	1182	7.77
40	31.5	56.1	1212	6.77
40	41.0	54.5	1150	6.68
40	52.5	54.1	1112	6.44
40	62.5	54.0	1138	6.14

---

[a] All treatments involving irradiation, as indicated by current values, were tested with 50 breaks or better.

variables. The only definite trend indicator was breaking strength. Time-current combinations of 31.5 seconds at forty milliamperes and 41.0 seconds at thirty milliamperes indicated approximately the same strength increase of irradiated over control; so, due to the time factor, the first combination was chosen.

In all discussion following, any irradiation was done with the apparatus described in Chapter II adjusted to irradiate the yarn for 31.5 seconds in the plasma at 1.5 ± 0.3 millimeters of mercury pressure and 40 ± 2 milliamperes current in the high voltage system. Fluctuations in pressure were due to variation in the linear density of the yarn; likewise, the current variations were caused by the pressure fluctuations.

Post Irradiation Treatment

Relaxation

The yarn was dragged through the irradiation apparatus and wound onto the wind-up drum under some tension. Allowing the yarn to remain under this tension for a short length of time resulted in a reduction in elongation. Also, storage space for this drum while the yarn was conditioning was limited. To solve these problems, the yarn was rewound onto warp bobbins after irradiation. This allowed relaxation and made a small package for storage while conditioning.

Conditioning

As mentioned in the previous section, conditioning time was critical. Yarn when taken from the irradiation chamber was dehydrated.

According to ASTM standards (2) yarn should be at constant moisture equilibrium with a 65 ± 2 per cent relative humidity and 70 ± 2°F air atmosphere before being tested. By a system of successive weighings it was determined that nine to ten days of conditioning were needed before constant weight was attained. It was also determined that all irradiated stock was at constant weight after fourteen days of seasoning. Therefore in the work described in this study all irradiated yarn was broken the fourteenth day after being placed in the conditioning room.

Specific Treatments of the Yarn

Irradiation and Control

Enough yarn for four hundred breaks was irradiated at each of the selected points over the range of twists. The means of these breaks were compared with the means of four hundred breaks of control stock with regard to strength, elongation and linear density. The method of breaking this yarn is presented in Chapter IV.

Ethanol Extraction and/or Irradiation

Because previous work indicated wax degradation (23) it was possible that only the wax on the surface of the yarn was being affected by irradiation. Hot ethanol extraction was performed on two twist points, the optimum control twist and the maximum strength increase twist. At each point the mean of four hundred breaks of extracted yarn was compared to the mean of an extracted and irradiated treatment.

The yarn was extracted with ninety-five per cent hot ethyl alcohol in a Soxhlet extractor for six hours (8). The extract was transferred to a separatory funnel and diluted with chloroform. Then the chloroform was washed with water to remove nonwax substances and the chloroform allowed to evaporate. The residue, both nonwax and wax, was weighed and per cent by dry weight calculated. At the low twist point 0.75 per cent wax and 0.85 per cent nonwax and at the high twist point 0.52 per cent wax and 0.76 per cent nonwax were removed.

Hot ethyl alcohol extraction removes all the wax and sugars and twenty-five per cent of the ash (17). Ward (27) gives the composition of typical, mature cotton fiber, dry basis, as 0.6 per cent wax, 0.3 per cent sugars and 0.4 per cent as one-fourth of the ash. Variations in wax are listed from low at 0.3 per cent to high at 1.0 per cent. It is felt that a thorough job of wax extraction was done and that any differences between extracted and extracted and irradiated yarn was not caused by wax.

Manipulation and Evacuation

The final treatment shown in this study was to draw control yarn through the irradiation chamber under vacuum. This was done to show the effect of manipulations during irradiation on the yarn. The same two points as in the extraction comparison were used in this treatment.

The results of testing the various treatments are shown in Chapter V.

CHAPTER IV

TESTING THE YARN

Description and Operation of the Uster Continuous Break Tester

A Uster yarn strength tester, manufactured by Zellweger Ltd., Uster Switzerland, type AD, number 96.1388/8, owned by Crops Research Division, Spinning Laboratory, ARS, USDA, Knoxville, Tennessee, ARS number 51266, was used to test the yarn for this study, Figure 13.

The length of thread between the grips that was tested for strength and elongation at rupture was invariable and measured five hundred millimeters, or 19.7 inches, Figure 14 (28).

The grips used to hold the thread were packed with stainless steel bushings. Steel was used to hold the thread securely without slipping. Very few "chuck" breaks occurred which indicated that grip damage to the yarn was a minimum.

The loading device worked according to the inclined plane principle, Figure 15. Pull on the yarn was exerted by a weight rolling down a plane with variable inclination. This pull, which depends on the size of the weight and inclination of the plane, was set for the zero to two thousand grams range. At each test, the plane moved slowly downward from the initial horizontal position until rupture occurred. Rate of increase was adjusted so that the maximum pull necessary to break the yarn was reached in ten seconds.

The apparatus was set to carry out one hundred tests in one working operation. After each one hundred tests the machine automati-

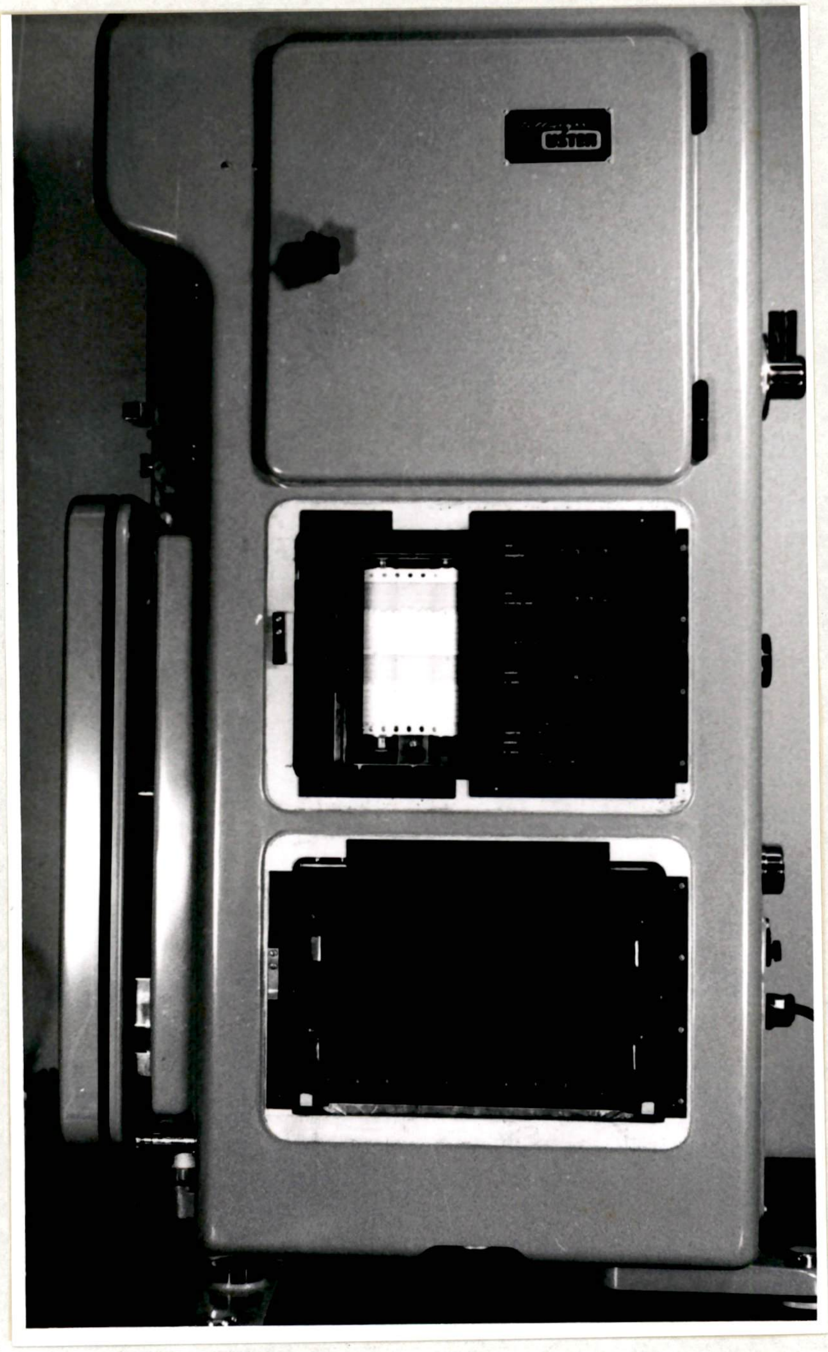


Figure 13. The Uster yarn strength tester.

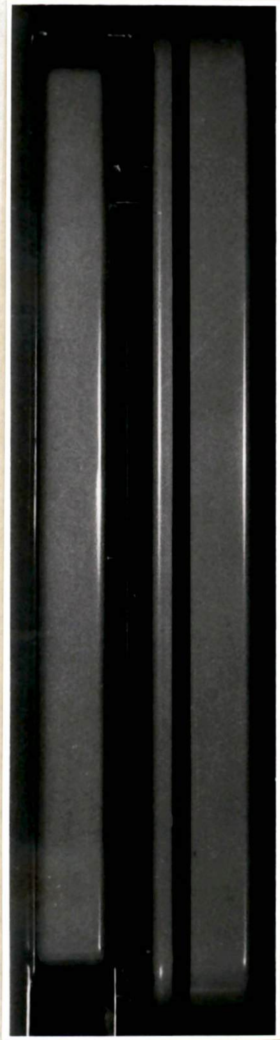


Figure 14. The grips of the Uster.

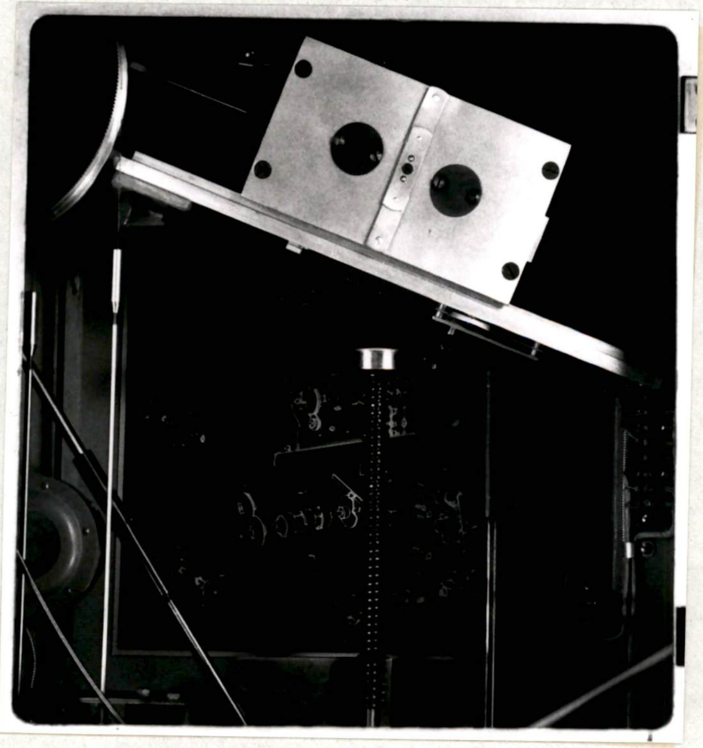


Figure 15. Inclined plane loading device.

cally stopped, then the broken yarn was removed and retained. This procedure was repeated until four hundred breaks had been made at each point. The retained broken yarn was used to determine the exact linear density of the yarn.

All breaking for this study was done on the same machine in a controlled condition room using the same breaking ranges for all treatments.

Machine Presentation of the Data

The breaking strength and elongation at rupture of each tested piece of yarn was recorded on a ruled paper strip, Figure 16. Each of the two values was represented by the length of a line drawn by a ball-point pen. Full scale on the ruled paper indicated one hundred per cent of the maximum for the elongation and breaking strength ranges selected. In this study, full scale for elongation represented twenty per cent, with full scale for breaking strength representing two thousand grams. Actual values were read from paper strips in per cent of full scale.

The values of breaking strength were also represented as frequency distribution, Figure 17. For each hundredth part of the load capacity used, the number of the measured values was represented by laying an equivalent number of balls into a groove which indicated the strength interval in question. This distribution was copied and recorded for each of the tested points. Special diagram paper caligrated to the size of the balls and grooves was used. Black crayon

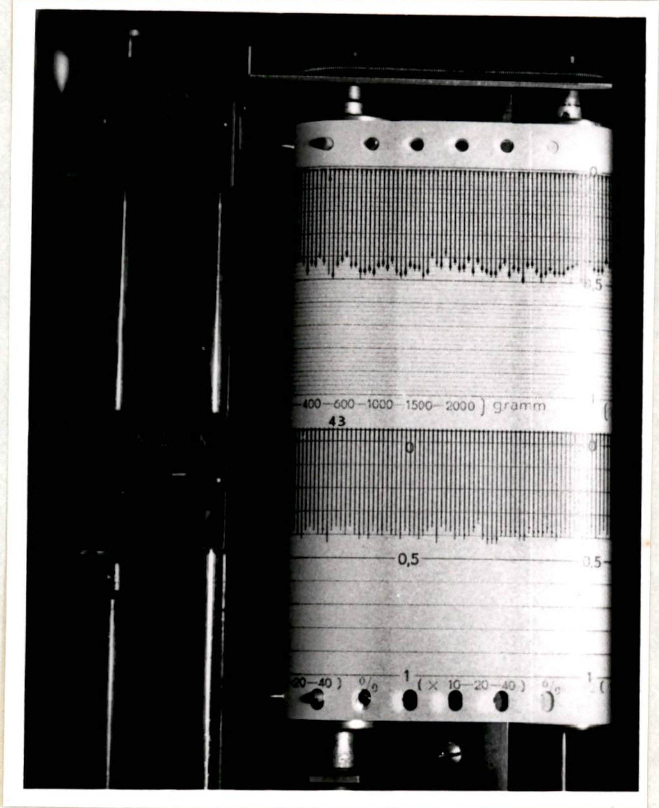


Figure 16. Ruled paper strip showing yarn strength and elongation recordings of individual breaks.

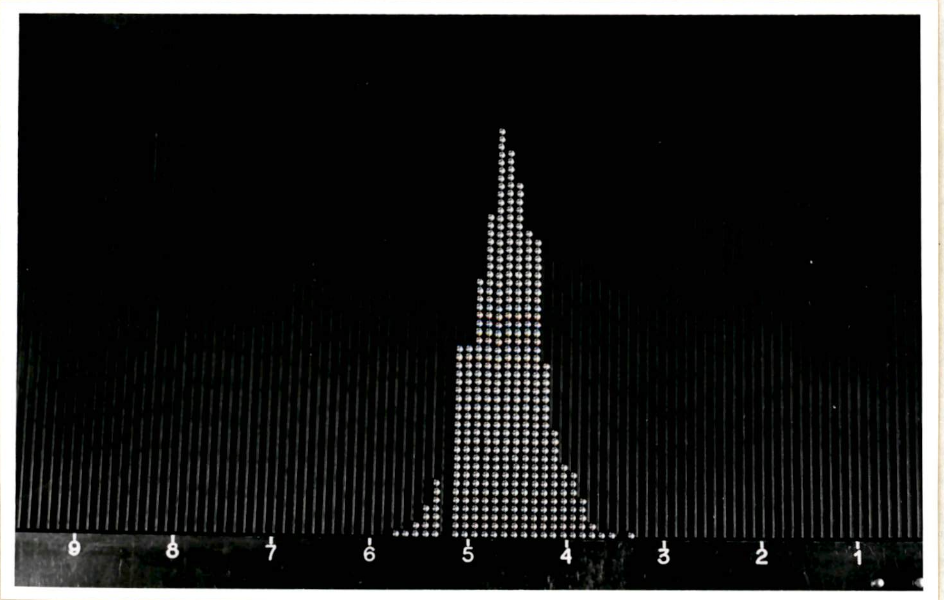


Figure 17. Breaking strength frequency distribution as dropped by the Uster.

was rubbed on the paper placed over the balls to give a permanent copy.

The sum of the elongation was given by a four-digit counter, Figure 18, ten per cent elongation gave a reading of one. A second four-digit counter gave the sum of the breaking loads with ten corresponding to a tensile strength equivalent to two thousand grams. A third four-digit counter totaled the number of tests carried out.

In each case the sum of four hundred tests were accumulated on the data recording devices. The term "Dial", appearing in following sections of this thesis, is used to classify data that was read directly from the machine accumulation, whereas "Chart" indicates data that was read and derived from the individual break recordings on the paper strip.

Methods of Evaluating the Measurements

For each treatment at each point the breaking strength and breaking strength standard deviation were calculated by two methods. The average values of strength were first determined from the readings of the breaking strength counter which continuously totaled the individual test data. The following formula was used: (28)

$$\overline{P} = 10\,Sp/n + k,$$

where:

$\overline{P}$ = the average breaking load in per cent of two thousand grams,

Sp = the reading of the breaking strength counter at the end of a test,

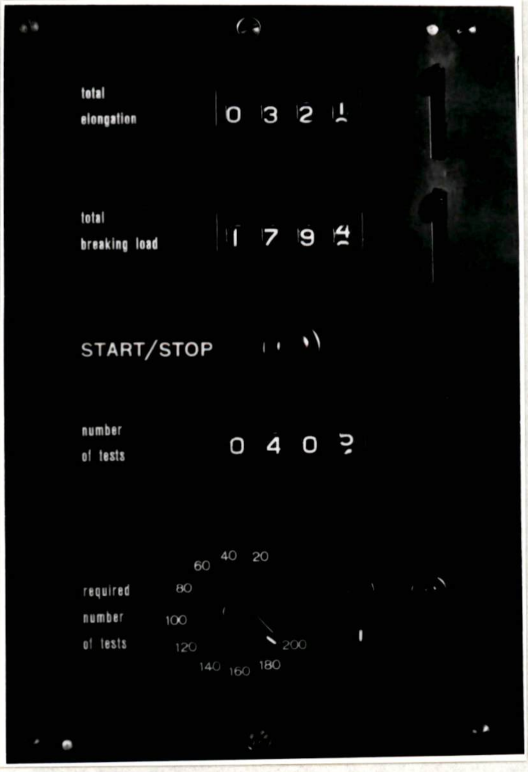


Figure 18. Accumulative breaking strength, elongation and number of breaks counters.

n = the number of breaks carried out, and

k = 2.3, a machine factor constant derived by the manufacturers for this machine.

An actual illustration of this method of strength determination is shown in Appendix B.

In any case if there was a malfunction of the apparatus, such as no thread being in the grips while a test was tried, dial indicators would register ten units for breaking strength, one unit for elongation and one unit for the number of breaks. Whenever this occurred, the readings were corrected in the manner prescribed in the operations manual for the Uster (28).

The mean breaking strength was also determined by reading point values for the individual breaks from the lined strips of paper. These values were summed and calculations made to determine the breaking strengths. A sample of this method is shown in Appendix B.

The standard deviation, or the average quadratic deviation of a single value from the arithmetic mean, is the criterion of unevenness used mostly in modern statistics. The standard deviation of breaking strength was calculated from the four hundred break values read from the strips of paper. The method used is described by Snedecor (22) and illustrated in Appendix B.

A second method of approximating the standard deviation from the frequency distribution on the diagram paper was used. This method, described in the Uster operations manual (28), gives an idea regarding the unevenness of the breaking load. The wider the frequency distribution measured at the base, the more uneven the breaking load of a tested yarn. A special ruler calibrated to the scale of the diagram paper was used to measure the base of the frequency distribution. This ruler was read directly in standard deviation in per cent of the breaking strength range.

Mean elongation was computed in much the same way as mean breaking strength. The elongation at rupture calculated from the readings of the counter was obtained by using the formula: (28)

$$E = 10\,Se/n + e,$$

where:

E = the arithmetic mean of all elongations in per cent,

Se = the reading of the elongation counter at the end of a test,

n = the number of breaks carried out and

e = 0.1, a constant derived by the manufacturers of the machine.

An actual illustration of this method of elongation determination is shown in Appendix C.

The mean elongation was also determined from reading individual point values for elongation, summing these values and making the necessary calculations. The elongation standard deviation was derived in the same manner described as the first breaking strength method. This is illustrated in Appendix C.

Data and results taken from the ruled paper strip are thought to be more accurate than results obtained from counter summations.

This opinion is due to the fact that some slipping and malfunctioning of the counters was noticed. In each test, data obtained from the counters and frequency distribution is presented as a check on the accuracy of values calculated from the individual point recordings. Data plotted in figures used to graphically present the results were derived from individual point determinations.

Linear density was determined at each twist point tested for all treatments. The salvaged yarn from each four hundred breaks was accurately weighed using an analytical balance manufactured by Voland and Sons, Inc., New Rochelle, New York, model number 220D, USDA number PI-9-9845. Weights were determined by the single deflection method of weighing (6). The following formulas were used: (28)

$$\text{Tex} = 1000\ W/nL,$$

where:

Tex = weight in grams of one-thousand meters of yarn,

W = weight of the salvage in grams,

n = the number of breaks and

L = 0.707 the length of yarn required for each test in meters.

$$\text{Count} = 590.5/\text{Tex},$$ where:

Count = the number of 840 yard hanks in a pound and

590.5 = a conversion constant (2).

An illustration of the actual calculation of tex and count is shown in Appendix D.

The coefficient of variation (1), a measure of relative variation, was calculated at each twist point for breaking strength and elongation. It seems rather characteristic that large things vary much and small things little (22). For this reason it is convenient and customary in the cotton industry to express the sample standard deviation as a fraction of the sample mean, the resulting statistic is called the coefficient of variation and expressed in per cent. Although cotton yarn breaking strength means and standard deviations vary considerably, the coefficient of variation remains about ten per cent (9). This fact is often used as a measure of the validity of the testing performed and was so used in this study.

CHAPTER V

RESULTS OF THE STUDY

General Statement

The results of this study, except for moisture content, are presented graphically for each treatment. Exact values of points plotted are listed in Appendix E, or in Tables II and III. Results for each treatment show breaking strength, breaking strength standard deviation and coefficient of variation, elongation, elongation standard deviation and coefficient of variation, linear density, mean comparisons where necessary and moisture contents. Lines joining points on the graphs indicate trend and should not be used to predict ordinate values for a given twist.

Appearance

Changes in appearance and physical characteristics resulting from irradiation were noticed by the author. The yarn prior to treatment was soft and smooth, appearing to slide apart when broken. The control yarn floated on the surface of water and did not wet.

When the yarn entered the plasma of the discharge the fuzz on the outer surface was singed off immediately. The burrs, or small pieces of trash, remaining in the yarn were scraped off by the compression fitting. The irradiated product was rough and harsh to feel, smelling slightly burned. This irradiated stock was very water absorbent, wetting instantly, and broke with a snap showing little fiber slippage.

The above mentioned characteristics are similar to effects produced by irradiation of cotton lint and seed reported by R. B. Stone, Jr. (23).

The hot ethanol extracted yarn was harsh to feel and had a greater affinity for water than the control. Yarn that was irradiated after extraction was harsher than the extracted stock. Irradiation caused the extracted yarn to have a still greater affinity for water than the ethanol extracted non-irradiated yarn.

Linear Density

Yarn count and tex were determined for all treatments at each twist point to show both relative uniformity and effect of treatment on linear density. The results are plotted in Figures 19 and 20. Differences can be attributed to moisture removal along with some singeing of the irradiated yarn and to variations in spinning.

Breaking Strengths and Strength Increases

Mean breaking strength versus twist for all treatments is shown graphically in Figure 21. The control curve rises sharply to a maximum and then gradually decreases with overtwisting. This is the curve form expected as explained by Landstreet, Ewald and Simpson (15).

The irradiated curve rises slightly from the lowest twist spun to the same optimum twist point as the control, then this curve decreases sharply with overtwisting. Strength increase of irradiated

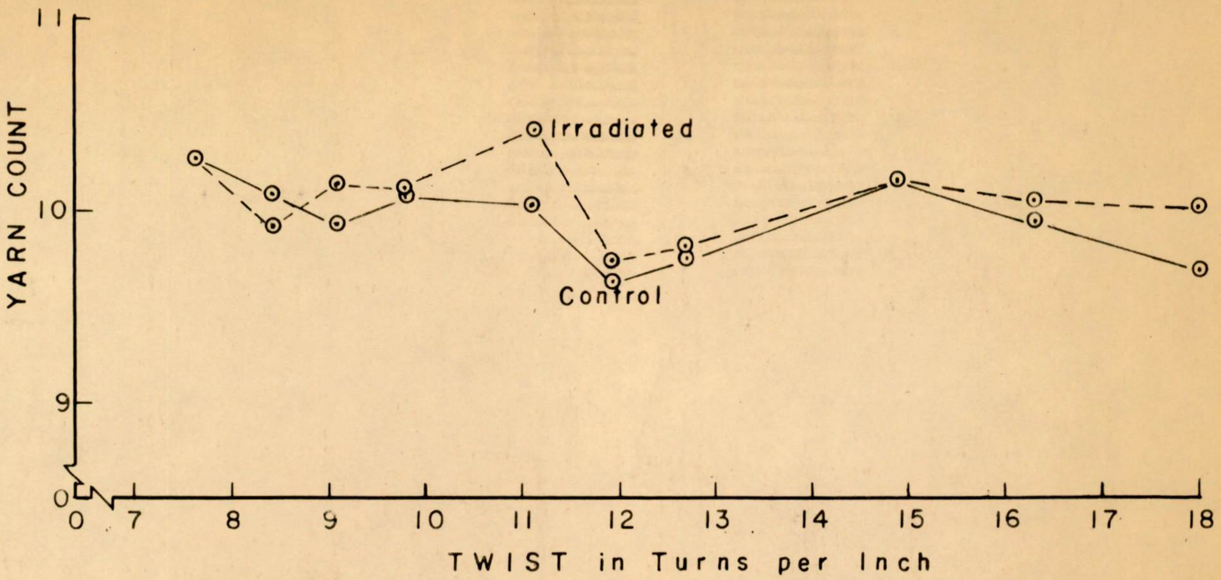


Figure 19. Yarn count versus twist for control and irradiated AEd1-10A cotton yarn.

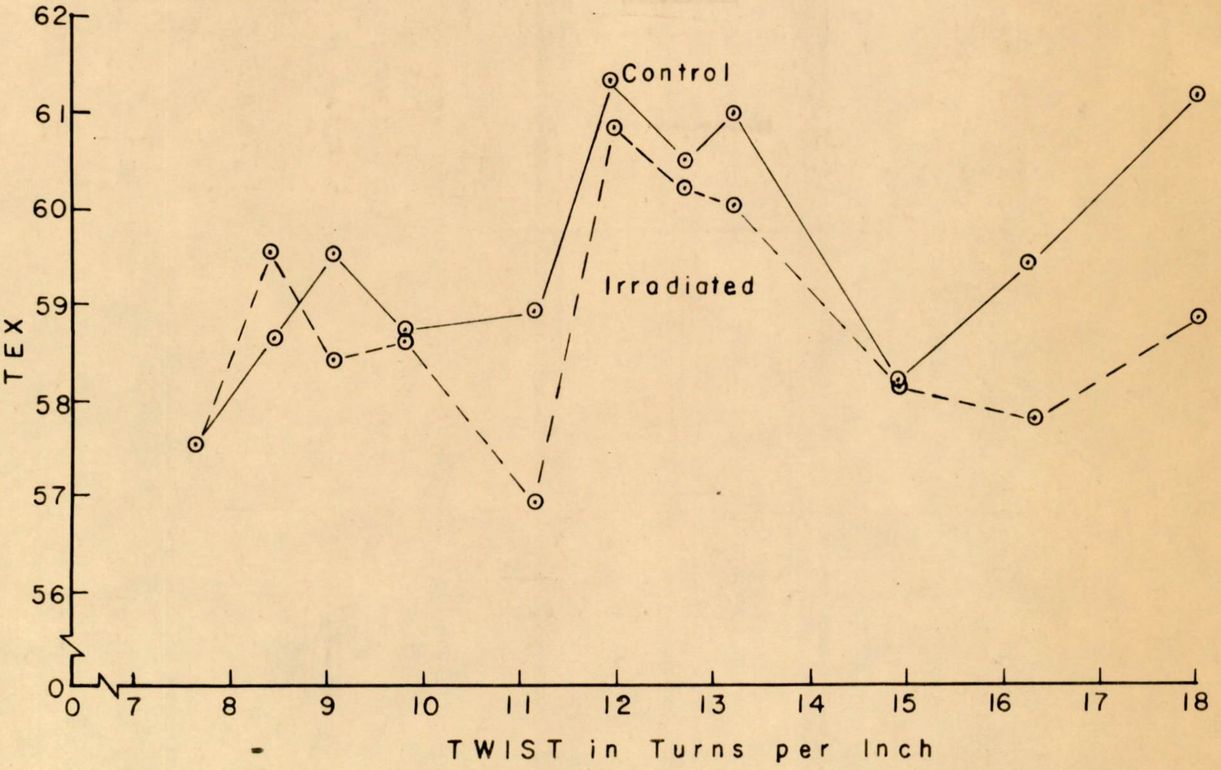


Figure 20. Tex versus twist for control and irradiated AEd1-10A cotton yarn.

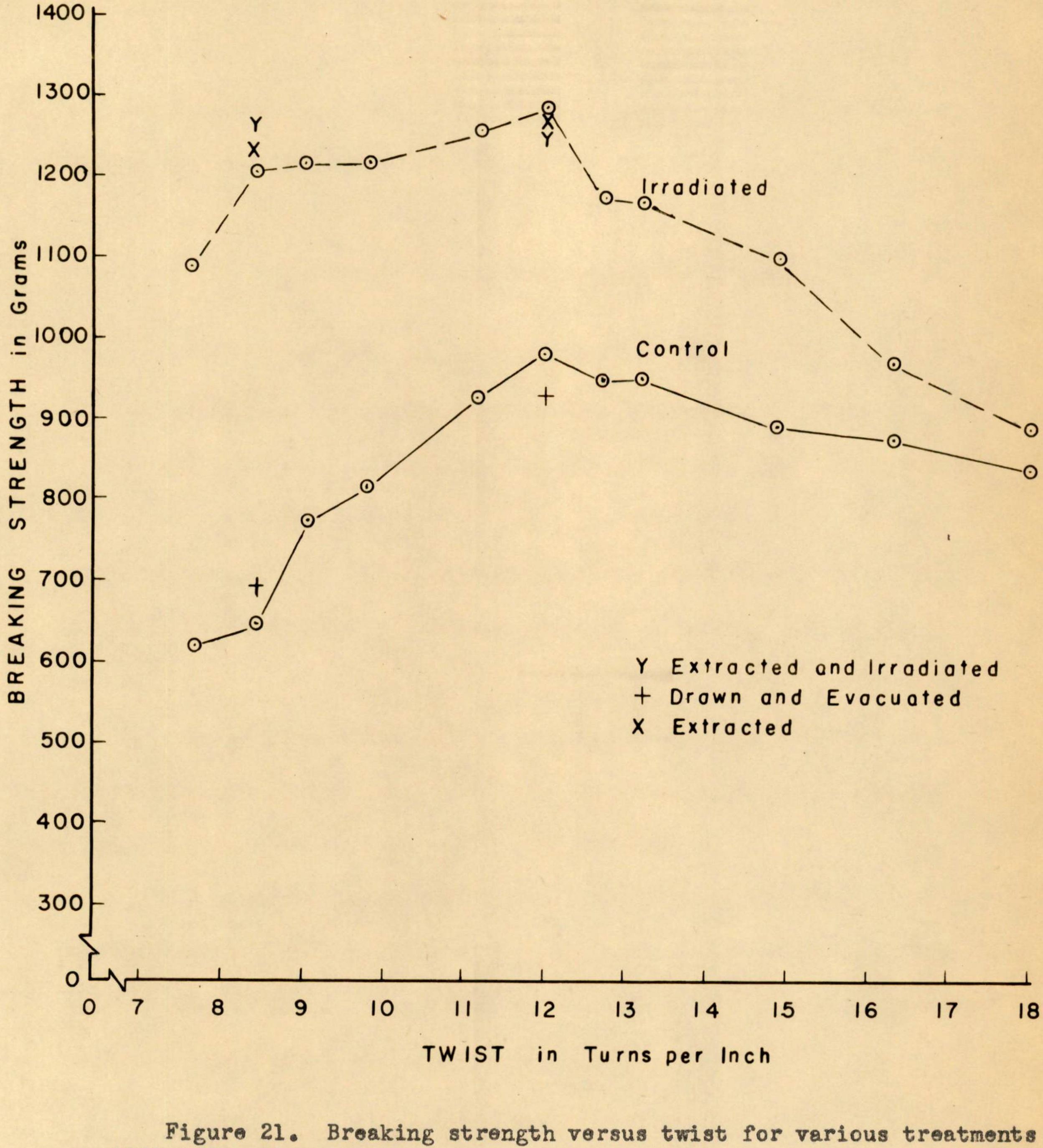


Figure 21. Breaking strength versus twist for various treatments on AEd1-10A cotton yarn.

over control on a control basis is shown graphically in Figure 22.

The breaking strength of the extracted and extracted and irradiated yarn at low and optimum twists was approximately the same as the irradiated. Similarly, drawn and evacuated yarn at the same two twists was approximately the same as the control.

Breaking Strength Standard Deviations

Breaking strength standard deviations are shown in Figure 23. In the control curve, standard deviation, a measure of variation, rises throughout the range of twists. The curve for the drawn and evacuated treatment indicated that yarn at low twist was affected by manipulation and/or evacuation to make a sample that was more uniform than the control. This treatment had relatively no effect on yarn at optimum twist.

The breaking strength standard deviations for the irradiation treatment rise sharply with the first two low twist points and then gradually decrease through the higher twists.

The standard deviation of extracted yarn at the two points tested indicate more variation in breaking than irradiated or extracted and irradiated yarn. This trend in variation indicates that irradiation had some effect on the extracted yarn.

Breaking Strength Coefficient of Variations

The coefficient of variations of breaking strength, a measure of relative uniformity, are shown in Figure 24. The results indicate

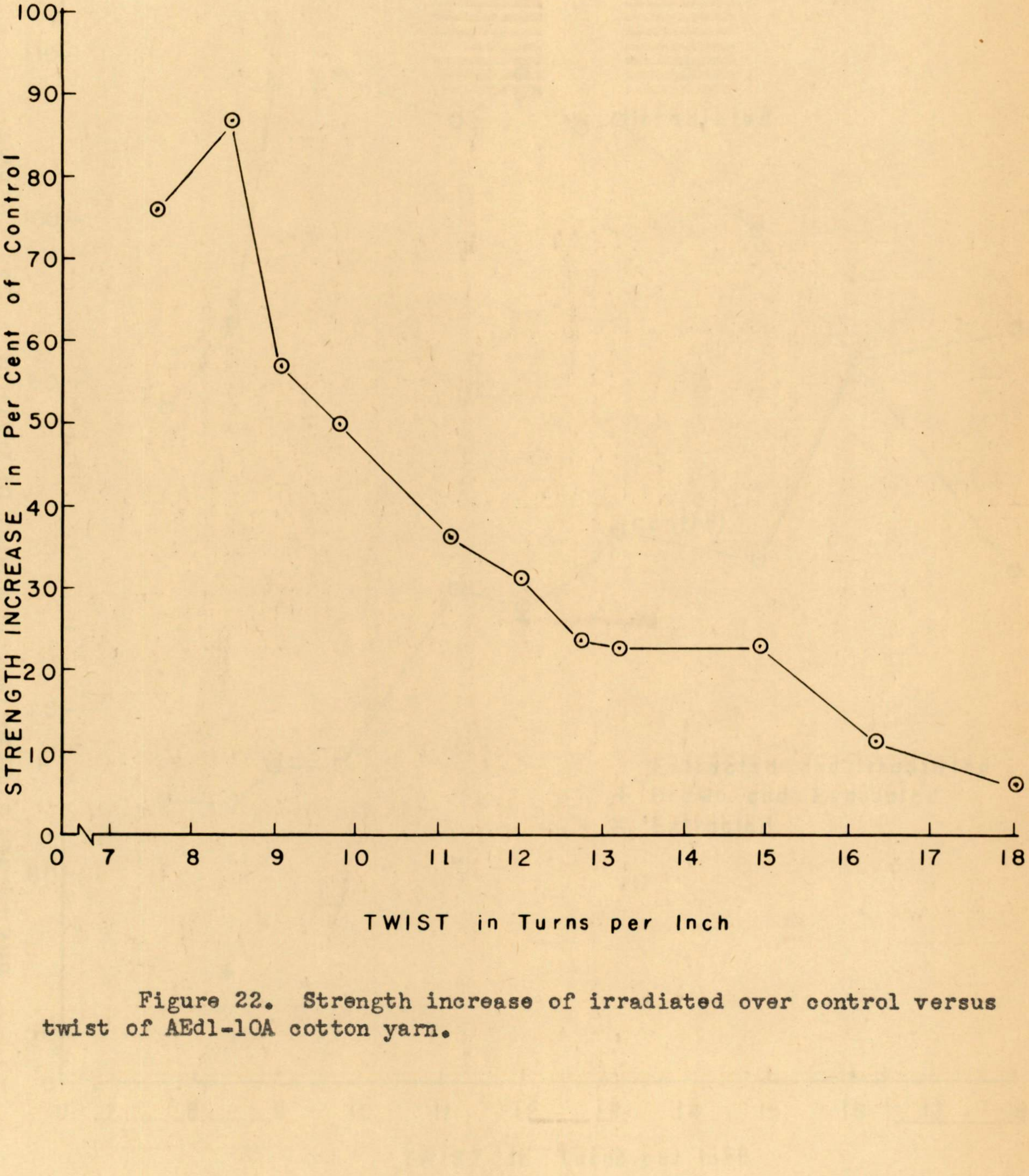


Figure 22. Strength increase of irradiated over control versus twist of AEd1-10A cotton yarn.

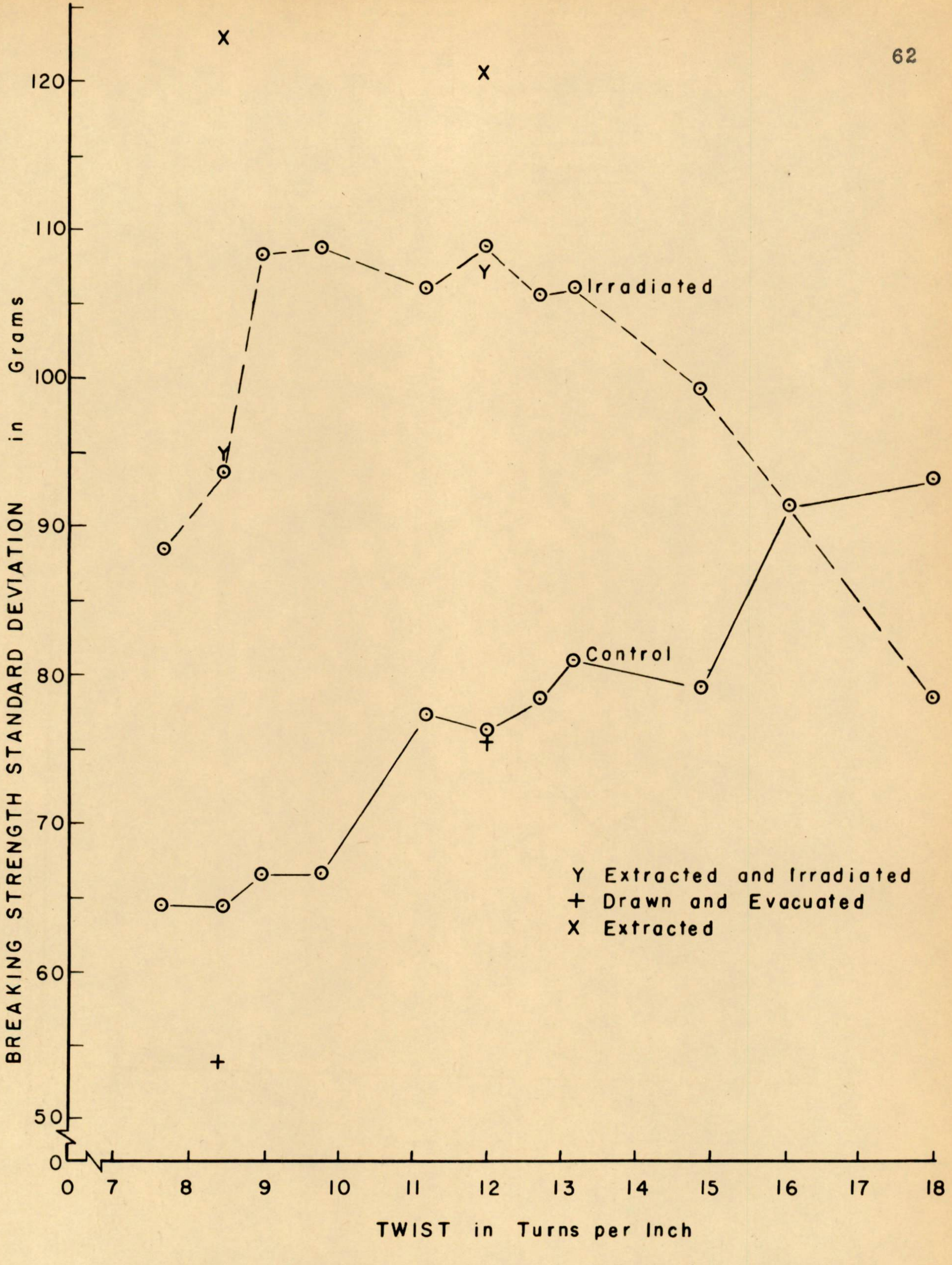


Figure 23. Breaking strength standard deviation versus twist for various treatments of AEd1-10A cotton yarn.

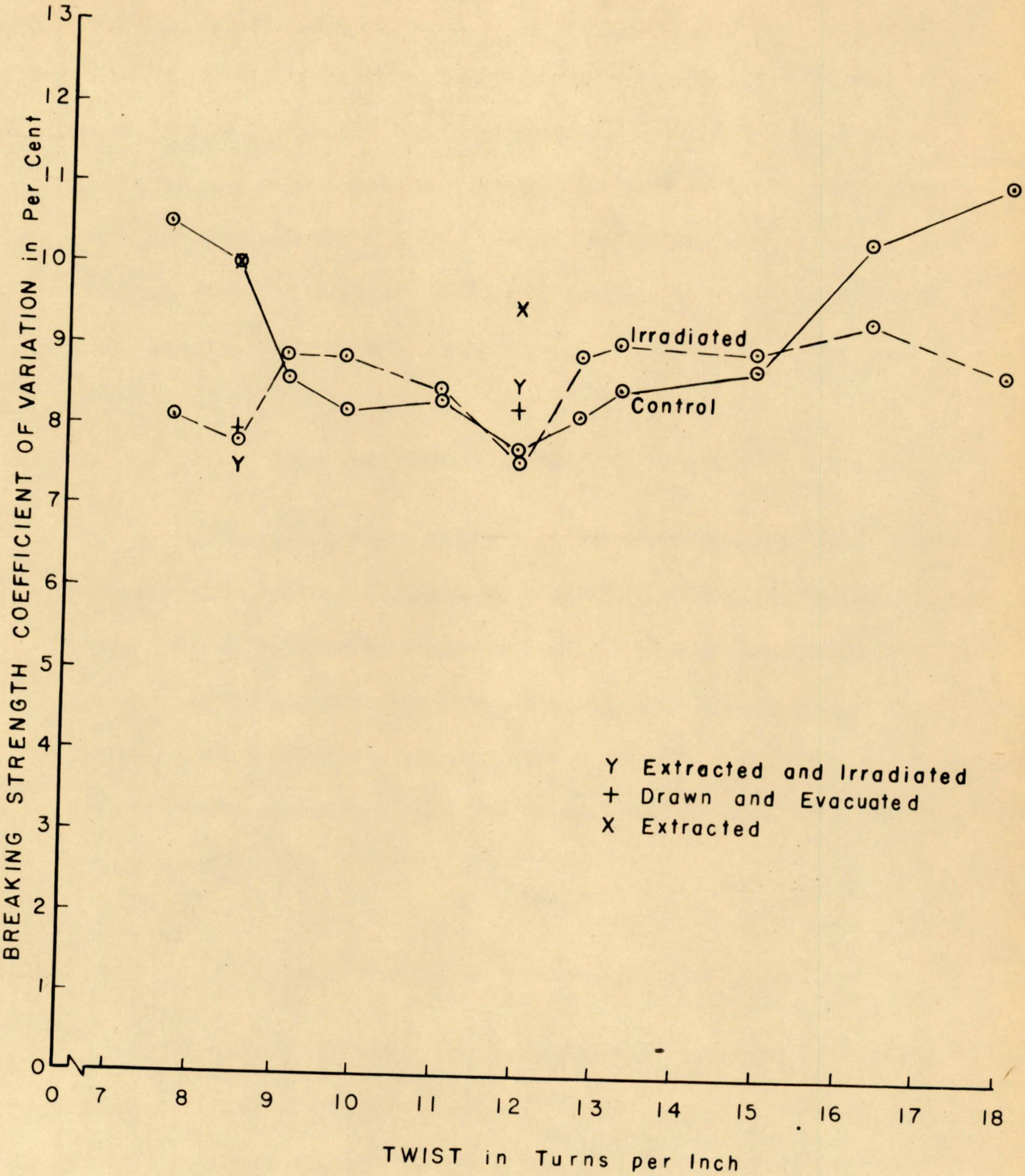


Figure 24. Breaking strength coefficient of variation versus twist for various treatments of AEd1-10A cotton yarn.

that the irradiated yarn breaking strength standard deviations vary uniformly with the means throughout the complete range of twists. Low means at the low twists and low means combined with high standard deviations at the high twists explain the pattern of the control curve. These curves indicate that the yarn tested broke with a ratio of breaking strength standard deviation to mean in a range similar to other studies of this type (9).

Breaking Strength Frequency Distributions

The frequency distributions illustrated in Appendix F show the variation in breaking strength of control, irradiated, extracted, and extracted and irradiated treatments at low and optimum twists. These figures, as copied from the Uster charts, show graphically that the variation of extracted yarn was greater than the variation of extracted and irradiated yarn, and that the control varied less than the irradiated yarn.

Mean Comparisons of Breaking Strengths

Comparison was made between treatments only and not between twist points of similar treatments. Comparison of irradiated and control stock on a point to point basis was unnecessary with strength increases such as they were.

The highest twist point had the smallest mean difference and approximately average mean standard deviation. By using "Student's" t test for mean difference it was shown for the 18.03 twist point that the mean breaking strength of irradiated yarn was significantly different and greater than the control. Probability level for this difference was 99.99 per cent using one hundred twenty degrees of freedom. This comparison is shown in Appendix G. Considering this, it can be concluded that the mean breaking strengths, irradiated compared to control, are different at each twist point as tested in this study.

In comparing the other treatments it was found that, statistically, each mean was different from any other at both the low and optimum twist check points at a probability level of 97.5 per cent or greater using one hundred twenty degrees of freedom. Due to the large sampling, the reversal of direction of mean differences at the two check points, the range of the individual breaking strength determinations and the variation of yarn linear density, realistically there is no difference in breaking strength of the irradiated, extracted, and extracted and irradiated samples of yarn as treated and tested in this study, or the control as compared with the drawn and evacuated treatment. The above applies to mean breaking strengths only.

Elongations

The mean yarn elongations at rupture are shown in Figure 25. Tests of irradiated yarn indicate uniform elongation throughout the complete range of twists. In breaking, the irradiated fibers did not appear to slip apart at any twist, but actually snapped. Elongation

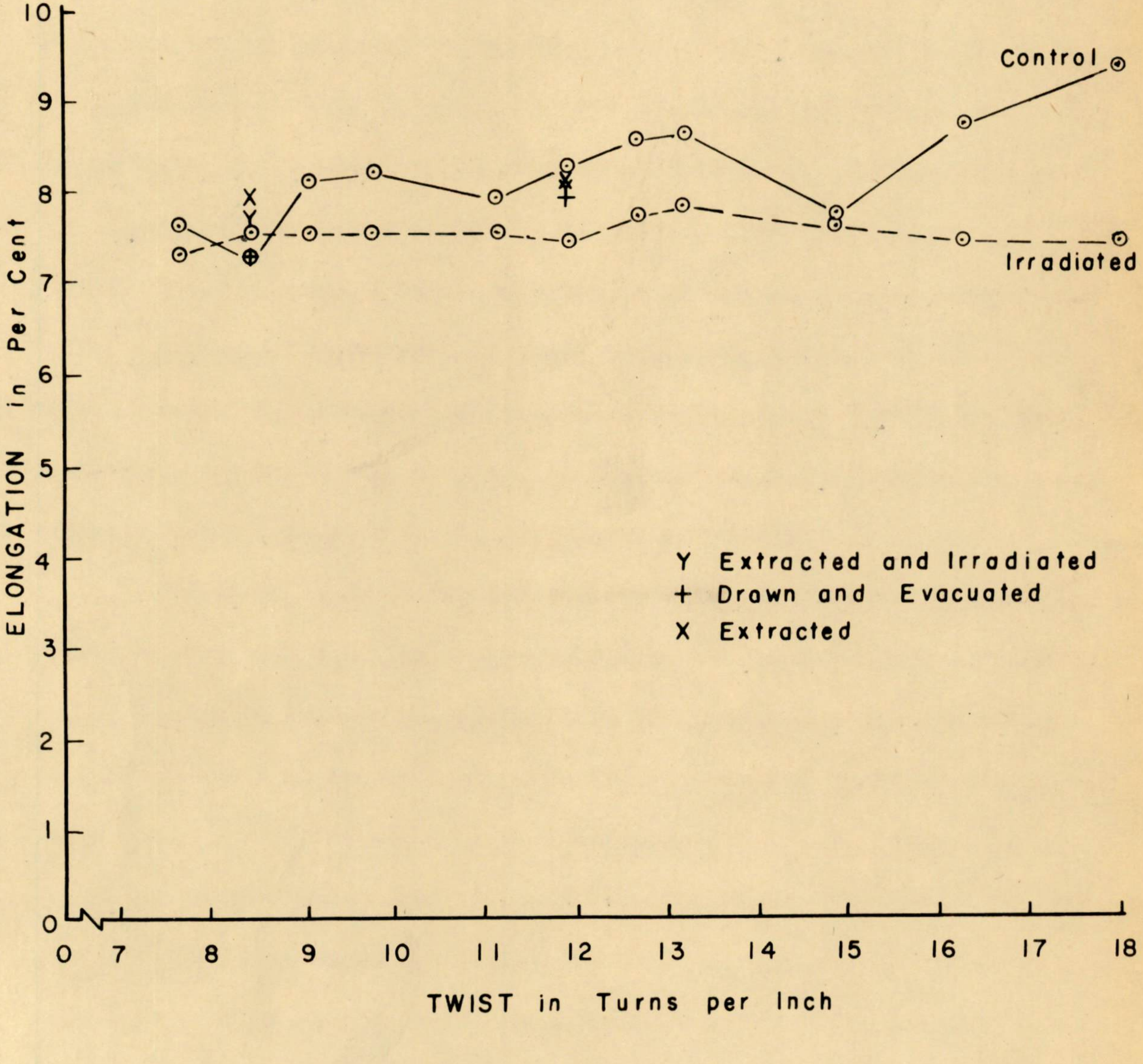


Figure 25. Elongation versus twist for various treatments of AEd1-10A cotton yarn.

of the irradiated yarn samples appeared to be a result of fiber elongation and tightening or squeezing of the fibers. It is thought that slippage, a factor in elongation of control yarn, had little or no part in elongation in the irradiated samples.

Over the range of twists the control curve appears to be more irregular than the irradiated. In the low points the fibers were not wound together tightly enough to prevent slippage. Some initial slippage was noticed in the mid-range of twists. The third point from the high end was wound rather tightly on the warp bobbin during spinning which could be a cause of the irregularity noticed there. The final two points were over-twisted to such an extent that kinks were sometimes formed in the samples. Elongation at these points included straightening the kinks along with the other factors.

Presented in Appendix H are plots of force applied in breaking tests versus time from initial application of force for low and optimum twist points of Deltapine-15 ten count yarn, broken on an Instron tester during the preliminary yarn studies that led to the research described in this thesis. The author takes liberty in presenting these plots without giving the complete background of them. They show exactly how yarn reacts with application of an increasing load. In the control plots curve in the rate of load lines indicates slippage between fibers. The irradiated plots show no indication of slippage between fibers during the breaking tests.

Elongation Standard Deviations

The elongation standard deviations, shown in Figure 26, indicated an irregular but steady increase with increasing twists. In the control curve, the irregular low points are attributed to fiber slippage, while the increased variation of the over-twisted points can be explained by kinking. The irradiated elongation standard deviations increase erratically, but regularly, with increasing twists. Variations from point to point are attributed to yarn variations resulting from spinning.

Elongation Coefficient of Variations

The coefficient of variations of elongation fell within the expected range with no unusually erratic points existing. These coefficients are shown graphically in Figure 27.

Moisture Contents

The moisture contents of the salvaged cotton yarns were determined for each particular treatment. The results are shown in Table V. The moisture contents of the control and the drawn and evacuated samples were similar to contents reported by Ward (27). The differences in irradiated and ethanol extracted stock or the similarity of irradiated to extracted and irradiated stock can not be explained. It is felt that the moisture contents are valid as reported.

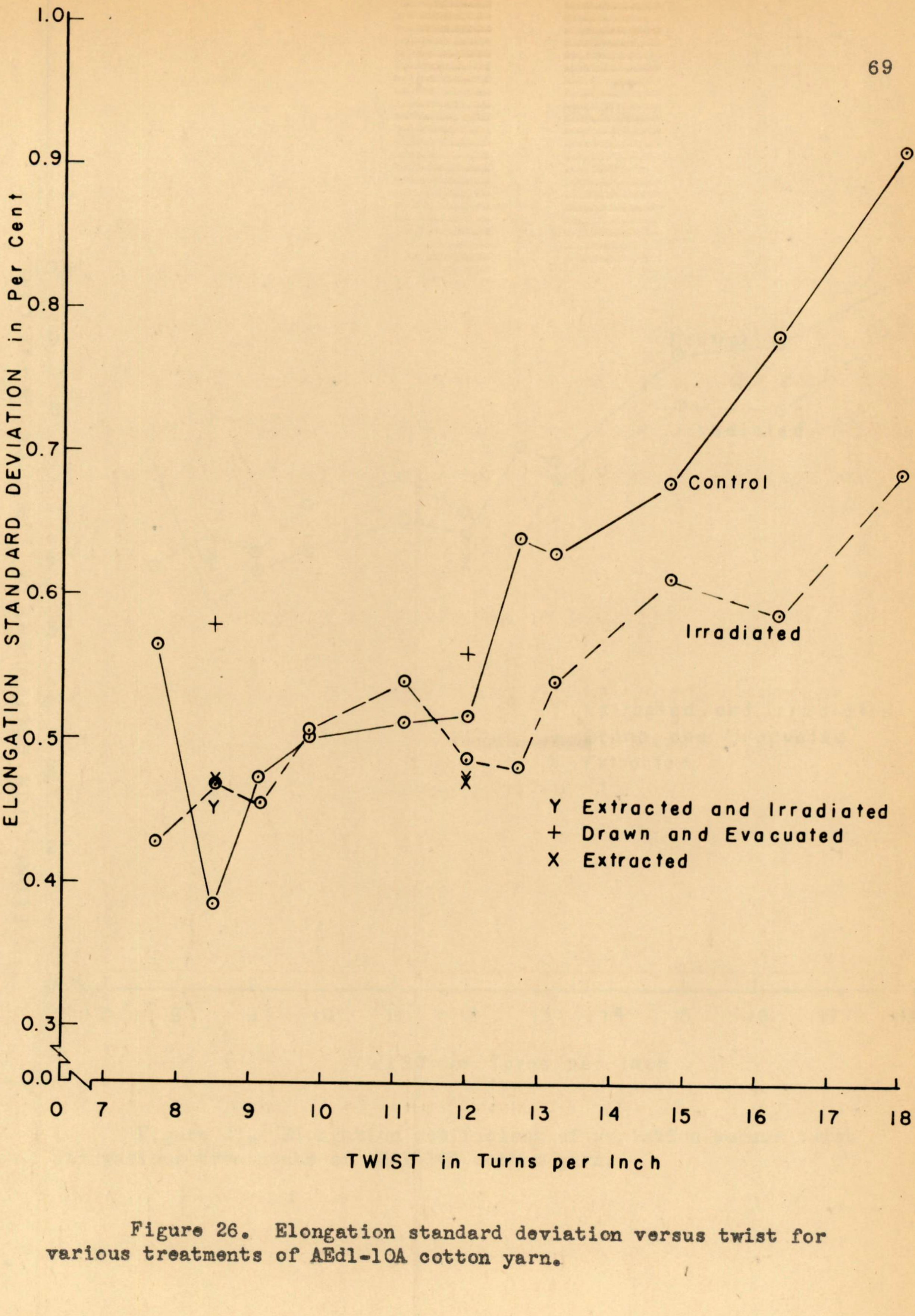


Figure 26. Elongation standard deviation versus twist for various treatments of AEd1-10A cotton yarn.

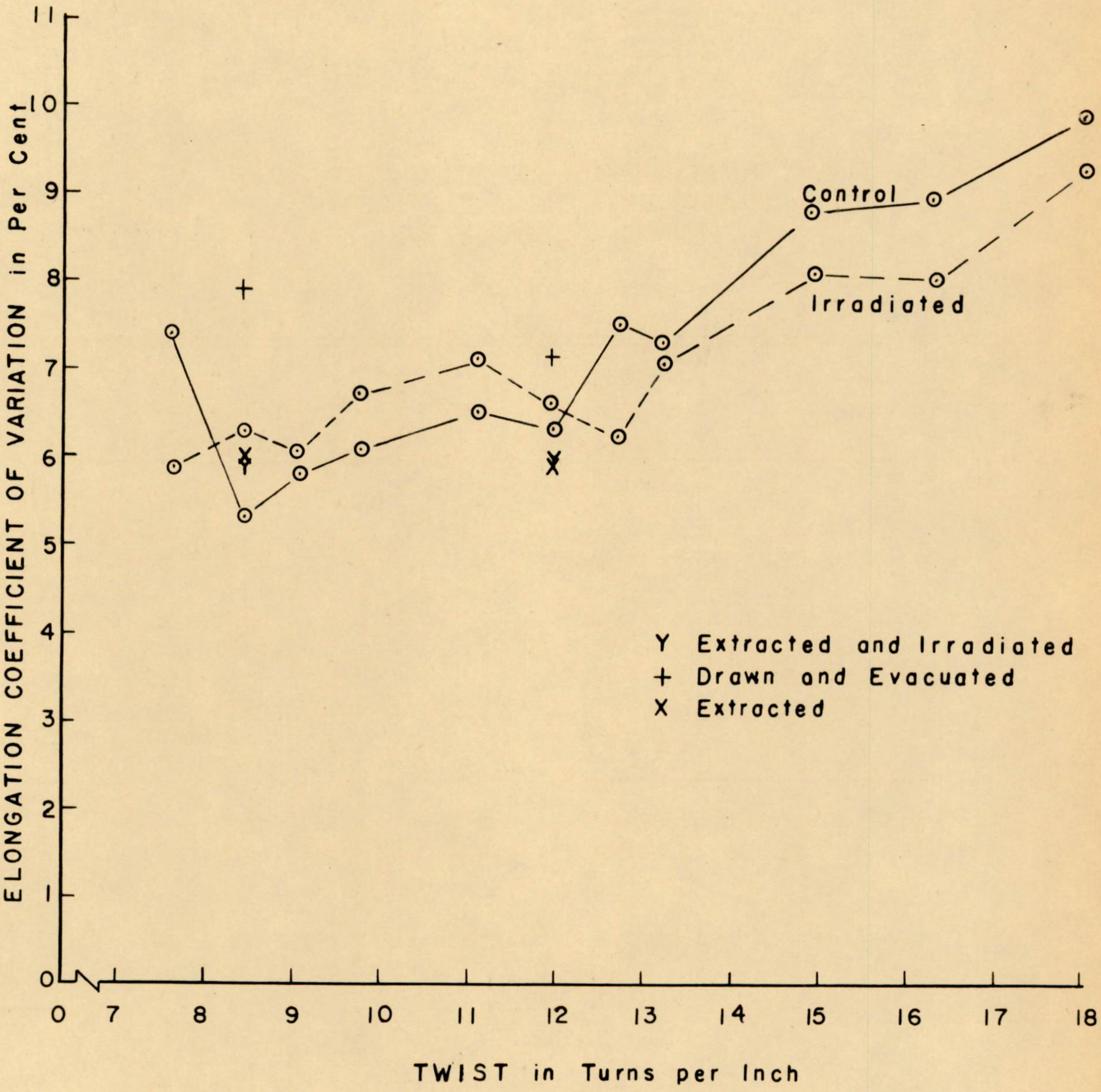


Figure 27. Elongation coefficient of variation versus twist for various treatments of AEd1-10A cotton yarn.

TABLE V

MOISTURE CONTENTS OF AEd1-10A COTTON YARN SAMPLES USED IN BREAKING STRENGTH AND ELONGATION TESTS

Method Of Treatment[a]	Twist In Turns/Inch	Dry Weight In Grams	Moisture Content In Per Cent
Control Sample 1	-	28.13	7.07
Control Sample 2	-	36.71	7.16
Irradiated Sample 1	-	49.85	6.82
Irradiated Sample 2	-	49.64	6.75
Ethanol Extracted	8.45	23.68	7.48
Ethanol Extracted	11.95	17.80	7.30
Ethanol Extracted & Irradiated	8.45	17.46	6.76
Ethanol Extracted & Irradiated	11.95	16.37	6.78
Drawn & Evacuated	-	35.08	7.07

[a] Cotton samples were at constant weight in an atmosphere of 65% relative humidity and 71°F temperature prior to removal of moisture by heating.

[b] Moisture content was derived on a dry weight basis.

Proposed Future Studies

Some future studies in irradiation of cotton with the plasma of an electrical discharge that might be made are:

1. Extended parameter check with longer times of irradiation.
2. Current density studies involving irradiation chamber sizes and shapes using the results presented in this thesis as measures of the effects produced.
3. Moisture content studies to show the effect of irradiation with plasma on moisture regain.
4. Breaking strength studies to show the effect of irradiation with plasma on yarn with moisture content at break as a variable.
5. Breaking strength studies to compare the effect of irradiation with plasma to kier boiling on low twist cotton yarn.
6. Wear and fatigue tests of irradiated yarn.
7. Development of a theoretical maximum strength for yarn using fiber qualities as predictors.
8. Various fabric tests of irradiated fabric and fabric made from irradiated yarn.
9. Power determinations throughout the irradiation system.
10. Separation of the components of the discharge in an effort to find just which or what combination are causing the effects noticed in this study.

CHAPTER VI

SUMMARY

Introduction

The purpose of the study described in this thesis was to show some of the effects of irradiation with the plasma of an electrical discharge through air at low pressure on cotton yarn. Appearance, uniformity, moisture content, strength, elongation and variation in the frequency distribution of strength and elongation were the yarn qualities used to measure the effects.

In recent years many studies of the effects of gamma, neutron and beta irradiation on cotton have been made. In general cotton yarns have been degraded by the irradiations although there have been some trend indications of beneficial results at low treatment levels. The study described in this thesis was of the effects on cotton of low energy plasma irradiation.

Effects of the Irradiation on Yarn Qualities

The general appearance of the yarn was altered by the irradiation treatment. The texture of the yarn was changed from a soft, smooth feel of the control to a harsh, rough feel of the irradiated. Affinity for water was increased by irradiation both on control and hot ethanol extracted yarn. Linear density, used as an indicator of uniformity, varied from twist to twist, but this variation is not attributed to the irradiation. Equilibrium moisture content of the yarn was affected by the irradiation treatment.

Yarn breaking strength, or average force necessary for rupture, was increased by irradiation. This increase, irradiated over control, was related to twist in the yarn with low twists having the greatest strength increase. The maximum increase was 87 per cent at 8.45 turns per inch, with the yarn being strengthened 31 per cent at the optimum control twist of 11.95 turns per inch. Hot ethanol extracted yarn was not stronger than the irradiated and irradiation did not strengthen the extracted samples. Manipulations similar to those used in the process of irradiation along with evacuation did not affect the yarn strength.

There was more variation in the frequency distribution of breaking strengths of the irradiated samples than in the control. Variation in the extracted samples was greater than the irradiated. Irradiation after extraction reduced the variation of the extracted samples to approximately the same as the irradiated only treatment.

Elongation of the irradiated samples, from application of force to rupture, was more uniform in magnitude over a range of twists than the control. Elongation variation of the irradiated treatments tended to be less than the control.

In general the effects of irradiation with plasma on cotton yarn as treated and tested were beneficial, and trends noticed in preliminary work were substantiated. The results of this study can be used as measures of effects produced in future irradiation studies that may be made to determine what caused the noticed effects.

Possible Causes of the Noticed Effects

The micrographs shown in "Effects of Exposing Cotton to Gas Plasmas, A Progress Report" (23) give some indication as to the severity of the irradiation along with a visual description of the surface of the cotton fiber. Mentioned in this report is the fact that the waxes on the individual fibers were degraded as a result of the same type of irradiation used in the study described in this thesis. These two facts indicate changes in cotton fiber surface characteristics that might result in an increased effective coefficient of friction at contact points between fibers in the yarn.

Bundle analysis indicated no change in fiber tenacity at the one-eighth inch gage length (24). The breaking strength standard deviation of hot ethanol extracted yarn was decreased by the irradiation treatment indicating that something other than the waxes were affected. One theory as to what is causing the effects is that electron bombardment releases enough heat both to degrade the waxes and to roughen the primary wall surface by rapid moisture vaporization.

Further studies related to the effects of plasma irradiation on agricultural products are being made by Farm Electrification Research Branch, Agricultural Engineering Research Division, ARS, USDA, at Knoxville, Tennessee under the supervision of R. B. Stone, Jr., Agricultural Engineer in charge.

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APPENDIX A

NUMBER OF BREAKS

The number of breaks required when a mean difference of ± 25 grams was desired to be significant at the 0.05 probability level was calculated in this manner:

$$r \geq 2(\sigma/\delta)^2(t_1 + t_2)^2,$$

where:

δ = the true difference desired to detect,

σ = the true standard deviation,

t_1 = "Student's" t at 0.05 P,

t_2 = t corresponding to 2(1-P),

r = number of breaks and

P = probability level,

therefore:

$$r \geq 2(103.6/25)^2(2.0 + 1.71)^2$$

$r \geq 471$, that is, if the assumption is made that 103.6 grams, the calculated standard deviation from one hundred breaks of DPL #15 yarn, is the true standard deviation, at least 471 individual breaks would be required for a ± 25 gram difference in means to be significant at the 0.05 probability level.

APPENDIX B

STRENGTH DETERMINATIONS AT THE OPTIMUM POINT FOR THE CONTROL

Dial

Calculations for mean strength determined from the dials of the Uster were as follows:

$$\overline{P} = 10\ Sp/n + k$$

where:

$\overline{P}$ = the average breaking load in per cent of two thousand grams,

Sp = 1889, the reading of the breaking strength counter at the end of the test,

n = 400, the number of breaks and

k = 2.3, a machine constant, giving

$$\overline{P} = 10(1889)/400 + 2.3,$$

$$\overline{P} = 49.525 \text{ per cent of 2000 grams},$$

$$\overline{P} = 990.50 \text{ grams}.$$

Chart

In reading the individual point indications from the ruled paper, $\overline{P}$ varied from 37 to 60 per cent, with the sum of the P's times the frequency of occurrence equal to 19,652 per cent. The sum of the frequencies times the P^2s equalled 971,337,

Therefore: $\overline{P} = \frac{19{,}652(2000)}{400} = 982.60$ grams.

The standard deviation,

$$s = \sqrt{\frac{\sum fP^2 - (\sum fP)^2/n}{n - 1}}$$

$$s = \sqrt{\frac{971,337 - (19,652)^2/400}{399}},$$

$$s = \pm 3.82382 \text{ in per cent of } 2000,$$

Therefore,

$$s = \pm 3.82382(2000)/100$$

$$s = \pm 76.4764 \text{ grams.}$$

The coefficient of variation is the standard deviation divided by the mean, or

$$Cv = (s/\overline{P})100,$$

$$Cv = (76.4764/982.60)100,$$

$$Cv = 7.78 \text{ per cent.}$$

APPENDIX C

ELONGATION DETERMINATIONS AT THE OPTIMUM POINT FOR THE CONTROL

Dial

Calculations for elongation determined from the dials of the Uster were as follows:

$$\bar{E} = 10\,Se/n + e,$$

where:

$\bar{E}$ = the arithmetic mean of all elongations in per cent,

Se = 319, the reading of the elongation counter at the end of the test,

n = 400, the number of breaks carried out and

e = 0.1, a machine constant, giving

$$\bar{E} = 10(319)/400 + 0.1,$$

$$\bar{E} = 8.075 \text{ per cent.}$$

Chart

In reading the individual point indications from the ruled paper, $\bar{E}$ varied from 6.8 to 9.6 per cent, with the sum of the E's times the frequency of occurrence equal to 3,301.4 per cent. The sum of the frequencies times the E^2s equalled 13,677.86, therefore

$$\bar{E} = 3{,}301.4/400 = 8.254 \text{ per cent.}$$

The standard deviation,

$$s = \sqrt{\frac{\Sigma fE^2 - (\Sigma fE)^2/n}{399}},$$

$$s = \sqrt{\frac{13,677.86 - (3,301.4)^2/400}{399}}$$

$s = \pm 0.51934$ per cent.

The coefficient of variation is the standard deviation divided by the mean, or

$Cv = (s/\overline{E})100$

$Cv = (0.51934/8.254)100$

$Cv = 6.29$ per cent.

APPENDIX D

LINEAR DENSITY DETERMINATION

Tex and count, measures of linear density were determined in the following manner:

$$\text{Tex} = 1000\, W/nL,$$

where:

Tex = the weight in grams of 1000 meters of yarn,

W = the weight of the salvage in grams,

n = the number of breaks and

L = 0.707, the length of yarn required for each test in meters,

thus, when $W = 17.3302$ and $n = 400$,

$$\text{Tex} = 1000(17.3302)/400(0.707),$$

$$\text{Tex} = 61.28 \text{ grams}/1000 \text{ meters},$$

and as count $= 590.5/\text{Tex}$:

$$\text{Count} = 590.5/61.28,$$

Count = 9.64, the number of 840 yard hanks in a pound where 590.5 is a conversion constant.

APPENDIX E

TABLE VI

BREAKING STRENGTH DATA FROM SINGLE STRAND BREAKS OF IRRADIATED AND CONTROL AEd1-10A COTTON YARN BROKEN ON A USTER TESTER

Twist In Turns/Inch	Breaking Strength In Grams[a] Control Chart	 Dial	 Irradiated Chart	 Dial	Strength Increase In Per Cent
7.66	620	630	1090	1097	76
8.45	645	648	1207	1216	87
9.07	774	775	1218	1224	57
9.80	814	821	1218	1223	50
11.14	925	927	1259	1263	36
11.95	983	991	1287	1286	31
12.69	953	955	1175	1183	23
13.17	954	955	1169	1174	23
14.89	895	900	1101	1103	23
16.31	880	877	969	967	10
18.03	840	846	890	884	6

[a] Each value is an average of 400 breaks.

TABLE VII

BREAKING STRENGTH DATA FROM SINGLE STRAND BREAKS OF AEd1-10A COTTON YARN TREATED BY VARIOUS METHODS AND BROKEN ON A USTER TESTER

Method Of Treatment	Twist In Turns/Inch	Breaking Strength In Grams[a]	
		Chart	Dial
Control	8.45	645	648
Irradiated	8.45	1208	1216
Drawn & Evacuated	8.45	686	694
Ethanol Extracted	8.45	1228	1233
Ethanol Extracted & Irradiated	8.45	1258	1266
Control	11.95	983	991
Irradiated	11.95	1287	1286
Drawn & Evacuated	11.95	927	934
Ethanol Extracted	11.95	1264	1272
Ethanol Extracted & Irradiated	11.95	1243	1249

[a] Each value is an average of 400 breaks.

TABLE VIII

BREAKING STRENGTH STATISTICAL DATA FROM SINGLE STRAND BREAKS OF IRRADIATED AND CONTROL AEd1-10A COTTON YARN BROKEN ON A USTER TESTER

Twist Turns/Inch	Breaking Strength Standard Deviations In Grams[a]				Breaking Strength Coefficient Of Variations In Per Cent[a]	
	Control		Irradiated			
	Calculated[b]	Indicated[c]	Calculated[b]	Indicated[c]	Control	Irradiated
7.66	64.858	61.2	88.644	88.2	10.47	8.13
8.45	64.449	64.0	93.719	92.0	9.99	7.76
9.07	66.824	65.4	108.378	106.0	8.63	8.90
9.80	66.599	68.8	108.094	109.0	8.19	8.88
11.14	77.460	79.4	106.006	106.6	8.37	8.42
11.95	76.476	78.8	98.098	101.6	7.78	7.62
12.69	78.264	79.6	105.605	101.6	8.21	8.98
13.17	81.015	82.6	106.006	103.8	8.49	9.07
14.89	79.185	78.4	99.359	100.8	8.85	9.03
16.31	91.363	84.6	91.543	93.2	10.38	9.45
18.03	93.262	92.8	78.450	82.2	11.10	8.81

[a] Each value was derived from 400 break observations.

[b] Calculated from individual breaking strength recordings on chart from the Uster.

[c] Indicated from Uster frequency distribution charts.

TABLE IX

BREAKING STRENGTH STATISTICAL DATA
FROM SINGLE STRAND BREAKS OF AEd1-10A COTTON YARN
TREATED BY VARIOUS METHODS AND BROKEN ON A USTER TESTER

Method Of Treatment	Twist In Turns/Inch	Breaking Strength Standard Deviation In Grams[a]		Breaking Strength Coefficient Of Variation In Per Cent[a]
		Calculated[b]	Indicated[c]	
Control	8.45	64.449	64.0	9.99
Irradiated	8.45	93.719	92.0	7.76
Drawn & Evacuated	8.45	54.081	61.6	7.89
Extracted	8.45	122.968	119.2	10.02
Extracted & Irradiated	8.45	94.978	96.4	7.55
Control	11.95	76.476	78.8	7.78
Irradiated	11.95	98.098	101.6	7.62
Drawn & Evacuated	11.95	76.457	68.4	8.25
Extracted	11.95	120.435	112.8	9.53
Extracted & Irradiated	11.95	106.778	106.0	8.59

[a] Each value was derived from 400 break observations.

[b] Calculated from individual breaking strength recordings on chart from the Uster.

[c] Indicated from Uster frequency distribution charts.

TABLE X

ELONGATION DATA FROM SINGLE STRAND BREAKS OF IRRADIATED AND CONTROL AEd1-10A COTTON YARN BROKEN ON A USTER TESTER

Twist In Turns/Inch	Elongation In Per Cent[a]			
	Control		Irradiated	
	Chart	Dial	Chart	Dial
7.66	7.62	7.50	7.27	7.13
8.45	7.23	7.15	7.50	7.40
9.07	8.14	8.00	7.50	7.40
9.80	8.19	8.10	7.48	7.46
11.14	7.85	7.78	7.51	7.40
11.95	8.25	8.08	7.43	7.38
12.69	8.54	8.38	7.71	7.58
13.17	8.66	8.55	7.68	7.55
14.89	7.70	7.60	7.62	7.58
16.31	8.73	8.63	7.36	7.20
18.03	9.31	9.13	7.43	7.35

[a] Each value is an average of 400 breaks.

TABLE XI

ELONGATION STATISTICAL DATA FROM SINGLE STRAND BREAKS OF IRRADIATED AND CONTROL AEd1-10A COTTON YARN BROKEN ON A USTER TESTER

Twist In Turns/Inch	Elongation Standard Deviations In Per Cent[a]		Elongation Coefficient Of Variations In Per Cent[a]	
	Control	Irradiated	Control	Irradiated
7.66	0.564	0.429	7.40	5.91
8.45	0.383	0.470	5.30	6.26
9.07	0.470	0.454	5.82	6.06
9.80	0.500	0.503	6.11	6.72
11.14	0.511	0.530	6.51	7.06
11.95	0.519	0.488	6.29	6.57
12.69	0.641	0.480	7.51	6.23
13.17	0.633	0.543	7.32	7.07
14.89	0.678	0.614	8.80	8.05
16.31	0.778	0.588	8.91	7.99
18.03	0.908	0.687	9.76	9.25

[a] Each value was derived from 400 break observations.

TABLE XII

ELONGATION AND ELONGATION STATISTICAL DATA FROM SINGLE STRAND BREAKS OF AEd1-10A COTTON YARN TREATED BY VARIOUS METHODS AND BROKEN ON A USTER TESTER

Method Of Treatment	Twist In Turns/Inch	Elongation In Per Cent[a]		Elongation Standard Deviations In Per Cent[b]	Elongation Coefficient Of Variations In Per Cent[b]
		Chart	Dial		
Control	8.45	7.23	7.15	0.383	5.30
Irradiated	8.45	7.50	7.40	0.480	6.70
Drawn & Evacuated	8.45	7.22	7.15	0.572	7.92
Ethanol Extracted	8.45	7.86	7.80	0.470	5.98
Ethanol Extracted & Irradiated	8.45	7.61	7.53	0.452	5.94
Control	11.95	8.25	8.08	0.519	6.29
Irradiated	11.95	7.43	7.38	0.488	6.57
Drawn & Evacuated	11.95	7.91	8.03	0.565	7.14
Ethanol Extracted	11.95	8.07	8.00	0.474	5.87
Ethanol Extracted & Irradiated	11.95	7.94	7.85	0.475	5.98

[a] Each value is an average of 400 breaks.

[b] Each value was derived from 400 break observations.

APPENDIX F

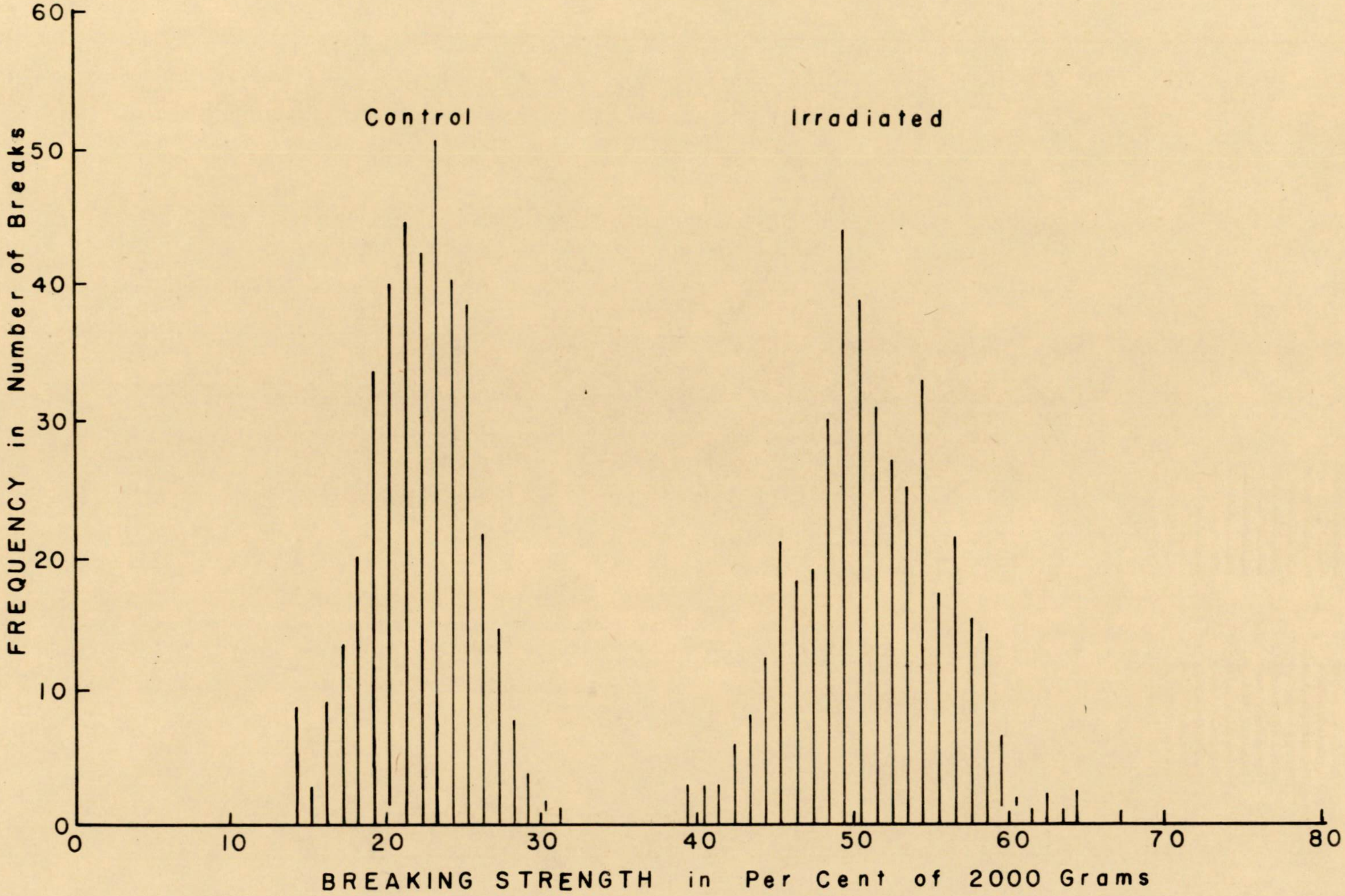

Figure 28. Frequency versus breaking strength of control and irradiated AEd1-10A cotton yarn at 8.45 turns per inch.

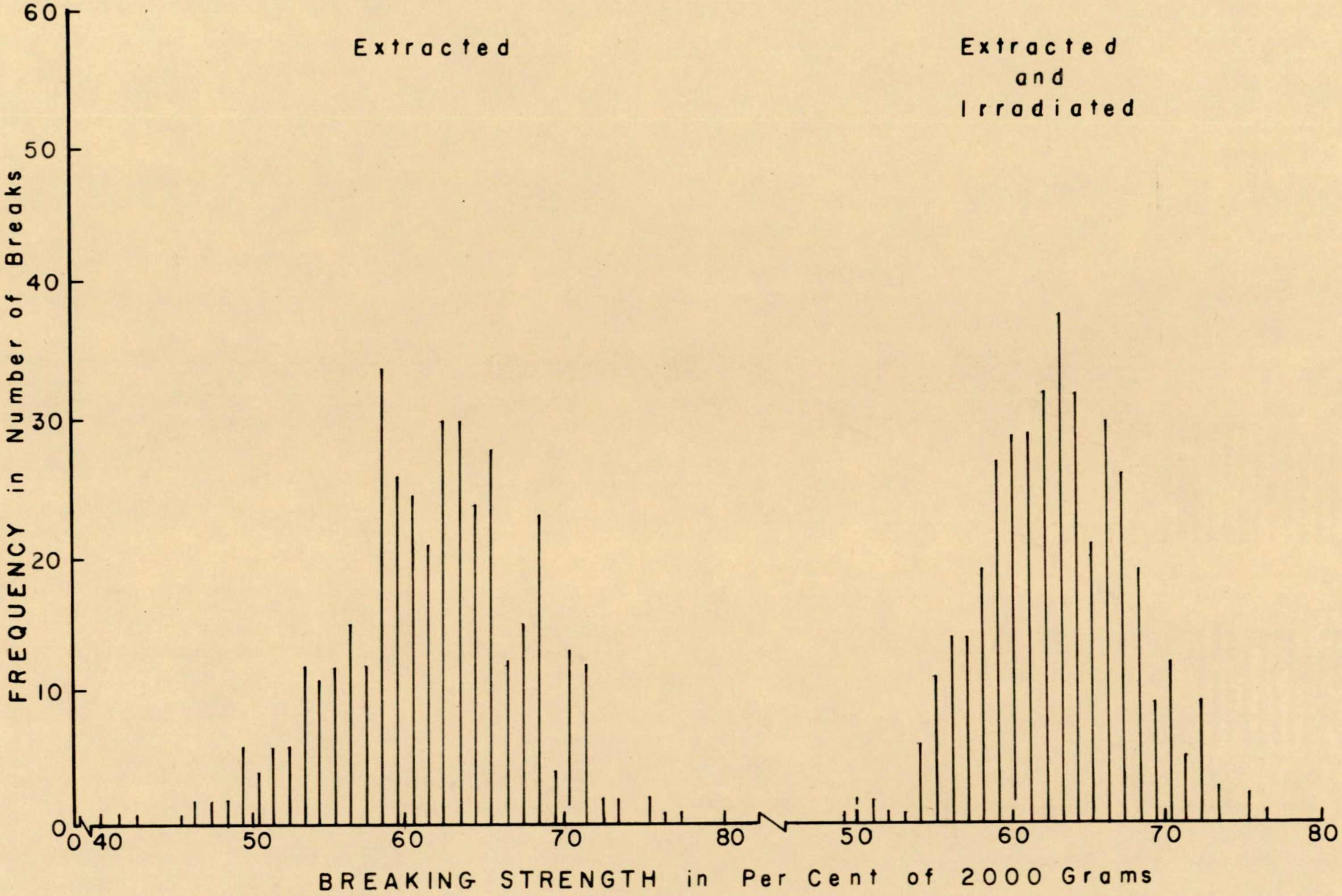

Figure 29. Frequency versus breaking strength of extracted and extracted-and-irradiated AEd1-10A cotton yarn at 8.45 turns per inch.

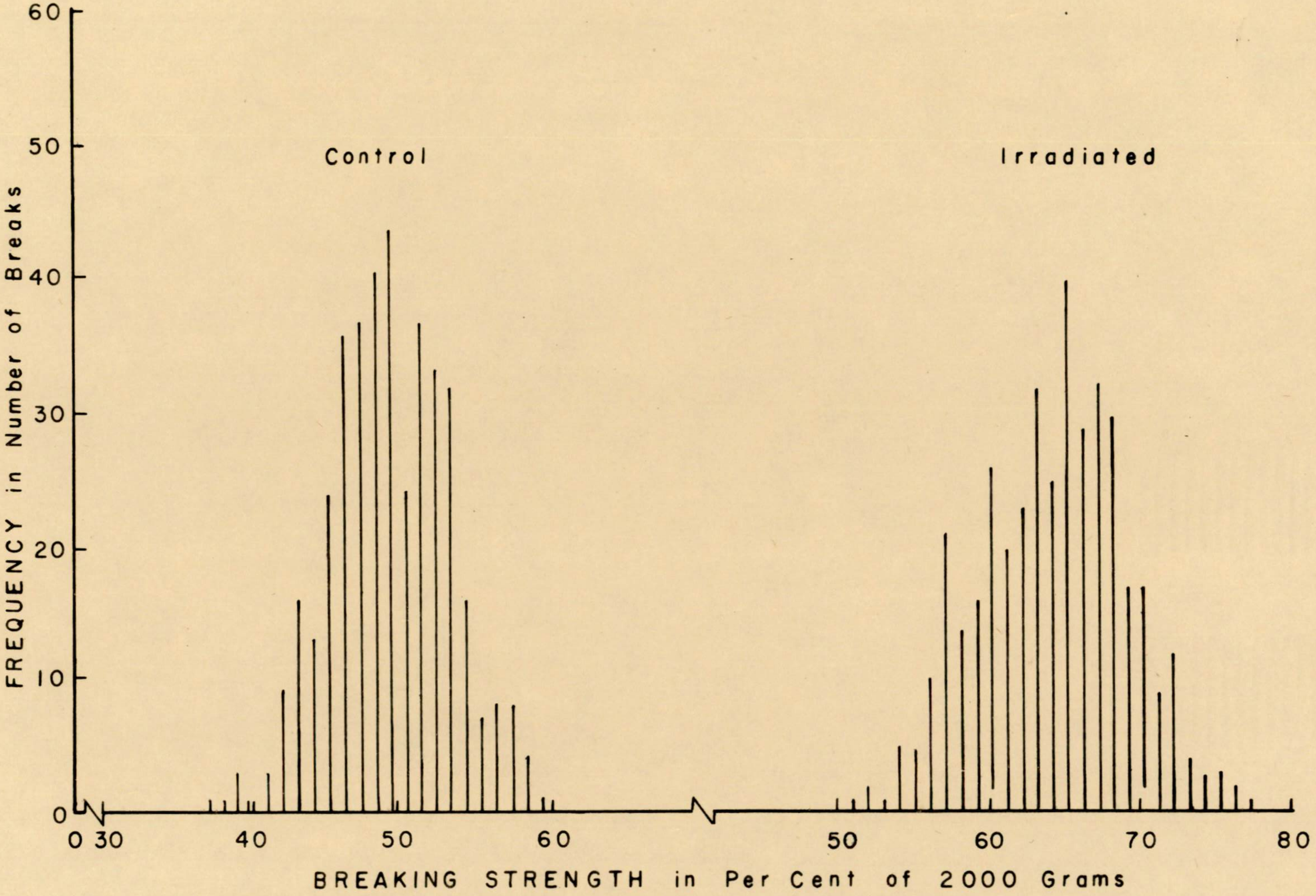

Figure 30. Frequency versus breaking strength of control and irradiated AEd1-10A cotton yarn at 11.95 turns per inch.

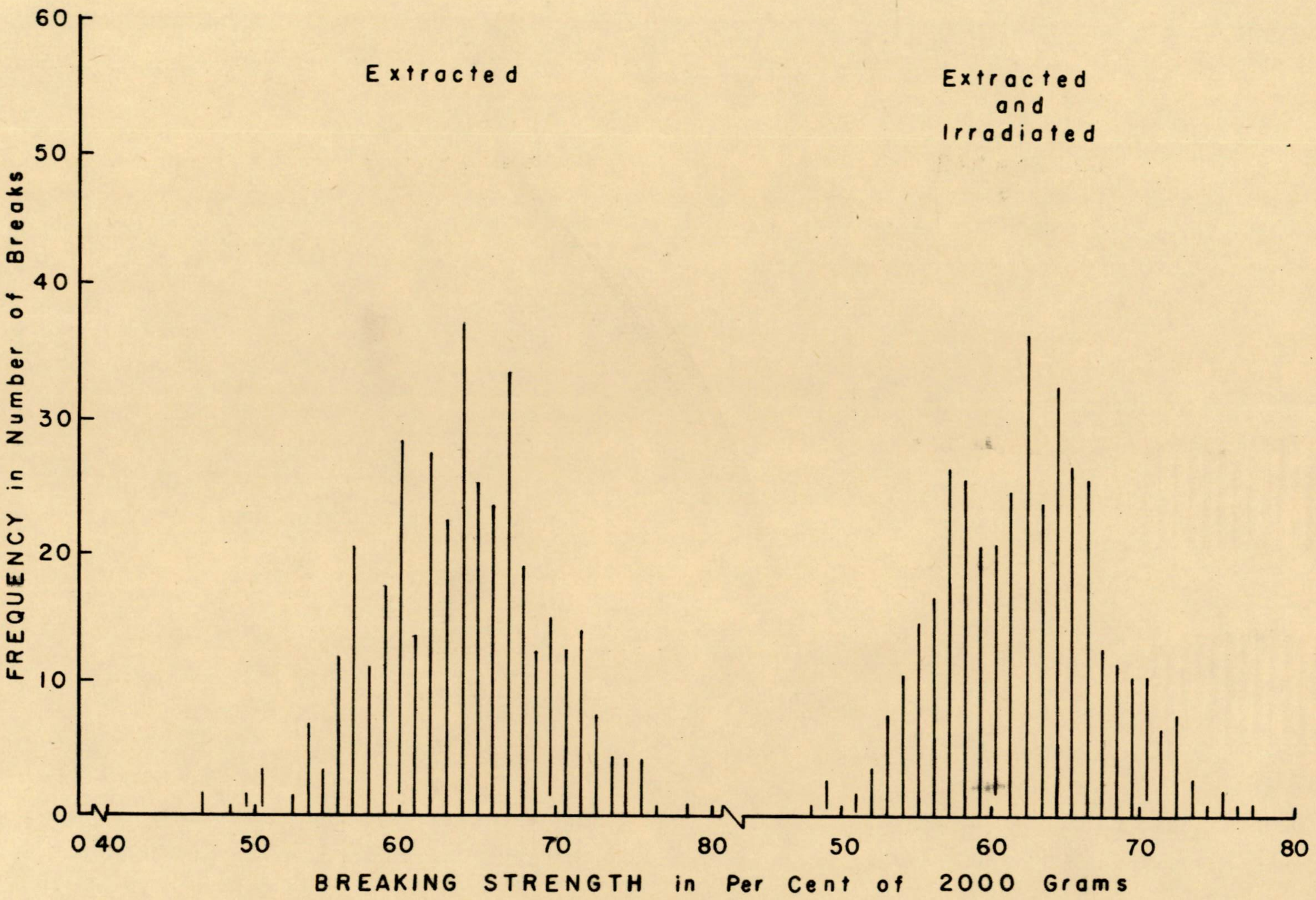

Figure 31. Frequency versus breaking strength of extracted and extracted-and-irradiated AEd1-10A cotton yarn at 11.95 turns per inch.

APPENDIX G

t TEST FOR MEAN DIFFERENCE

The following procedure was used in the comparison of means:

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - (U_1 - U_2)}{s_{x_1 - x_2}},$$

with the hypothesis $U_1 - U_2 = 0$ indicating no difference in the means,

$$t \text{ becomes } \frac{\bar{X}_1 - \bar{X}_2}{s_{\bar{x}_1 - \bar{x}_2}}$$

where,

$\bar{X}_1$ = the mean of one sample,

$\bar{X}_2$ = the mean of the other sample and

$$s_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{\Sigma x_1^2 + \Sigma x_2^2}{n(n-1)}}$$

with Σx^2 = the sum of the squares of X_1 and X_2 respectively,

therefore:

$$t = (\bar{X}_1 - \bar{X}_2)\sqrt{\frac{n(n-1)}{\text{Pooled } \Sigma x^2}}$$

at the highest twist, the pooled Σx^2 = 6139 plus 8676, with $n = 400$ and a mean difference of 50.10 grams, so

$$t = 50.10 \sqrt{\frac{400(400-1)}{6139 + 8676}}$$

$t = \pm 8.2219$ which is significant to void the null hypothesis at the 99.99 probability level indicating a real difference in means.

APPENDIX H

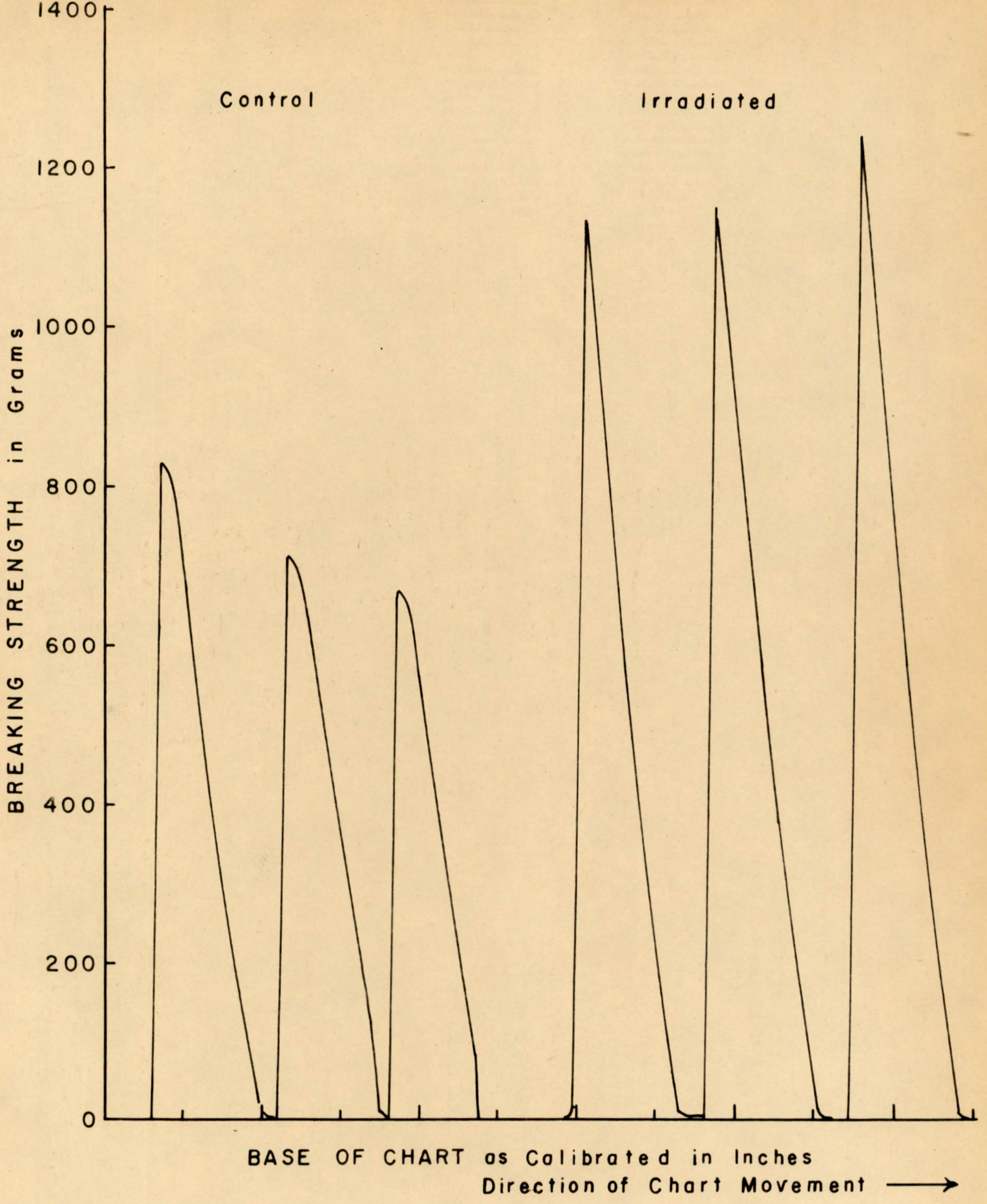

Figure 32. Breaking strength versus base of Instron chart showing low twist control and irradiated yarns reaction to loading.

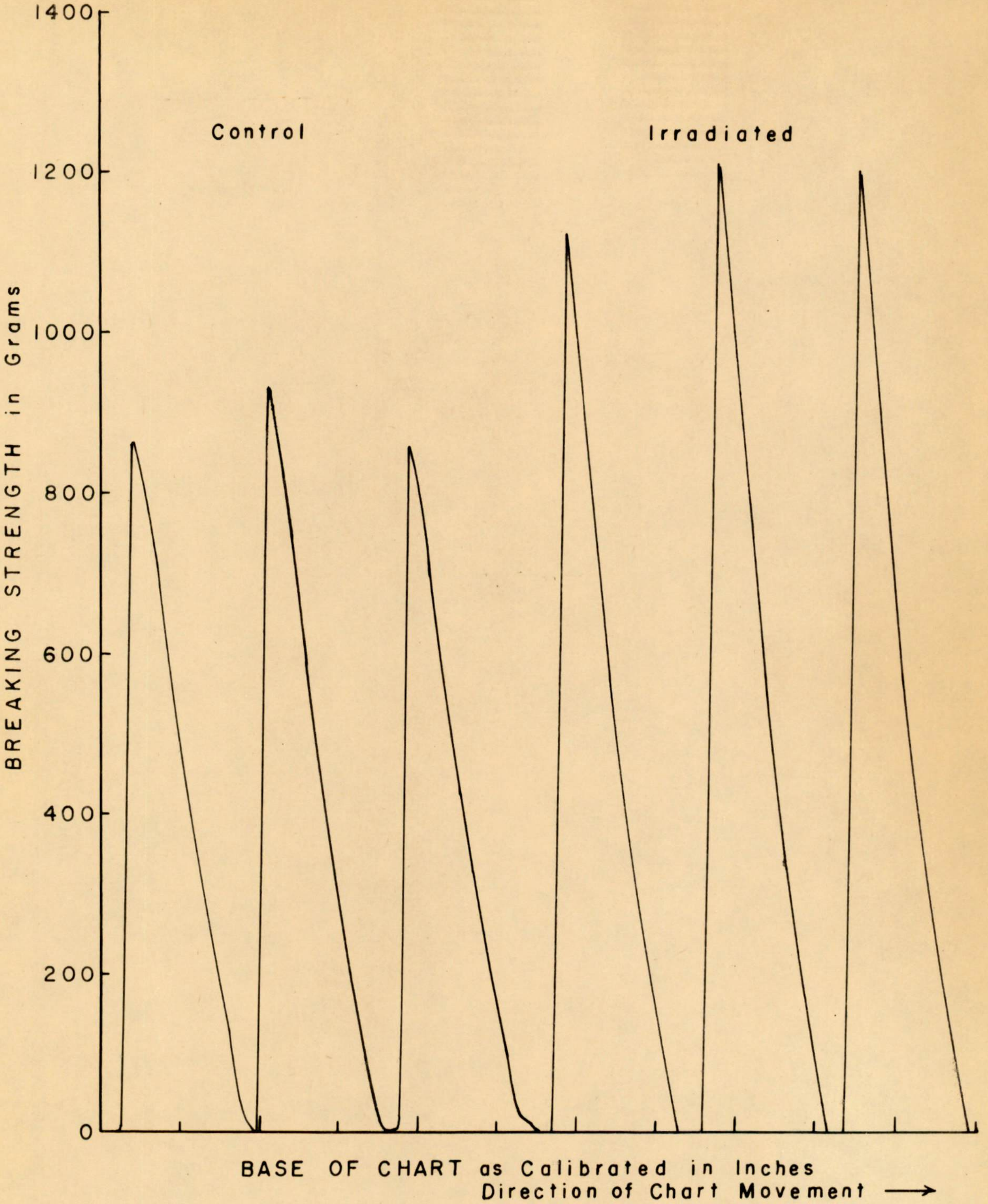

Figure 33. Breaking strength versus base of Instron chart showing optimum twist control and irradiated yarns reaction to loading.