ELECTROPHOTOGRAPHIC DEVELOPING TECHNIQUES
AS APPLIED TO THE ELECTROGRAPH
RECORDING OSCILLOGRAPH

By

JOHN CHARLES WESTERVELT

Bachelor of Science

University of Oklahoma

Norman, Oklahoma

1950

Submitted to the faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1960

ELECTROPHOTOGRAPHIC DEVELOPING TECHNIQUES

AS APPLIED TO THE ELECTROGRAPH

RECORDING OSCILLOGRAPH

Thesis Approved:

Herbert L. Jones
Thesis Adviser

Chas. F. Cameron

[signature]
Dean of the Graduate School

PREFACE

There has long been a desire on the part of people using recording oscillographs to do away with the wet chemical developing of the record. A dry photographic process was developed by Haloid-XeroX, Inc. and is known as xerography. The photosensitive medium here is a selenium plate. Later research by the Radio Corporation of America produced Electrofax paper which possesses photoconductive properties similar to selenium. Century Electronics and Instruments, Inc. took on the task of building a recording oscillograph (the type using light-beam galvanometers) that would use Electrofax paper. I was assigned the portion of the total oscillograph that is known as the developer. The developer is a unit that applies toner (charged plastic type particles) to the latent electrostatic image. Out of the developer then comes the visible recording. The first developers delivered with Century's Electrograph were of magnetic type using iron powder and toner. Difficulties with iron powder in the magnetic assembly of the light-beam galvanometers prompted additional research. This research then produced the fur developer.

I should like to express appreciation to Haloid-XeroX, Inc. and R.C.A. for help both from publications and in conference between Century Electronics and Instruments, Inc. and these companies. Century Electronics and Instruments, Inc. made possible this research. I should like to thank, in particular, R. A. Broding, J. D. Schroeder, C. O. Vogt, and J. N. Hilderbrand, who were active in the engineering design of the Electrograph.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

There are a number of techniques for recording analog information. This analog information is usually in the form of a current or voltage. One family of recorders uses pen and ink for direct recording. Another family of recorders uses light-beam galvanometers and photographic paper. A recorder that would combine the advantages of the direct-writing pen and ink recorder with the multi-trace and high sensitivity advantages of the light-beam galvanometer recorder would be desirable.

A dry photographic process based on physical and electrical phenomena rather than chemical developing was invented by Mr. Chester F. Carlson in 1937. The rights to the process were acquired by Haloid-XeroX, Inc. At the present time xerography is a commercially available photographic process in equipment of Haloid-XeroX, Inc. The process employs a selenium plate which is charged in the dark, exposed with light, and then developed with a dry powder. The print is then transferred from the selenium plate to paper.

In the early 1950's, RCA developed Electrofax. This was an outgrowth of work with phosphors for cathode ray tubes. Electrofax is very similar to xerography except a coated paper is used instead of the selenium plate. A typical coating material is zinc oxide held in a binder. Both the selenium and the zinc oxide are semiconductors with a photoconductive property. The Electrograph applied the Electrofax process to a light-beam recording oscillograph.

Century Electronics and Instruments, Inc. of Tulsa, Oklahoma, beginning in 1955, developed the Electrograph. The Electrograph is a light-beam galvanometer oscillograph using Electrofax paper.

The subject of this thesis is an area of the development that the author was responsible for. Before getting into the developing techniques of the Electrograph, it will be helpful to outline the principles of operation of the Electrograph.

CHAPTER II

PRINCIPLES OF OPERATION OF THE ELECTROGRAPH

There are some materials that have the property of holding an electrostatic charge in the dark and releasing this charge where light impinges on the material. This latent image can then be developed by dusting with a fine charged powder to produce a visible image. Typical photoconductive materials as used in xerography and Electrofax, respectively, are selenium and zinc oxide. The zinc oxide suspended in a binder on the paper can be charged. Charging in the Electrograph is accomplished with three .001-inch diameter tungsten wires spaced near the paper. About 6000 volts on these wires produces corona. The resulting ionization produces a negative charge on the surface of the paper. (Figure 1 shows the side view of the Electrograph with the charger indicated. Continue to refer to Figure 1 throughout this paragraph.) After charging, the paper is exposed. Light from the galvanometer lamp strikes the galvanometer and is focused onto the paper. Timing lines are also exposed on the paper by the timing line generator. This latent image is then developed by the brush developer. As the paper continues to move, the developed oscillogram or record is viewed at the viewing platen. The record is next fused with heat by the fixer drum to obtain a permanent record. The material of this thesis now proceeds to investigate the process of developing.

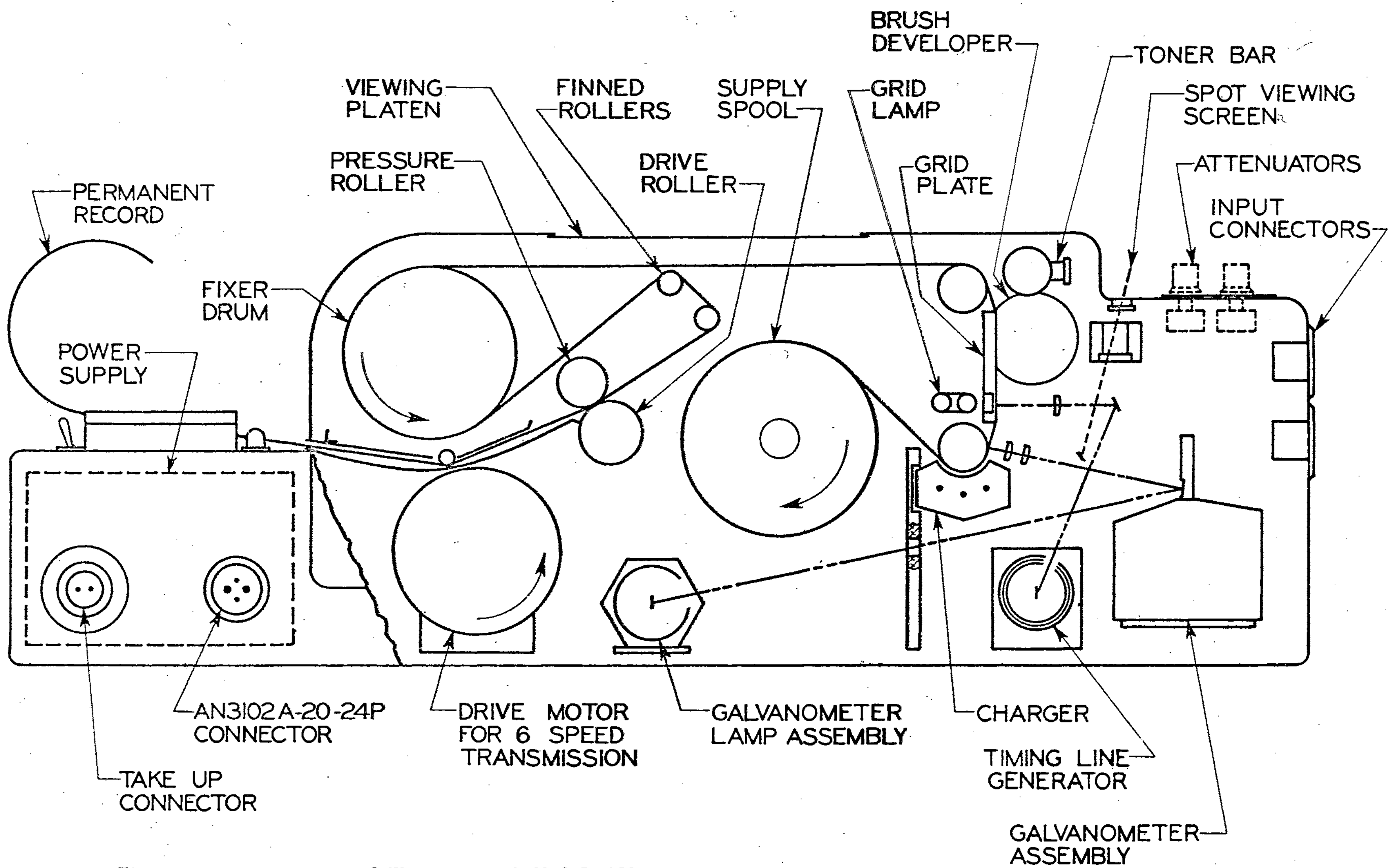


Figure 1. Side View of Electrograph Model 420

CHAPTER III

PHYSICS OF THE DEVELOPING PROCESS

Let us first consider the physics of the developing process. The existence of electrostatic charge is a rather common observation. The experiments of beginning physics involving rubbing a glass rod with silk, or a hard rubber rod with cat's fur, indicate to the observer the existence of electrostatic charge. A cataloging of materials with respect to their frictional electrostatic charge properties is published as the "Triboelectric Table."[1] The term "triboelectric" means, simply, frictional electricity. Numerous studies of frictional electricity have been made. Much literature has been published by the British with an emphasis on frictional electricity in the woolen mills. One reason for the success of the early woolen mills in damp England was reduction of charge by the humid air. Another study of frictional electricity was made in the United States where the dry winds of West Texas can work on the sand of a dust storm to produce electrostatic charge ending up in an electrical storm. These are cases of frictional electricity.

More recently, work has been done in contact electrification.[2] Contact electrification consists of placing two dissimilar materials

---

[1] TRIBOELECTRIC TABLES, Smithsonian Physical Tables, 8th Revised Edition.

[2] Henry P. S. H., CONTACT ELECTRIFICATION, Science Progress (British) October, 1953.

in contact with each other. The two items are then separated and a charge is observed on each of the materials. For this experiment the materials are ground to a near molecular smoothness. It is believed that enough molecular nuclei of one material are close enough to electrons in orbit of the other to actually attract the electrons. The result is oppositely charged bodies when separated. Some authors are asking, Is not triboelectricity the same thing as contact electrification? The rubbing cat's fur or silk or the wind force on sand particles may just be a means of close contact.

Materials were classified in the triboelectric series at about the turn of this century. Later it became a dead subject, but recently it has been revived by work in contact electrification. Table I shows a triboelectric series. Many other materials may be placed in the table. As a general rule, any material is positive with respect to any material below itself and negative with respect to any material above itself. This characteristic will permit developing a positive or negative print by changing the material used to make the fine powder in the developer of the Electrograph. For example, when using powdered iron as carrier held by a magnet, a negatively charged developer powder results if Vinsol Resin is used and a positively charged developer powder is obtained if a particular Piccolastic Resin is used.

TABLE I

THE TRIBO-ELECTRIC SERIES - TABLE 482

P 408 Smithsonian Physical Tables
8th Revised Edition

The following Table is so arranged that any material in the list becomes positively electrified when rubbed by one lower in the list. The phenomenon depends upon surface conditions and circumstances may alter the relative positions in the list.

1. Asbestos (sheet).
2. Rabbit's fur, hair, (Hg).
3. Glass (Combn. tubing).
4. Vitreous silica, opposum's fur.
5. Glass (fusn.)
6. Mica.
7. Wool.
8. Glass (pol.), Quartz (pol.), glazed porcelain.
9. Glass (broken edge), ivory.
10. Calcite.
11. Cat's fur.
12. Ca, Mg, Pb, Fluor spar, borax.
13. Silk.
14. Al, Mn, Zn, Cd, Cr, felt, hand, wash-leather.
15. Filter paper.
16. Vulcanized fiber.
17. Cotton.
18. Magnalium.
19. K-alum, rock-salt, satin spar.
20. Woods, Fe.
21. Unglazed porcelain, salammoniac.
22. K-bichromate, paraffin, tinned-Fe.
23. Cork, ebony.
24. Amber.
25. Slate, chrome-alum.
26. Shellac, resin, sealing-wax.
27. Ebonite.
28. Co, Ni, Sn, Cu, As, Bi, Sb, Ag, Pd, C, Te, Eureka, straw, copper sulphate, brass.
29. Para rubber, iron alum.
30. Guttapercha.
31. Sulphur.
32. Pt, Ag, Au.
33. Celluloid.
34. Indiarubber.

CHAPTER IV

ELECTROPHOTOGRAPHIC DEVELOPING TECHNIQUES

The author's work with developing techniques began with a bar magnet, iron powder and some sample toner supplied by Radio Corporation of America. Equipment required for this development includes a darkroom, a hand corona charger, a lamp with shutter, a contact print pattern and the hand developer. This equipment was set up in the laboratory of Century Electronics and Instruments, Inc. in Tulsa, Oklahoma. Two basic families of toners were used with the bar magnet and iron powder. One type is called positive toner; the other type is called negative toner. This identifying description follows from the fact that the positive toners take on a positive charge and the negative toners a negative charge when in contact with iron. These toners could be selected from the triboelectric table if all materials were cataloged in the table.

The zinc oxide in a binder that makes up the photoconductive surface of Electrofax paper (a similar paper manufactured by Haloid XeroX, Inc. is called LectroX paper) accepts a negative charge. Attempts by the author to charge the commercially available zinc oxide papers positively were unsuccessful. It may be noted that the selenium plates in the Model D processor and Copyflo machines of Haloid are charged positively. The fact that the Electrofax paper accepts a negative charge means that the positive toner will make a positive print. This follows from a latent image of negative charge in those areas of no light and no charge where the light strikes the paper. The dark toner then develops the areas that are dark in the pattern being reproduced. A negative toner, then, will produce a negative of the pattern. At this stage of development it was easier to get a good reproduction with positive toner than with negative toner. Large areas were especially difficult to develop with negative toner. In the case of positive toner a negative charge is standing by to attract the positively charged toner particle. In the case of the negative toner the phenomena requires additional explanation. The fields on the paper are from the negative charge to the areas of no charge. Fine lines can be developed readily, while large areas are difficult to develop. This is because the field strength is high into the small area of the line.

A potential can be applied between the developing mixture and the paper backing to aid the fields attempting to apply toner to the exposed areas. This voltage was applied by connecting the negative terminal of a power supply to the magnet and the positive terminal to the ground plate supporting the paper. This technique materially improved the negative toner developing process.

CHAPTER V

MECHANIZATION OF THE DEVELOPING PROCESS

The next step in the development program of the Electrograph was to mechanize the magnetic developing process. One design consideration was to automatically and continuously develop over a paper speed range of from 1/8 inch per second to 8 inches per second. Another design consideration was to be able easily to load the paper into the developer.

The initial developer was patterned after an arrangement suggested by Radio Corporation of America. This developer is shown in Figure 2. A magnetic field is established to support the iron filings. (A satisfactory type of iron filings is Belmont Type H supplied by Belmont Smelting and Refining Works, Inc.) Four Anico V magnets were used in the cold-rolled steel circuit. The magnetic path in Figure 2 is from a north pole to a south pole, through cold-rolled steel to a bearing block, then down the shaft of the brush, out the washers to the paper and air gap, and back in the north pole. This magnetic circuit will hold the iron against the paper. The shaft can be turned to improve developing. The turning brush scrubs the paper for better developing. The turning of the brush also drops iron on the side away from the magnetic path. This means new iron with toner attached is continually brought in contact with the paper. For continuous developing the toner must be replenished.

An upper speed limitation is imposed on the rotating brush by

MAGNETIC DEVELOPER

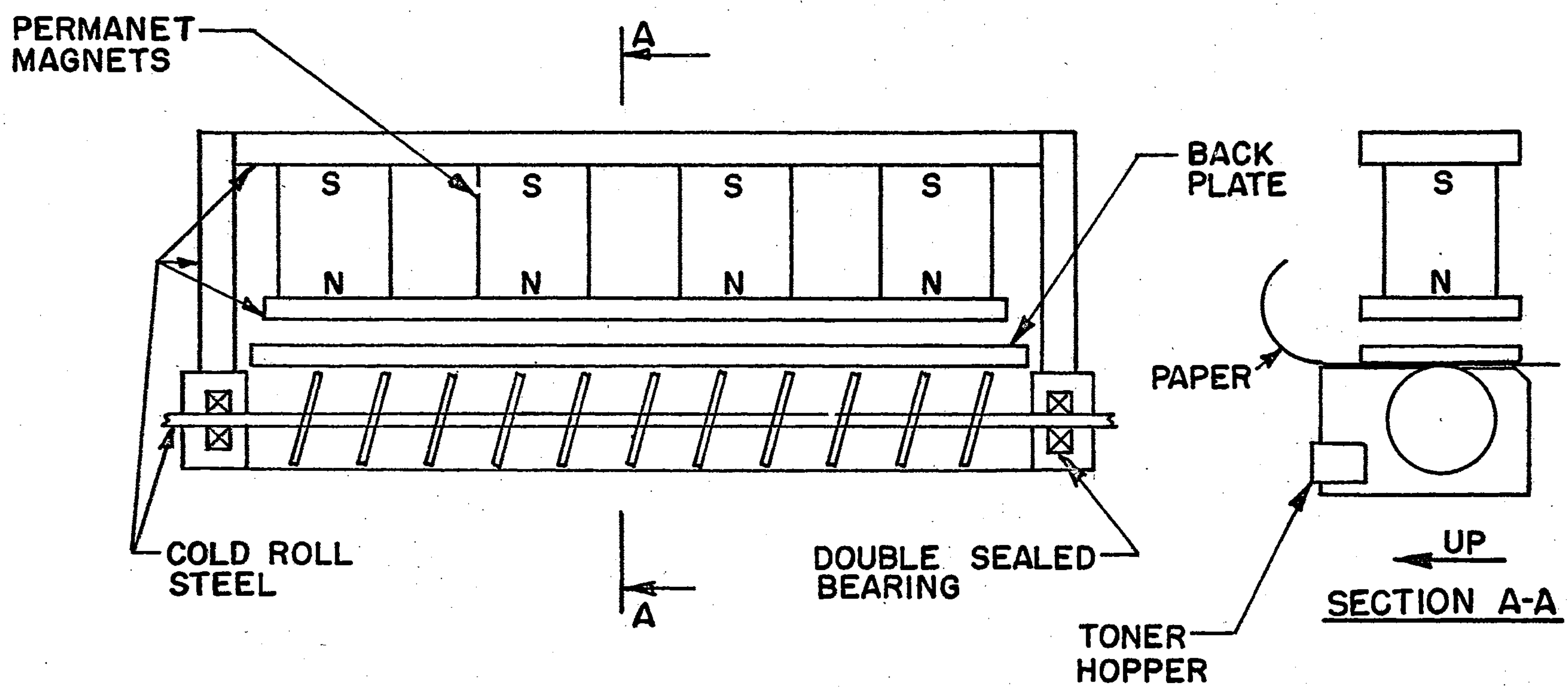
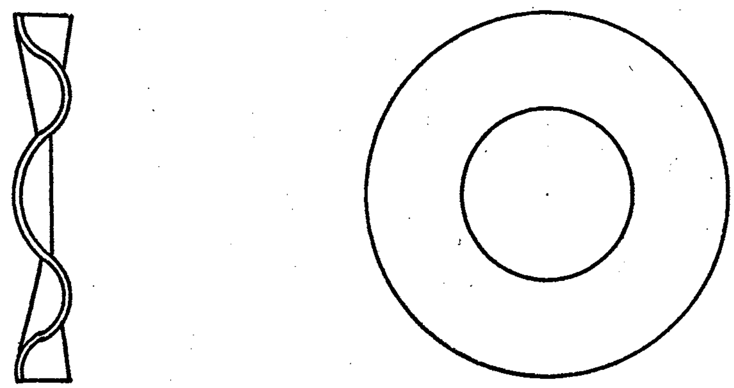


Figure 2. Magnetic Developer

centrifugal force acting on the iron. At high paper speeds portions of the record were undeveloped because the washers on the brush were turning too slowly. Figure 3 shows a Century type developer washer. These washers were pressed out of tin plate (soft iron base metal). A brass spacer of smaller diameter was placed between the washers. This arrangement meant less rotation was required to cover the gap between the washers. A developer very similar to the one shown in Figure 2 with the Century type washer was delivered with the first Electrographs.

The toner (fine black powder; in this case vinsol resin) must be supplied to the developer. It will be well to mention the toner manufacturing technique. In the early stages of the development program the author made toner as outlined in RCA patent applications. The final process of toner manufacture is one of passing it through a 200-mesh screen. Considering this particle size, a 50-mesh screen was used in most of the toner dispensing systems of the Electrograph. Let us return now to the toner replenishing problem. The first developing technique was to add enough toner to the iron mixture to develop considerable record. There is a limit to the amount of toner that can be added. Too much toner in the mix gives excessive background in developing. It soon became apparent that replenishment in operation would be required to develop 200 lineal feet of paper. A toner hopper was added as indicated in Figure 2. The initial hopper consisted of a tray with a 50-mesh screen in the bottom which was filled with toner with a spoon. The toner dispenser was redesigned to simplify toner supply replenishing. The toner was packaged in a plastic tube much like the tube that toothbrushes are packaged in. The operator need

CENTURY TYPE DEVELOPER WASHER



TONER DISPENSER CAM VIBRATOR

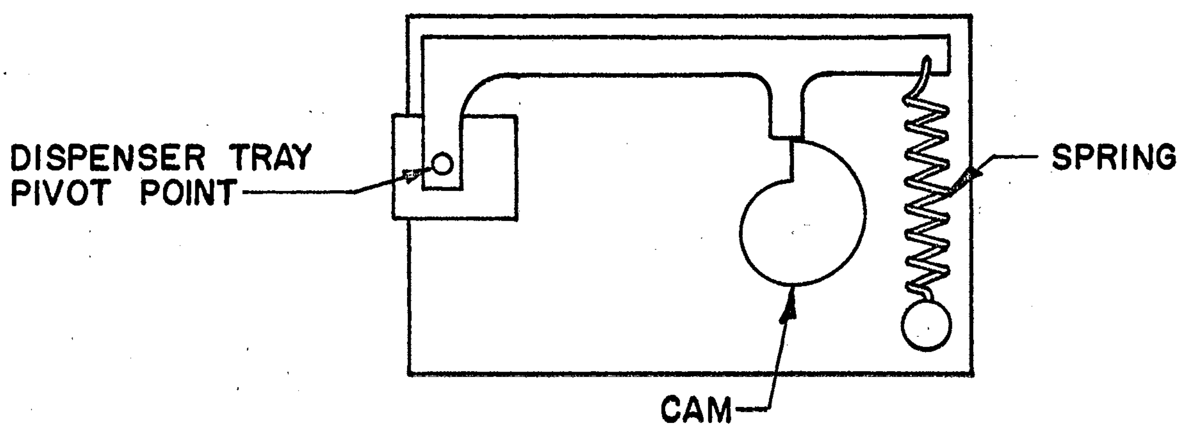


Figure 3. Developer Washer and Toner Dispenser

only strip a piece of tape from the tube and place the tube in the dispenser. Large holes in the tube would empty out into the tray. The 50-mesh screen would then finely divide the toner before dumping it into the iron. Several methods of vibrating the dispenser tray to shake through the toner were tried. One attempt at vibrating the toner dispenser was to use 60-cycle A.C. in a coil-buzzer arrangement. An improved version made use of a spring-loaded mechanical linkage that was moved out and spring returned against a stop. A final version retained the spring-loaded linkage, but let the hammer arm ride a cam. The cam would slowly move the dispenser tray in a small angle of arc about the longitudinal axis of the tray. At the end of the arc the spring would drive the tray to the starting point again. (See Figure 3, Toner Dispensing Cam Vibrator.)

In the discussion of the basic developing techniques, it was pointed out that a biasing voltage was helpful in developing with negative toner. This biasing or aiding field was supplied by the addition of a back plate. The developer brush itself is at ground potential. Therefore, a positive voltage is supplied to the back-plate. The backplate consists of a piece of aluminum about 7-3/4" x 1" x 1/8" set into a piece of linen base phenolic. It will be recalled that 4 to 6 thousand volts negative are required for charging. The several hundred volts positive are obtained by establishing the ground of the supply in the middle of bleeder resistors with several hundred volts positive in one direction and 4 to 6 thousand volts negative in the other. This positive voltage is used only to establish a field, so there is practically no current flowing. This means there is practically no loading of the high voltage supply.

CHAPTER VI

DEVELOPER FOR THE ELECTROGRAPH MODEL 421

As the Electrograph 420 went into production a new program was begun to build a developer to new specifications. The additions in the specifications were: 16 inches per second maximum paper speed, 14-inch wide paper, and 19-inch relay rack mounting of the equipment.

It was experimentally observed that the Electrograph Model 420 would not develop at paper speeds above 8 inches per second because of centrifugal force on the iron particles. The following reasoning indicated a larger diameter brush would permit faster paper speed:

$$F = m\ r\omega^2$$

F = force on particle
m = mass
r = distance to particle from wheel center
ω = angular velocity

$\omega = \frac{V}{r}$ V = tangential velocity or peripheral speed

$$F = \frac{mV^2}{r}$$

$V^2 = \frac{Fr}{m}$ for a constant force and constant mass

$$V = k\sqrt{r}$$

This says that peripheral speed that can be obtained varies as the square root of the radius. A larger diameter brush was fabricated for developing tests. Higher speed developing could be obtained.

Another approach to higher speed and cleaner developing was to harden some washers and permanently magnetize them. This would keep the iron mixture in the tray when threading the paper, as well as increase the force of magnetic attraction on the iron particles. This technique met with little success. A similar approach was to use ceramic magnets. These magnets, as a commercially feasible item, are only several years old. They consist of barium and iron oxides which are blended, molded and sintered. The resultant material has the appearance and general properties of a ceramic. It is practically a non-conductor.

Figure 4 shows the demagnetizing curve of a typical ceramic magnet and of an Alnico V magnet. Alnico V is one of the better permanent magnets commercially available. Its large area under the demagnetizing curve shows maximum energy per unit volume. It also has a high residual induction. By comparison to this familiar magnet, the typical ceramic magnet has about 1/6 the residual induction, but over twice the coercive force. The high coercive force means the magnet cannot be easily demagnetized.

The first arrangement using ceramic magnets was to use the same magnetic circuit as used in Figure 2. The Alnico magnets were replaced with soft iron. The disc-shaped ceramic magnets were magnetized as shown in Figure 5 with a north pole in the center of the disc and a south pole along the outside. A multiplicity of 1/4" thick discs were stacked on a cold-rolled steel shaft. The advantage here was one of moving the magnetic induction force closer to the iron powder. This increased the iron holding power of the magnetic circuit. The ceramic magnets were next polarized as shown in the lower sketch of Figure 5.

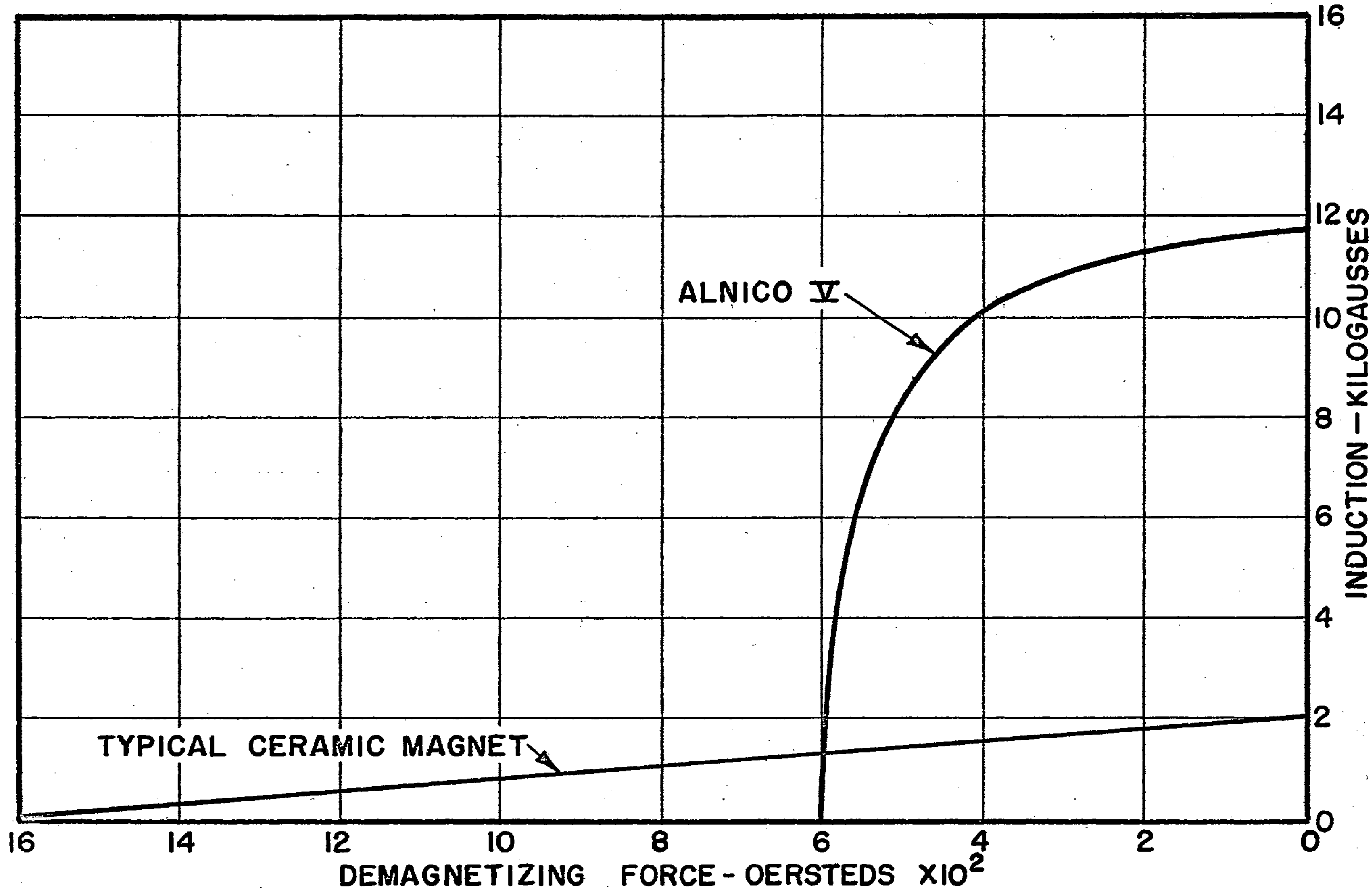


Figure 4. Demagnetizing Curves of Ceramic and Alnico V Magnets

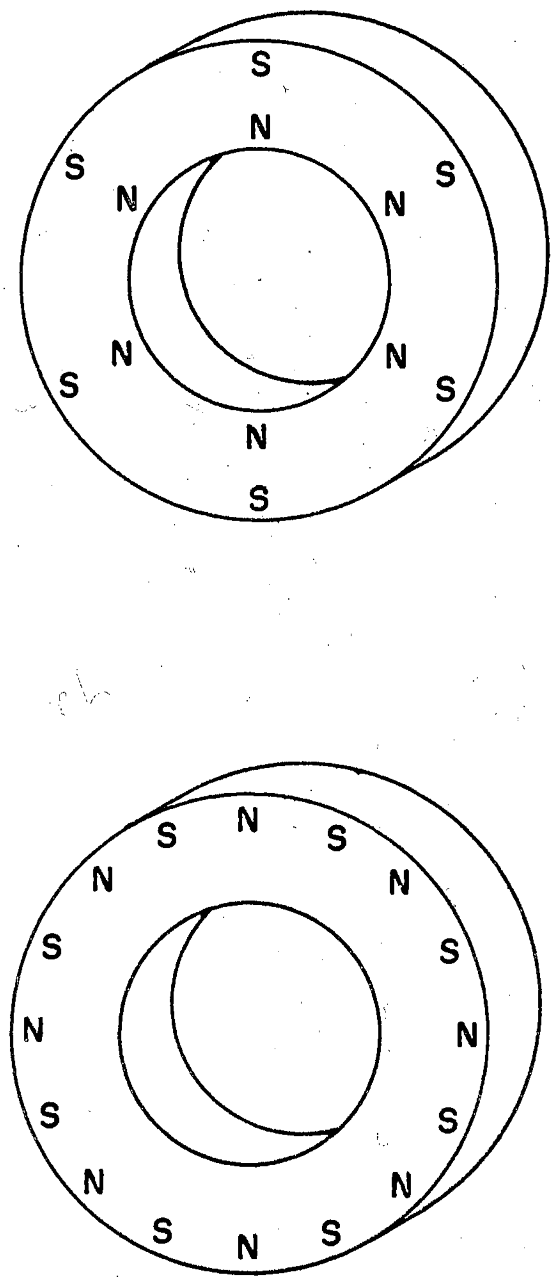


Figure 5. Pole Locations of Magnetized Ceramic Magnet

Here a multiplicity of north and south poles were placed in the surface of the disc. This can readily be done with ceramic magnets since the magnetization is a local thing. A multiplicity of these discs were then stacked on an aluminum shaft. This arrangement eliminated the external magnetic circuit. This would materially aid in holding the iron inside the developer for cleanliness. Initial tests of ceramic magnet developers were encouraging. However, with extensive testing, problems of mixing the replenishing toner arose. The iron falling off the back side of the soft iron developer was helping to continuously bring a fresh toner iron mixture to the area of developing. The best of ceramic magnetic developers had enough shortcomings that further developing techniques were investigated.

The methods of developing discussed above were aimed at the higher speed of developing in the 16" per second paper speed specification. As the over-all layout of the new relay rack mounted Electrograph took shape, other design considerations in the developer took on importance. It will be noted in Figure 1 that the paper travel is in the upward direction. With this paper travel direction the force of gravity is available to hold the developer mix in the developer. Any developer mix trying to adhere to the paper will fall back into the developer as the paper leaves the developer. The design specifications of the Electrograph Model 421 of Figure 6 included relay rack mounting. This meant the paper must travel in a downward direction where viewed. To develop at a point of upward paper travel seriously limited the paper travel arrangements possible. It would be possible to develop the paper moving up, but extra length would be required between exposing and viewing. To minimize this exposing to viewing distance was another design specification.

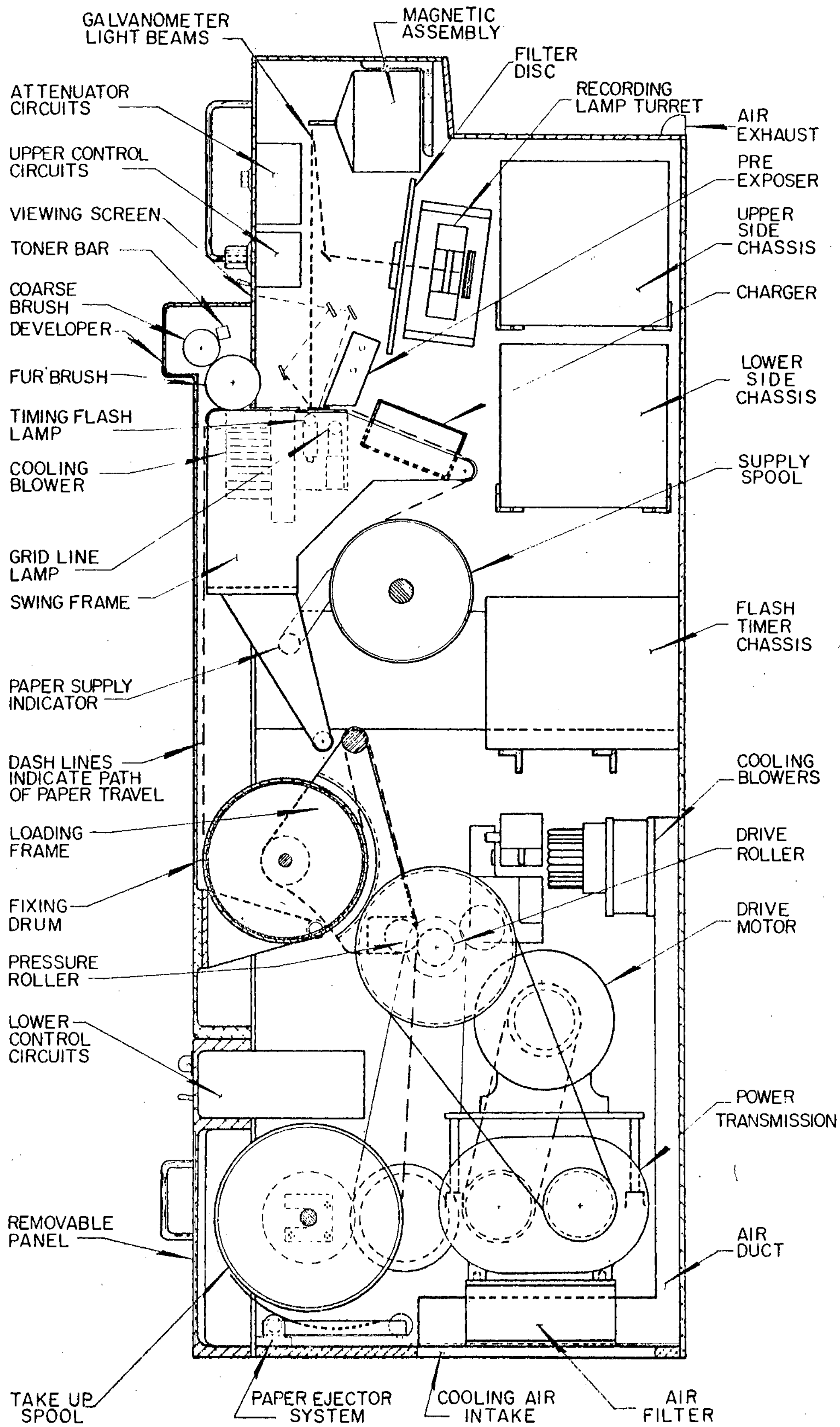


Figure 6. Electrograph Model 421

CHAPTER VII

FUR DEVELOPER

These several requirements then moved the project back into the research stages. If a carrier for the toner could be found that was captive, the forces of gravity would not be needed to control particle movement. The basic experiments of rubbing a hard rubber rod with cat's fur, or a glass rod with silk, were reconsidered. A large number of animal furs and other materials were checked in the darkroom with the simple hand charging and exposing technique. Table II is a compilation of results with these different materials with the vinsol resin toner. It was decided to limit the initial experiments to this type toner. It was previously established that of numerous toners tested, vinsol resin had the most desirable fusing temperature. Our objective then was to match a carrier material to this toner for good triboelectric charge characteristics.

Of the materials cataloged in Table II, the first ones tried were synthetic materials. If a synthetic material were found that worked well, it should be easier to reproduce the material. The quality control on nylon manufacture should be better than animal skins from a furrier. Local carpet people supplied samples of many synthetic carpets. This included nylon and rayon. As the research investigation continued, all types of fabrics and furs were tested. Many types of soft fabrics were available from department stores and upholstery people.

TABLE II

MATERIALS TESTED FOR DEVELOPING IN THE ELECTROGRAPH

Material	Developing Results: Good	Fair	Poor
Afghanistan Lamb	X		
Mouton		X	
Alaskan Seal	X		
Racoon		X	
Ocelot		X	
Leopard		X	
Nutria		X	
Kolinsky			X
Rabbit			X
Rabbit, Sheared		X	
Fitch			X
Skunk			X
Muscrat			X
Chinese Caracal			X
China Mink			X
Wild Mink			X
Grey Persian Paw			X
Labrador Seal			X
Russian Weasel			X
Marmot			X
Fox			X
Hudson Seal	X		
Caracul			X

TABLE II (Concluded)

Material	Good	Fair	Poor
Lynx			X
Civet Cat			X
Elk			X
Polyester Foam		X	
Horsehair			X
Asbestos			X
Felt			X
Cotton Rag	X		
Rayon Carpet	X		
Cotton Carpet		X	
Wool Carpet		X	
Nylon Carpet			X
Seraton Carpet			X
Cotton Powder Puff	X		
Toner only	Reverse printing with heavy background		
Velvetine	X		
Automobile Body Cloth	X		
Velvet, Cotton-Rayon	X		
Mohair		X	
Camel's Hair	X		
Ox Hair		X	
Sable Hair		X	

A good grade of velvet in particular showed promise. In discussion with furriers it was discovered that numerous furs were available commercially. Fortunately, scrap pieces of even expensive furs such as mink were readily available at no cost. As fur testing continued it was discovered that the same animal sheared or not sheared gave different developing results. The shearing exposes the soft down. Here, and also between different animals, it was established that a soft fur was better than a coarse one. This was not a characteristic of the triboelectric charge so much as an abrading effect by the coarse material. At this point it might be added that standard paper was established for fur testing. It was found that some rough Electrofax papers gave smearing, while a smooth surface Electrofax paper would give good results. This emphasizes again that after obtaining a material with a good triboelectric charge relationship, a non-abrading combination is also required. Animal products were tested, both as fur and as fabric. For example, wool cloth and wool carpet were evaluated.

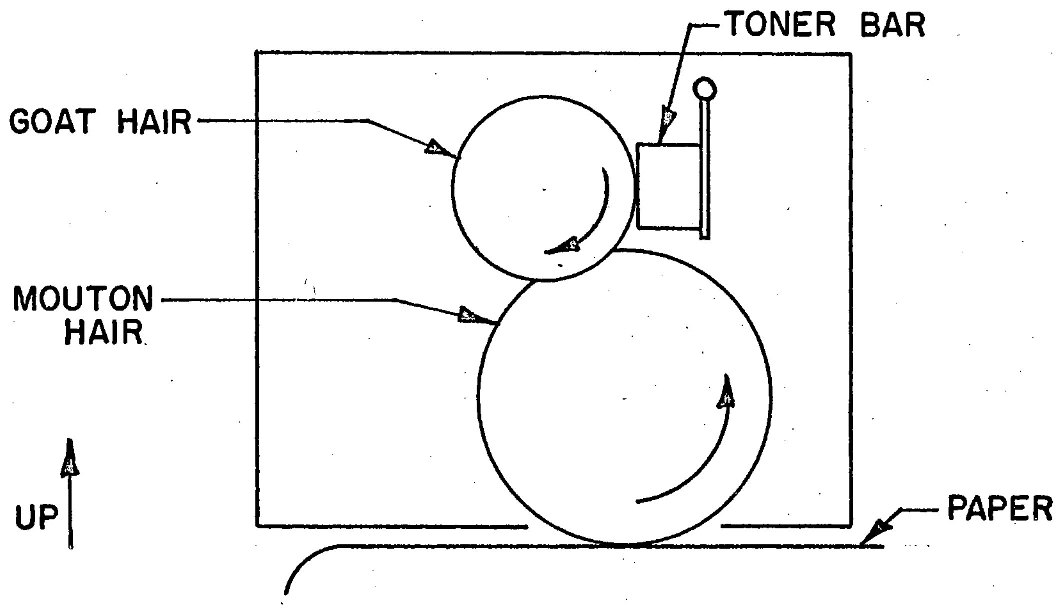
Brushes of various types were tried as developers. The softness requirement led to camel's hair brushes. It was new information to the author that camel's hair brushes are made of various types of Russian squirrel. Several other commercially available artist brushes were tested. An order was placed with the Jenkins Brush Company for a cylindrical brush of several inches of their softest nylon and several inches of a soft goat hair. Goat hair from some parts of the goat's body can be relatively soft. An evaluation of this cylindrical brush proved that these bristles were too stiff. It is interesting to note that a later evaluation used this same brush effectively to comb a softer brush continuously in operation.

Many furs were attached to a round shaft for developing. Several techniques were used to apply the fur to the shaft. One attempt was to sew the fur together at the joint and slide it onto the shaft. This gave a projection at the seam that made the developing uneven. The next approach was to use an adhesive to secure the fur to the shaft. Initial tests used Scotch brand pressure-sensitive tape of the double-coated type. Later, Vulcalox cement was used to attach the fur. There was a minor problem of lack of developing as this butt seam passed the paper. At the seam the hair density was less. An improved arrangement was a spiral wind made of a long strip of fur.

A simple fur brush would give improved developing if the fur were scraped on the side of the roller opposite the paper. Fur brush developers used at this time were about the same physical size as the magnetic brush. One example might be a 1/2-inch shaft covered with a 1/2-inch thick mouton fur. The scraping action supplied two phenomena: One, it agitated the fur and rearranged the toner particles, placing a fresh supply on the fur ends; and, secondly, it seemed to add friction that helped to promote good charge relationship between the fur and toner. In crude tests, cardboard served as a scraper. Metal or hard rubber or other materials could be used for a commercial grade scraper. One need not met by this type scraper was the requirement to lift the fur back up. Continuous rotation of the fur brush would tend to lay the fur over.

The next developmental fur developer is shown in Figure 7. The goat hair brush that had been fabricated by the Jenkins Brush Company was

FUR DEVELOPER
ELECTROGRAPH MODEL 421



FUR DEVELOPER
ELECTROGRAPH MODEL 420 AND MODEL 422

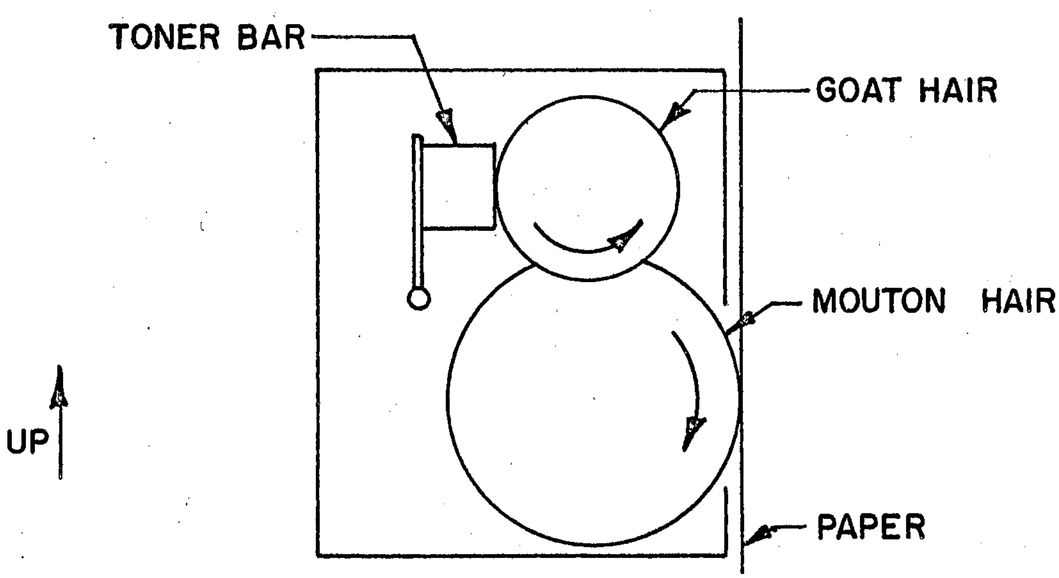


Figure 7. Fur Brush Developer

used in conjunction with a soft mouton fur. The peripheral speed of the goat hair brush was made a little faster than the peripheral speed of the mouton brush. The earlier scraper advantages were retained and, in addition, the fur was continually brushed up from its laying-down position. It is of interest here to note that the nylon fabricated brush would not work, whereas the goat hair was effective. The nylon seemed to try to hold all the toner, rather than re-distribute it on the fur. A fur brush similar to Figure 7 was delivered with later models of the Electrograph, Model 420 and Model 422, as well as in the relay rack mounted equipment of the Model 421.

The backplate voltage that was used to aid the electrical field in the magnetic brush was not used with the fur brush. The distance over which the field acted in the magnetic brush was only the thickness of the recording paper. In the case of the fur brush, this distance was about a half-inch -- namely, from the developer shaft to the paper. Over this distance the field gradient needed would have required an extremely high voltage. The field effects that develop the latent image work very well for the line developing of oscillograph traces. If area developing were required, the fur brush developer as arranged in Figure 7 would not give good results.

At about the same time the fur brush was being considered, a problem arose in toner dispensing. A customer had stored toner in a warm location. Over a period of time at these elevated temperatures the toner tended to flow and, as a result, would not shake out of the plastic container. Some toner was compressed to see if, in a cake form, it could be made to ride against the fur brush and be lightly wiped off in the quantities needed for developing.

A number of materials were tried as binders for making cake toner. Some of these were: Kaolin, Superjel "GF," Hallmark pure powdered gum arabic #1 U.S.P. superior, Canary "S" dextrine, cornstarch, and Bentonite. These were tested with varying amounts of water added to the material and toner mix. Also, the amount of material per net measure of toner was varied. The addition of most of these binders tended to make the toner bar too hard to be easily brushed off in use. Kaolin gave the best results of the materials tested for use as a binder. More refined tests were next made with Kaolin. This included a multiplicity of combinations of toner-to-Kaolin-to-water ratio. A combination that gave good results was 9 parts toner to 1 part Kaolin to 1 part water by volume. Another effective toner bar was made with toner and water and a carefully controlled pressure in pressing.

Attempts to wipe off the toner with the soft fur were not too effective. It was at about the same point in the research program that the combination brush as shown in Figure 7 evolved. The fur developer with both the mouton and goat hair brushes was a natural for toner bar dispensing. The toner bar could be brought in contact with the goat hair brush. This brush, stiff by comparison, flakes off the toner and distributes it to the mouton. A developer of this type was delivered with the Electrograph Model 421. This same type developer was made available for the Electrographs Models 420 and 422. With extended usage of the iron powder developer, iron powder would get loose in the machine. This iron powder would tend to collect on the magnetic assembly. Any iron powder that worked its way inside the magnetic assembly might short a galvanometer. For this reason many of the Electrographs

Models 420 and 422 were retrofitted with a developer of the type shown in Figure 7.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

This thesis reports on three years of research with electrophotographic developing techniques as applied to the Electrograph recording oscillograph. The first Electrograph recorders used a magnetic developer employing powdered iron and toner. Other approaches to magnetic developing were investigated. Various synthetic and natural fibers and furs were investigated as a developing medium. The improved fur developers replaced the magnetic developer in the Electrograph. This developer is the most feasible developer for the particular requirements of the Electrograph recorder--that is, the most feasible in the light of the present state of the art. This is not to say that continued research will not produce a better developing technique for the Electrograph. The principles of electrostatic photography would indicate that other areas of developing techniques might well be investigated.

BIBLIOGRAPHY

Broding, R. A., J. D. Schroeder, and J. C. Westervelt. "The Electrograph," I.R.E. Transactions on Instrumentation, Volume 1-6, Number 4, December, 1957, pp. 220-224.

Dessauer, J. H., G. R. Mott, and H. Bogdonoff. "Xerography Today," Photographic Engineering, Volume 6, No. 4 (1955), pp. 250-269.

Henry, P. S. H. "Contact Electrification," Science Progress, October, 1953.

Smithsonian Physical Tables, Eighth Revised Edition, Triboelectric Series Table 482.

Vogt, Calvin O., and John C. Westervelt. "Electrophotography Applied to Oscillography," Industrial Photography, June, 1957, pp. 52-54.

Young, C. J., and H. G. Greig. "'Electrofax' Direct Electrophotographic Printing on Paper," RCA Review, Volume XV, No. 4, December, 1954, pp. 469-484.

VITA

John Charles Westervelt

Candidate for the Degree of

Master of Science

Thesis: ELECTROPHOTOGRAPHIC DEVELOPING TECHNIQUES AS APPLIED TO THE ELECTROGRAPH RECORDING OSCILLOGRAPH

Major Field: Electrical Engineering

Biographical:

Personal data: Born in Oklahoma City, Oklahoma, December 9, 1927, the son of Wallace W. and Ruth Westervelt.

Education: Attended Jefferson grade school, Harding Junior High School, and Classen High School in Oklahoma City, Oklahoma, graduating from Classen in 1945. Received the Bachelor of Science Degree from The University of Oklahoma in June, 1950, with a major in electrical engineering; completed requirements for the Master of Science Degree in May, 1960.

Professional Experience: U.S. Navy, Electronics Officer, 1950-1953; Dorsett Laboratories, Inc., Project Engineer, 1953-1954; Bell Telephone Laboratories, Member of Technical Staff, 1954-1955; Century Electronics & Instruments, Inc., Development Engineer, 1955-1958; Century Geophysical Corporation, Project Engineer, 1958-1959; Century Electronics & Instruments, Inc., 1959 to present, Engineering Supervisor.

Organizations: Member of Eta Kappa Nu, Tau Beta Pi, Sigma Tau, Institute of Radio Engineers, and Oklahoma Professional Engineers.