FINAL STUDY AND TEST PLAN
for
OPEN GATE FILM-TO-FILM CONTACT PRINTER
AND FILM CLEANING

[redacted]

STATINTL

to

U.S. GOVERNMENT

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APPENDIX

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ABSTRACT

This study evaluated the feasibility of applying open gate techniques to achieve improved performance in a continuous film-to-film contact printer. As a second objective, a study of film cleaning methods applicable to this printer was performed.

The open gate study centered around the problem of assuring intimate film contact in the open printer gate. Included was the consideration of using a "liquid gate" to assure contact and to enhance the resulting transfer of photographic information.

A limited test program was performed to evaluate the effect of contacting pressure on information transfer, as well as the effect of inserting a contacting fluid between the films. These tests were conducted under specular as well as diffuse illumination conditions.

Although test results were somewhat limited by the low-contrast photographic targets used, they indicated a significant improvement resulting from the use of a "liquid gate." Information transfer appears to be relatively independent of contacting pressure for pressures above 1 PSI in a dry system. These tests set performance criteria for the various techniques considered.

1.0 INTRODUCTION

1.1 Background

Considerable effort has been expended over the years to minimize loss of resolution in duplicated copies of aerial photographs produced in film-to-film contact printers. It is well recognized that a continuing loss of information is inherent in the process of photographic duplication as progressive generations are reproduced. Considerable ingenuity has been applied to maximize the transfer of information or resolution between successive generations of duplicated photography. However, the resolution loss remains significant, especially where the image contrast is low.

Currently, continuous strip-film-to-film printers tend to use a rotating drum as the platen surface. Film contact is maintained either by film tension or by using a tense fabric web to produce contact pressure. Exposure can be external or internal with respect to the drum depending on whether film or web tension is used. However, distortion resulting from the curved platen or relative slippage of the films further tend to degrade information transfer and fidelity. Dirt and scratches can be easily generated in a system with inherent film slippage.

These problems appear to be minimized by going to a flat gate system. Here, by definition, the films move through the exposing station with zero relative velocity so that distortion and image smear caused by film slippage is eliminated. Moreover, by eliminating the glass platen, a possible source of dirt and film scratching is removed from the system. A further advantage of this so-called "open gate" system is the improvement in quality resulting from the elimination of distortion or image defects produced by the glass platen.

1.2 The Open Gate System

For purposes of definition in this report, the "open gate" system refers to a photographic printer configuration wherein the duplicating film is exposed in contact with the negative stock as they move without slippage through a flat printer gate. Machine contact with the image areas is eliminated by removing the usual glass platens. Contacting pressure can be maintained between the films by a variety of techniques which are discussed in this report.

1.3 Object of this Study

The object of the present study was to evaluate the feasibility of applying the various techniques considered to assure film contact in the gate of a continuous "open gate" printer. Evaluation was based on maintaining high performance compatible with current state of the art. Arbitrary performance criteria have been set at an output resolution of 300 lpm (line pairs/mm) from a high quality, high contrast input target with the printer operating at a film speed of 50 feet per minute. Consideration has been given to other factors contributing to degradation of image quality in the printer. Included in the study was an evaluation of techniques for film cleaning.

Based on this study, a test plan has been prepared defining an evaluation program to prove-out the concepts advanced in this report and to explore the engineering problems encountered when these techniques are incorporated in an automatic printer. This test plan is included as Section 4.0 of this report.

1.4 Technical Consideration

Evaluation of the various techniques considered was based on several performance criteria. These are described briefly below:

1.4.1 Contact Pressure - Each technique was initially selected and then evaluated as a method of producing cohesive or compressive force between the negative stock and duplicating film in the printer gate to assure contact. Pressure levels used were based on an experimental evaluation related to their effect on information transfer.

1.4.2 Image Distortion - Each technique was evaluated based on its possible contribution to image distortion. These would be primarily due to lack of flatness in the printer gate or the introduction of distorting optical media into the optical path at the printer gate. Also, of course, relative image motion during exposure will produce a loss in resolution due to smearing.

1.4.3 Light Sources - Each technique was evaluated to assure compatibility with the light source requirement of the printer.

1.4.4 Film Handling - Each technique was evaluated with regard to its influence on the film handling requirement. The integrity of the negative film must be preserved under all operating conditions. In other words, any system developed cannot produce scratches, dimensional distortions or any other film damage on the archival negative film.

1.4.5 Environmental Effects - Each technique was evaluated in terms of the requirement to maintain a controlled environment in the area of the film. Compatibility with the photographic requirement for clean conditions, controlled temperature and freedom from toxic vapors or materials was considered.

1.4.6 Other Considerations - Other factors were also evaluated. These include ease of implementation, compatibility with a continuous operating mode and engineering practicality.

Other specific factors were considered such as exposure of the raw film stock by electric spark discharge. These considerations are discussed in greater detail in the appendix.

1.5 Operational Requirements

Although the physical and chemical characteristics of the film base and emulsion of the negative stock, and the density range, contrast and graininess of the developed silver image are uncontrollable factors in the negative, it has been demonstrated that several factors can be controlled to maximize information transfer. These are itemized below.

- Maintain uniform film contact with sufficient contact pressure.
- Minimize film buckling or curl.
- Use normal specular illumination for exposure (over a narrow angle)
- Introduce "liquid gate" techniques
- Eliminate unnecessary optical media from the light path
- Remove dirt and contaminants from the system
- Match the spectral characteristics of the source to the response of the raw stock
- Minimize distortions due to film tension
- Eliminate relative slip between negative and duplicating film
- Keep exposure time short
- Minimize machine vibration

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In this study the ultimate goal has been to maintain a resolution limit of at least 300 lpm in second generation duplicate negatives produced in a printer operating continuously at 50 feet per minute. In order to meet this goal, the following criteria were established at the beginning of the study:

1.5.1 Both input negative or positive and raw stock must move at the same velocity without significant vibration, jitter or creep.

1.5.2 Contact pressure at the gate must be adequate to assure maximum information transfer.

1.5.3 If a liquid gate system is used, there must be no film damage, distortion or contamination.

1.5.4 Environmental conditions within the printer must be controlled to meet the photographic requirement for dust and dirt elimination, as well as temperature and humidity control. In addition, the requirement for minimizing the generation of R.F. interference was imposed.

2.0 OPEN GATE STUDY

The open gate study consisted of a survey and analysis of applicable techniques. These included novel approaches which may require development to reduce to practice. In order to evaluate the applicability of the approaches considered, a limited test program was performed to establish several important criteria which included the following:

1. Pressure level required to maximize transfer.
2. Effect of a contacting liquid on information transfer.
3. Effect of source diffusion on information transfer.

Several techniques were considered and are discussed in the following order:

- Liquid Gate Systems
- Air Bearing Systems
- Hydraulic Systems
- Vacuum Systems
- Electrostatic Techniques
- Electromagnetic Techniques
- Mechanical Systems
- Other Considerations

2.1 Test Program

In order to determine the effect of contacting pressure and liquid gate conditions on the transfer of photographic information in a contact printer configuration, limited tests were performed with the best photographic target we could prepare on available equipment. The tests were designed to answer the following questions:

- What is the effect of contacting pressure on information transfer?
- What is the effect of liquid contact on information transfer if operating in the "liquid gate" mode?

- What is the effect of specular or diffuse illumination on information transfer?

1. Target

A 45x5X photo-reduction of a USAF 1951 test target, on Eastman SO-105 emulsion, was used. The visual resolution threshold was 650 lp/mm with a microdensitometer contrast (ΔD) of 0.02, measured with an effective slit width of 0.3 microns.

This target was then sequentially contact printed nine times through an Eastman 649-GH intermediate to produce an Eastman SO-132 nine-target-array to be used as a submaster. Final microscopic resolution in the submaster ranged from 230 to 290 lp/mm. Microdensitometer contrast ranged from 0.10 to 0.18 at the limiting resolution.

The resulting submaster target consisted of nine test targets in a 3 by 3 matrix array on approximately 1 inch centers. The overall target was approximately 70 millimeters square.

2. Test Setup

Tests were performed in the test configuration shown in Fig. 2.1. The gate was illuminated by a .040" pinhole aperture at a distance of 5 feet. The pinhole was effectively filled by radiation from a mercury lamp, filtered to limit maximum wavelength to 5000 angstroms. Spectral

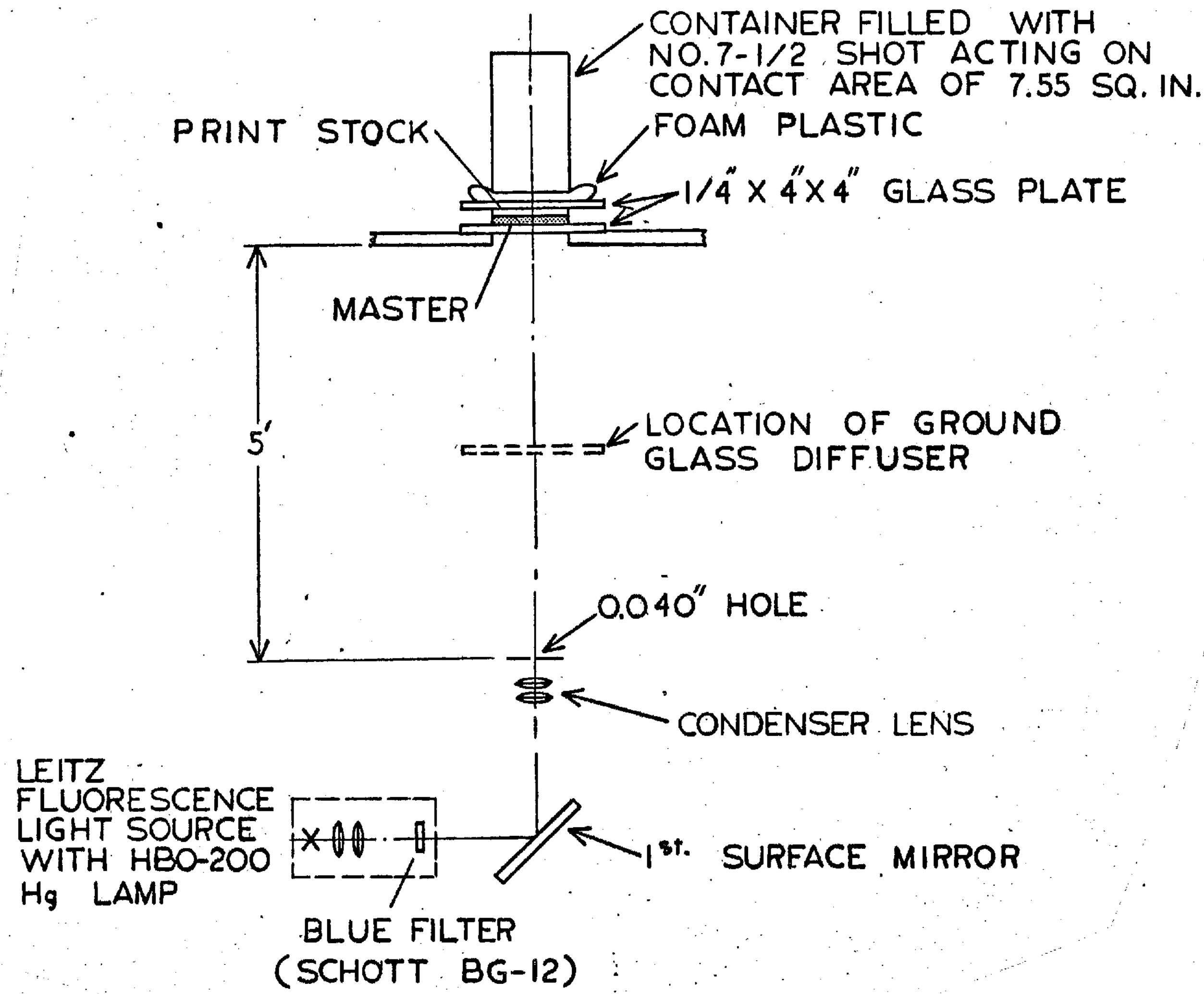

FIGURE 2.1 Experimental Setup

characteristics of the lamp and filter are attached in Appendix A. Provision was made for diffusing the light on an optional basis. This was accomplished by inserting a ground glass diffuser midway between the pinhole and the printing gate.

The submaster test target and the negative raw stock were inserted in emulsion contact between 1/4" plate glass platens. Effective contact area was 7.55 square inches. Contact pressure was applied by weighing the upper platen with a calibrated amount of lead shot.

3. Test Procedure

Tests were performed under twelve test conditions. These included three conditions of contact pressure, with and without liquid gate, and with and without optical diffusion in the system. Prints were made on Eastman SO-278 (Type 8430) photographic film.

Duplicate test images were made for each test condition. Test sequence was randomly arranged to minimize the effect of systematic error. The latent images were processed in accordance with the manufacturers' recommendations and the images were evaluated microscopically by two observers. Data correlation was reasonably good.

The test conditions are given below:

Pressure: 0,0.33, 2.12 psi

Liquid Gate: (90% toluene, 10% Freon-113) optionally inserted

Diffusion: Ground glass, optionally inserted

4. Test Results

The results of these experiments are plotted in Fig. 2.2. A detailed description of the experiment is included as Exhibit C in the appendix.

From these experiments, we conclude that a significant improvement in information transfer results from the use of liquid gate techniques. Moreover, liquid gate assures intimate film contact since resolution is essentially independent of contacting pressure under these conditions.

Under dry conditions, resolution improves rapidly with contact pressure at low pressure values but improvements are small above pressures of 1 pound per square inch, especially in the case where specular illumination is used.

2.2 Open-Gate Technique Evaluation

A critical evaluation of several techniques applicable to open gate systems included a comprehensive literature search of U.S. Government reports, private communications, patent literature and periodicals. A bibliography is attached as Exhibit B. The following conclusions were reached as a result of this study.

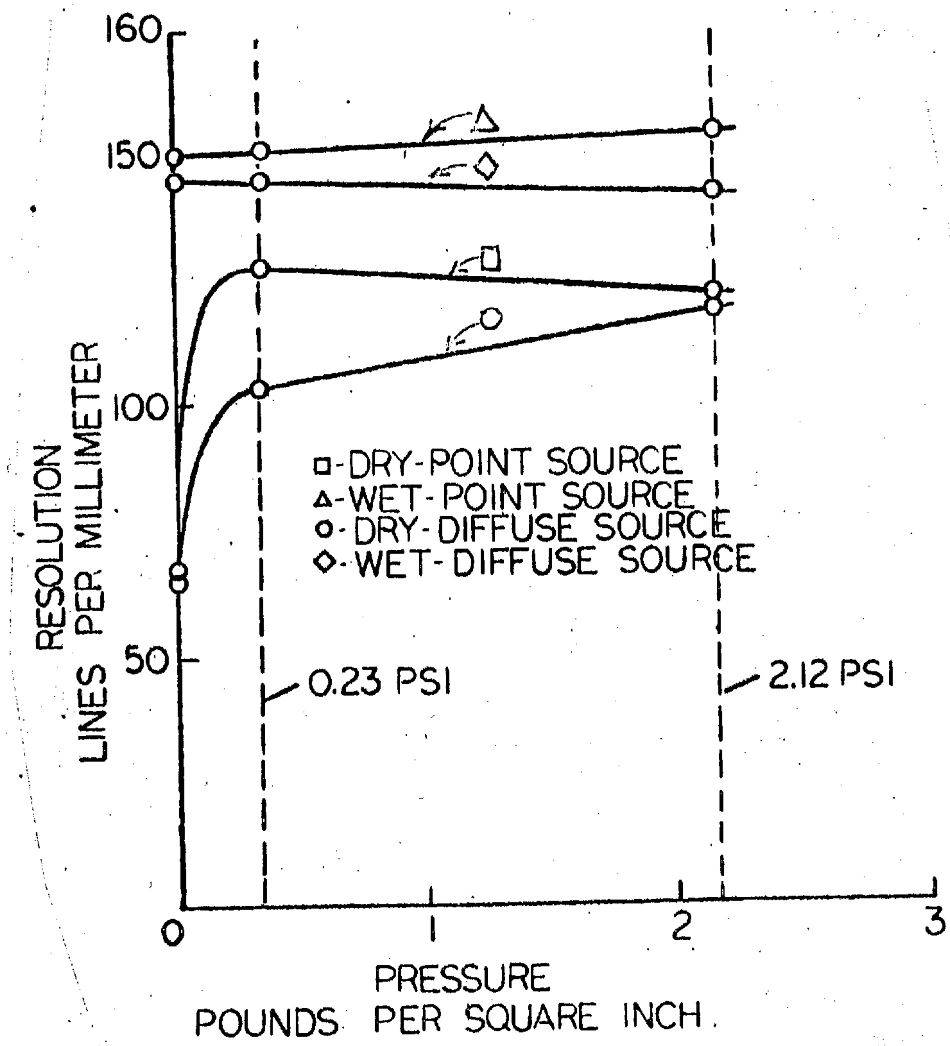

FIGURE 2.2 Effect of Contacting Pressure on Output Resolution.

2.2.1 Liquid Gate Systems- Measurements have been made of the attractive force between Mylar sheets brought in intimate contact with a thin water film separating them. The adhesive force is thought to be created by a pressure differential produced when the intermediate air-film is displaced by a liquid. Shear forces measured were approximately 0.23 psi.

A liquid gate system was reported in 1957 for printing motion picture films.[1] In this system two wringer rollers were mounted so that the films "V" together under sufficient pressure to leave only a thin liquid layer between the films. Excessive wringer pressure had to be avoided because it caused the two films to adhere so tightly that irregular slippage occurred between the negative and raw stock as they passed over the periphery of the drive roller.

Liquid gates (wet printing) are in use for films as large as 70 millimeters[2]; however, the literature emphasizes that experience and equipment are predominantly for 16 and 35 millimeter films.

The reported purpose of the liquid gate systems in general is (1) the virtual elimination of printing defects caused by scratches and other surface irregularities on the negative and (2) improvement of definition by providing a continuous optical medium through which the exposing light passes from the negative to the raw stock.[1,3] Where total immersion techniques were used for contact and projection liquid gate printing, Newton rings were never observed and the acuitance of a second duplicate in immersion printing is twice that obtained in ordinary printing[1,4].

In gate designs where the liquid circulates, cooling and better film positioning result[5]. Cooling of the film is especially desirable when a high intensity source with its attendant heat is used.

Immersion printing minimizes deterioration of tone reproduction caused by light scattering. However, there is practically no difference in the graininess of prints obtained by either dry or wet printing methods. All prints obtained by immersion printing had resolution greater than that obtained in ordinary contact printing. The gain in resolution is greatest when liquids are applied to all film surfaces, intermediate when applied only to the emulsion interface and least when applied only to the substrate sides[4].

If scratches alone are considered, the effects of scratches can be eliminated on the negative by applying a thin liquid layer to the support side of the film just before printing since most film scratching occurs on the support side. Slight emulsion scratches can usually be ignored whereas deep emulsion scratches cannot be eliminated with liquids in any case[6].

In any total immersion system, air bubbles tend to follow splices in the films. These bubbles have been successfully removed by a fine camel's hair brush contacting the films within the liquid bath[1].

In addition to simple immersion, contacting liquids have been applied by wick, spray or roller. In order to minimize film damage, the method chosen must not introduce contaminants in the contacting liquid.

Uniform distribution is of prime importance for if the films are not wet evenly, improper contact of the materials results in distortion and variation in print resolution.

Criteria for selection of liquids are exacting, but an evaluation[7] by Delwiche, et al., is comprehensive.

It has been definitely established from our limited testing program and from the literature search that a liquid interface between the film enhances information transfer. The advantage of this technique to automatic printers must be carefully weighed, however, against the substantial engineering problems introduced by the liquid handling. These include possible film damage effects, machine contamination, liquid handling and supply systems, and vapor venting requirements.

2.2.2 <u>Air Bearing Systems</u> - Air bearings are being used in film and paper transport systems with much success[8,9]. Studies by Ott, et. al.,[10] show that application of air directed by jets against the base of one film provides contact nearly equal to that obtained with a vacuum frame. The advantages of such a system are:

a. No friction or rolling action,

b. Economy by using air,

c. Cleaning action on films,

d. Independence of base thickness of either negative or positive.

Problems which may be encountered are possible limitation of gate size and possible degrading effects of air turbulence on information transfer. Basic concepts of an air-bearing or hydrostatic-bearing system [11] are presented below.

A simple, single-recess air-bearing system is shown in Fig. 2.3. All air-bearings have two main parts - the bearing pad which is stationary; the runner which may or may not move with respect to the pad.

The important parts of an air pad are the recess, the air inlet orifice, and the sill (Fig. 2.3). The runner is flat and separated from the pad by a full film of pressurized air. The amount of separation is termed "air film thickness." Air bearings may take any geometrical form from flat to cylindrical, conical and spherical. However, in all cases, the runner shape must conform to that of the pad. Air from the recess flows across the sill to the pad exit, where it is discharged. To maintain the air film clearance, the outflow of air from the bearing must be continually replenished.

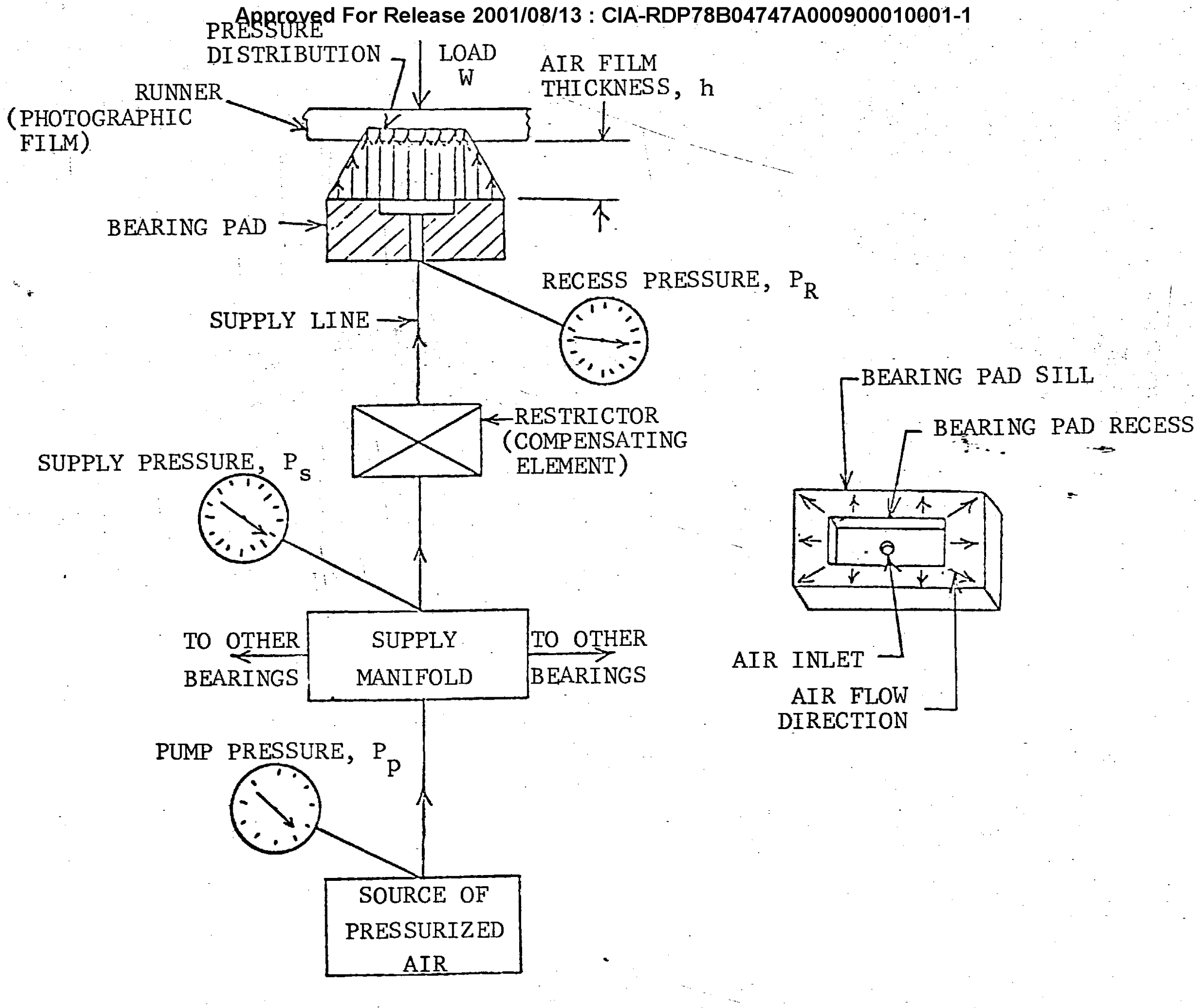

FIGURE 2.3 Typical Air Bearing System

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Air bearings can be applied to almost any device. Full-flow filtration insures the delivery of clean air required for film cleanliness. Breakdown of the air supply system will result in bearing failure; in critical applications, such as the film-to-film printer, standby systems are provided to prevent film damage. Although air bearings require a relatively expensive and complex supporting system, they offer advantages not found in any other type of bearing.

These include:

a. High load carrying capacity at all speeds (including zero speed) for all types of relative motion.

b. No starting friction and extremely low running friction.

c. No contact between bearing or film at any operating speed; thus, bearing life is dictated by air supply system life.

d. Predictable and adjustable bearing performance with regard to load-displacement characteristics, frictional drag, temperature rise, and stiffness.

e. Minimum driving force (film tension) required for the films at any film velocity.

Some external circuitry is required for all air bearings. Thus, the bearing is really a part of a system, and its operation depends upon other members within the system. A simple bearing system with the pressure source at zero

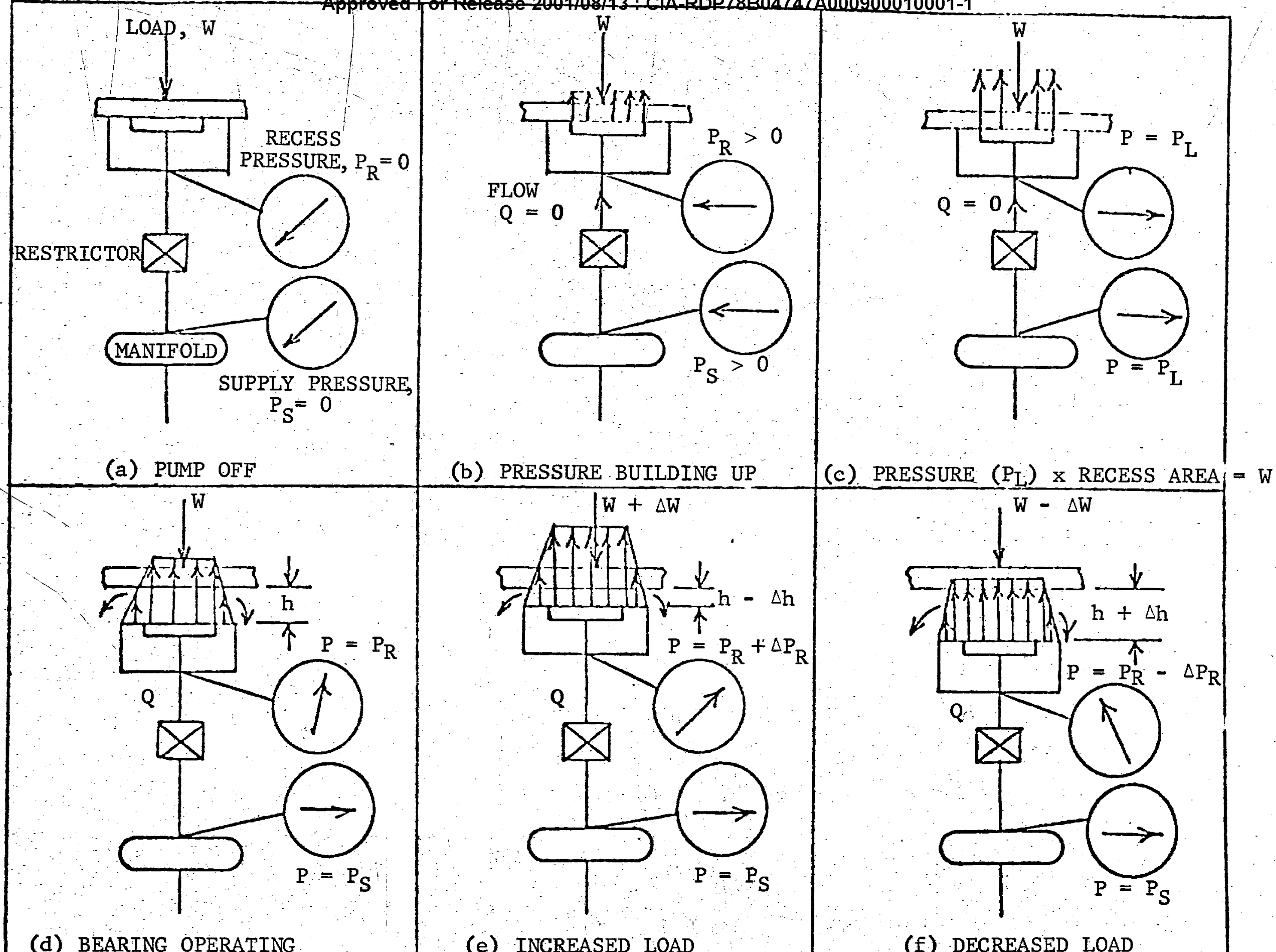

FIGURE 2.4. Formation of Air Film in an Air Bearing System

pressure is shown in Fig. 2.4a. The runner or film under the influence of a load, W, is seated on the bearing pad. As the source pressure builds up (Fig. 2.4.b) the pressure in the pad recess also increases. The pressure in the recess is built up to a point where the pressure on the runner (photographic film) over an area equal to the pad recess area is just sufficient to lift the load (Fig. 2.4c). This is commonly called the "lift" pressure.

Just after the runner (photographic film) separates from the bearing paid (Fig. 2.4d), the pressure in the recess is less than that required to lift the film. After lift, flow commences through the system. Therefore, a pressure drop exists between the pressure source and the bearing (across a restrictor) and from the recess to the exit of the bearing.

If more load is added to the bearing (Fig. 2.4e), the air film thickness decreases and the recess pressure rises until pressure within the bearing clearance and recess is sufficient to carry the increased load. If the load is now decreased to less than the original (Fig. 2.4f), the air film thickness increases to some higher value, and the recess pressure decreases accordingly. The maximum load that can be supported by the pad is reached, theoretically, when the pressure in the recess is equal to the pressure at the source.

A system for use as an air bearing open gate is shown in Fig. 2.5. Basically, an air bearing is used as the platen of the system to support the raw stock. Air nozzles or jets are used against the backing of the negative to provide clamping or contact pressure at the open gate aperture.

System operation dicates a single manifold. Volumetric flow rates of the nozzles and air bearing must be equal, $Q_N = Q_B$, the air films remain equal, $h_N = h_B$, for any drop or rise in manifold pressure in the single manifold system.

2.2.3 Hydraulic Systems - The relationships and diagrams used for the air bearing in Section 2.2.2 apply either to liquid or air. Figures 2.3, 2.4, and 2.5 can also be used to describe a type of hydraulic system in which a liquid is used in a hydrostatic bearing as a backing platen and air jets are used at the aperture for pressure contact. Choice of liquids is important to prevent film damage or contamination but the rest of the system analysis is the same as that of the air bearing.

Another approach involves the use of liquids under pressure in a confined volume. As an example, Fig. 2.6 depicts a gate system using such a pressurized liquid. Pressure is only great enough to provide true laminar flow; that is, the Reynolds' number is less than 2000. Seals are used to prevent excessive leakage and, essentially, to squeegee the films into

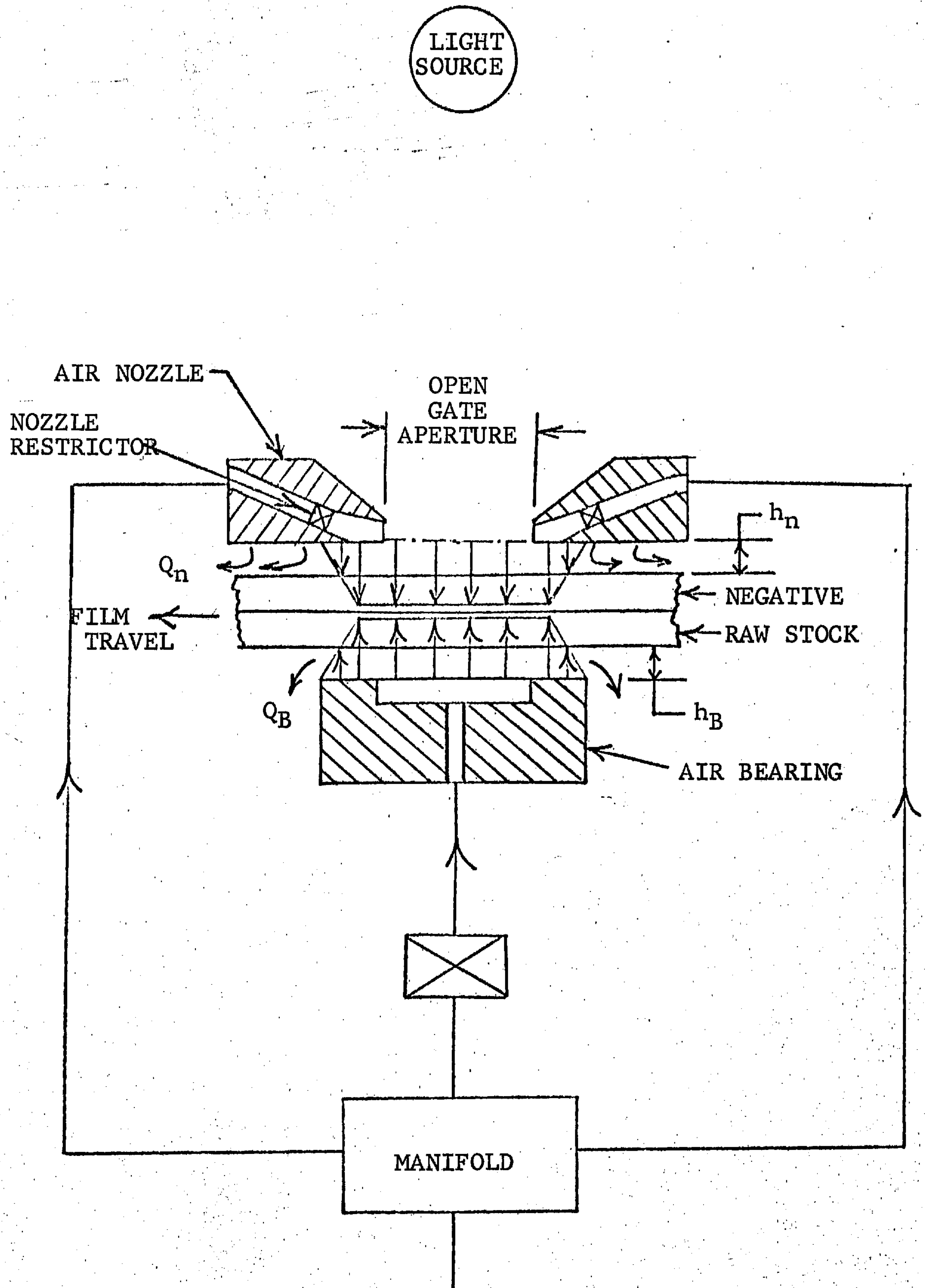

FIGURE 2-5 Air Bearing Open Gate

SOURCE

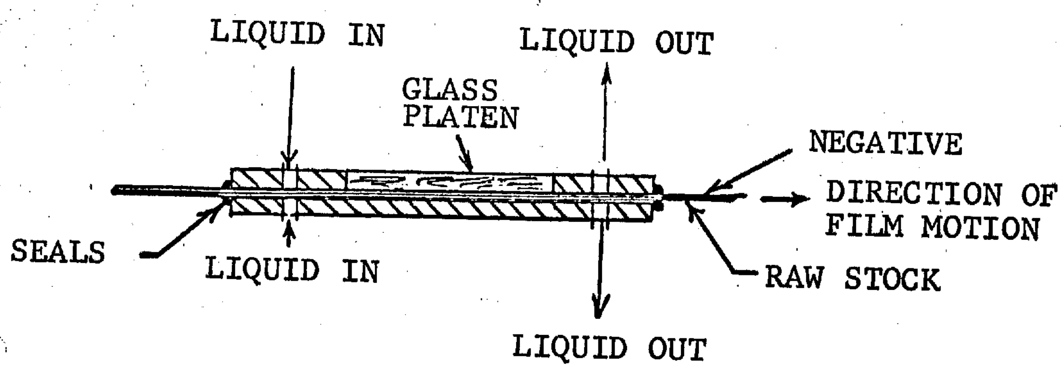

FIGURE 2.6 Hydraulic Gate

intimate contact. The liquid under pressure prevents the film surfaces from contacting the glass and maintains film contact. The liquid entrance and exit can be joined to the supply to provide a semi-closed cycle. This is not a true open gate because of the glass platen, but it maintains film contact in the gate without mechanically contacting the film.

2.2.4 <u>Vacuum Systems</u> - Good contact between two films can also be produced by a vacuum printing frame, but this is impractical in a continuous film-to-film printer. Therefore, requirements must be established to define another type of vacuum system: The following would be system requirements:

a. Techniques for maintaining vacuum between the films without requiring abrading contact with them.

b. Maintenance of a vacuum between films in a continuous flow system.

c. Prevention of contamination in the evacuated areas from external environment.

The following are possible design considerations:

a. The use of a chamber for applying vacuum between films.

b. The control of contamination by use of an absolute filter type packing.

c. An increase in contact pressure by use of an external air bearing in conjunction with a vacuum.

Two unique systems of vacuum contact printers are described in the patent literature[12]. The first system is step and repeat, and the second is a continuous contact printer.

The system depicted in Fig. 2.7 combines a side vacuum with a preliminary vacuum chamber and air bearings in close proximity. The purpose of the chamber is to eliminate as much entrapped air as possible. For clarity on Fig. 2.7, the exposure gate with its air bearing, air jets, and side vacuum is shown separated from the vacuum chamber. Actually, they are immediately adjacent to the chamber and may be part of it. As the films leave the vacuum chamber, they are immediately acted upon by the air jets, the air bearing and

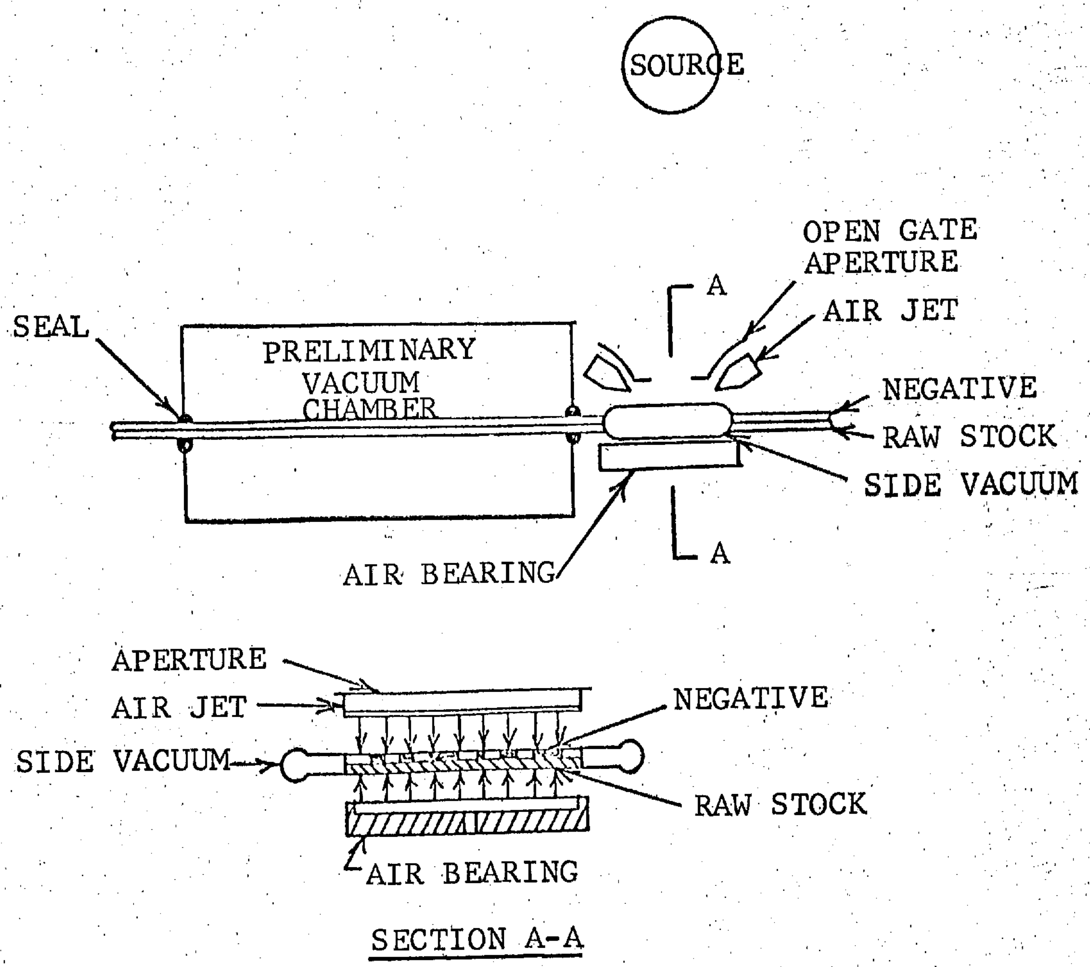

FIGURE 2.7 Vacuum Contact Printer

side vacuums. After exposure, the films separate normally and are rolled on their take-up reels. This is a continuous system and all sections operate at a continuous vacuum and flow rate.

2.2.5 Electrostatic Attraction - Based on the fact that charged bodies in an electric field exert mutual mechanical forces upon each other, tending to produce relative motion to decrease the field energy, electrostatic attraction was considered as a possible technique for films in an open gate. A preliminary experiment to determine feasibility was performed.*

Thin Mylar film, simulating film base, was mechanically charged using a charged steel roller. The attractive force between two oppositely charged sheets was gauged by measuring the shear and normal forces necessary to separate them. The experimental results never produced the level of contacting pressure theoretically predicted, presumably because of inefficient transfer of charge or inadequate mechanical contact. Moreover, when sensitized photographic film was charged with a contacting roller, the surface pattern of the roller was imprinted on the film as a photographically developable latent image.

Another approach, involving an ion generator, may permit the application of electrostatic charge to photographic films without mechanical contact. Such a system concept is depicted in Fig. 2.8. The emulsions are shielded from the

*Appendix, Exhibit "D"

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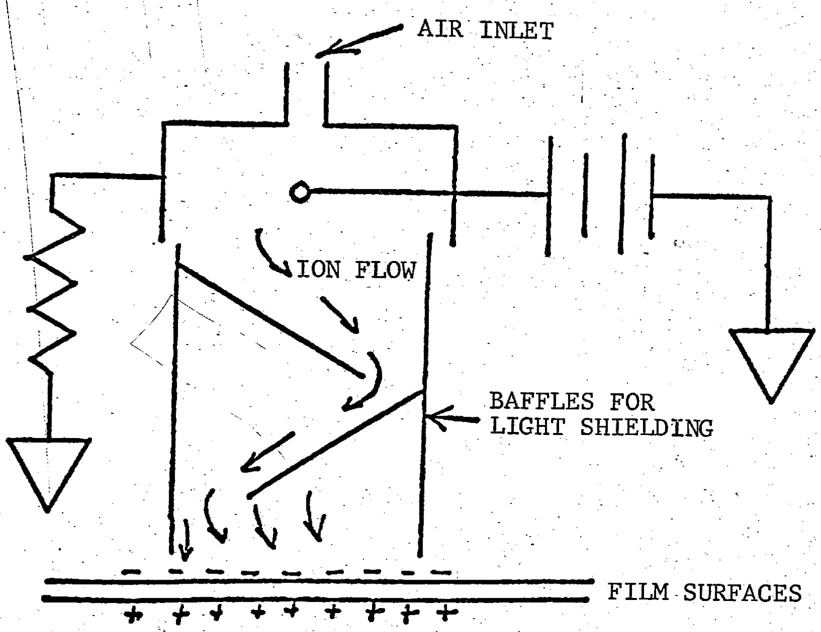

FIGURE 2.8. Corona Attraction

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corona glow by light baffles, and ions are carried by an air stream to the film surface. Air velocities are an unknown requirement but estimates range from one to 4 inches per second. Close control and protection of equipment and personnel from stray ions would be required.

2.2.6 Mechanical Systems - Mechanical systems for maintaining film contact usually consist of drive rollers, pressure rollers, various tension devices, and platens. One such contact printer is described in an unclassified report[14]. Although the system described is not an open gate system as defined, it is an example of present mechanical systems.

A pressure roller open gate, such as the one depicted in Fig. 2.9, may be advantageous. The gate aperture width is determined by exposure requirements. The pressure rollers are spaced at minimum distances to permit the optimum support for the films; a tension system drives the films. Even though this system is a continuous open gate, several possible problem areas do exist; among them distortion effects due to film tension, contamination due to roller contact, and perhaps inadequate film contact in the gate.

Figure 2.10 depicts a belt transport open gate. Assuming that a semi-rigid belt can be developed, the negative and raw stock can be clamped by air jets to it in the narrow gate aperture. Pressure rollers (indicated by dotted lines) can be used if contact pressure does not damage the film.

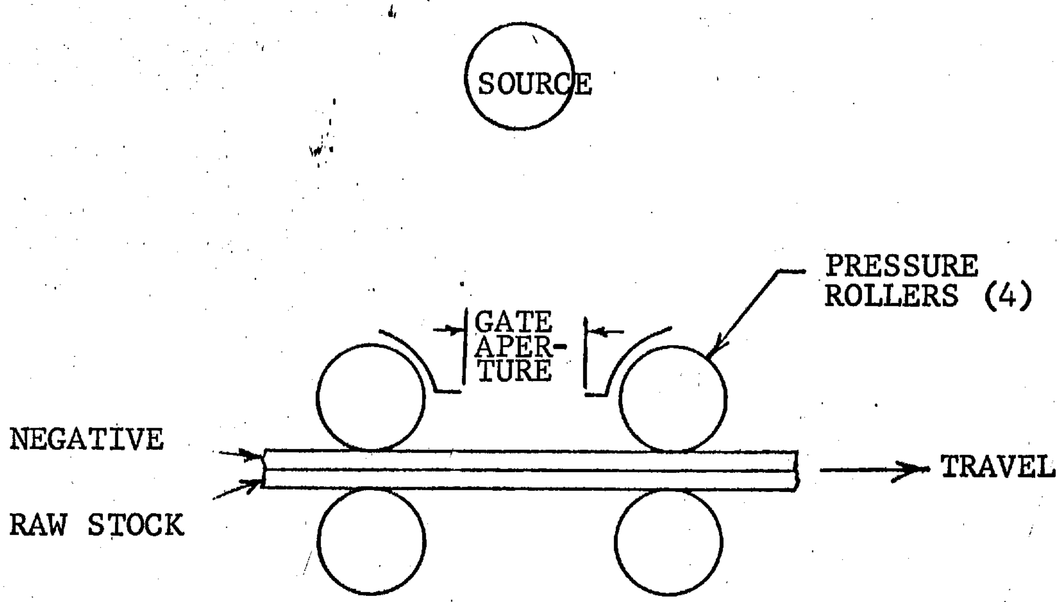

FIGURE 2.9 Pressure Roller Open Gate

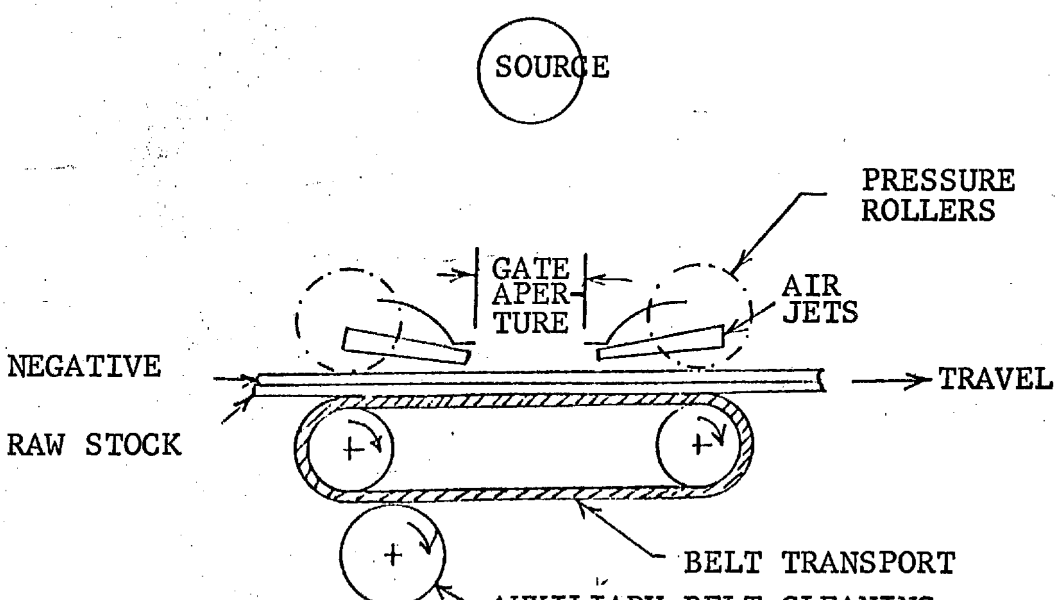

FIGURE 2.10. Belt Transport Open Gate

The endless belt could be maintained at a cleanliness level necessary for high resolution printing by an auxiliary cleaning system.

2.2.7 Electromagnetic Techniques - Electromagnetic techniques have been adapted for the purpose of shaping metal. The particular technique reported[15], called "Magneforming", takes advantage of the magnetic repulsion produced between the fields of an electromagnet and those produced by eddy currents in an electrical conductor exposed to the primary field.

In this technique, a dynamic field is produced by discharging a capacitor through a shaped coil. Mutually repelling fields are produced by the coil and by the eddy currents in a conductor in the field. Sufficiently intense repulsion can be produced by this technique to force metal into a variety of shapes.

If a conducting layer existed on one film layer, the possibility of using a dynamic magnetic field to assure film clamping might be attractive. The conductivity of the developed silver grains in the negative is probably not high enough to produce a useful effect.

Obviously, force must be exerted against a rigid backing plate if the film is not to be badly distorted. Such a support could be an air-bearing support plate. Presumably a high frequency AC field would be required to insure continuous contact in a strip-printer.

Such a system is shown schematically in Fig. 2.11.

2.2.8 Other Possible Considerations -

1. Adhesive Systems

Some advantage might develop if the negative stock and raw stock were tacked together adhesively during exposure. This would assure minimum relative motion between them and if the optical properties of the tacking material were properly chosen, would offer the enhanced information transfer found in liquid gate systems.

Systems can be visualized where the two films are attached over the entire format area or simply tacked at the film edge out of the useful frame area. The latter technique might offer some advantage in conjunction with a vacuum system for drawing out residual air from between the films.

There are several problem areas which must be studied in detail before such a system would be practical. These include the following:

(1) Methods of application and removal of the adhesive material without film damage on a continuous basis and with uniform contact.

(2) Choice of an adhesive which will have no detrimental effect on either negative or raw stock.

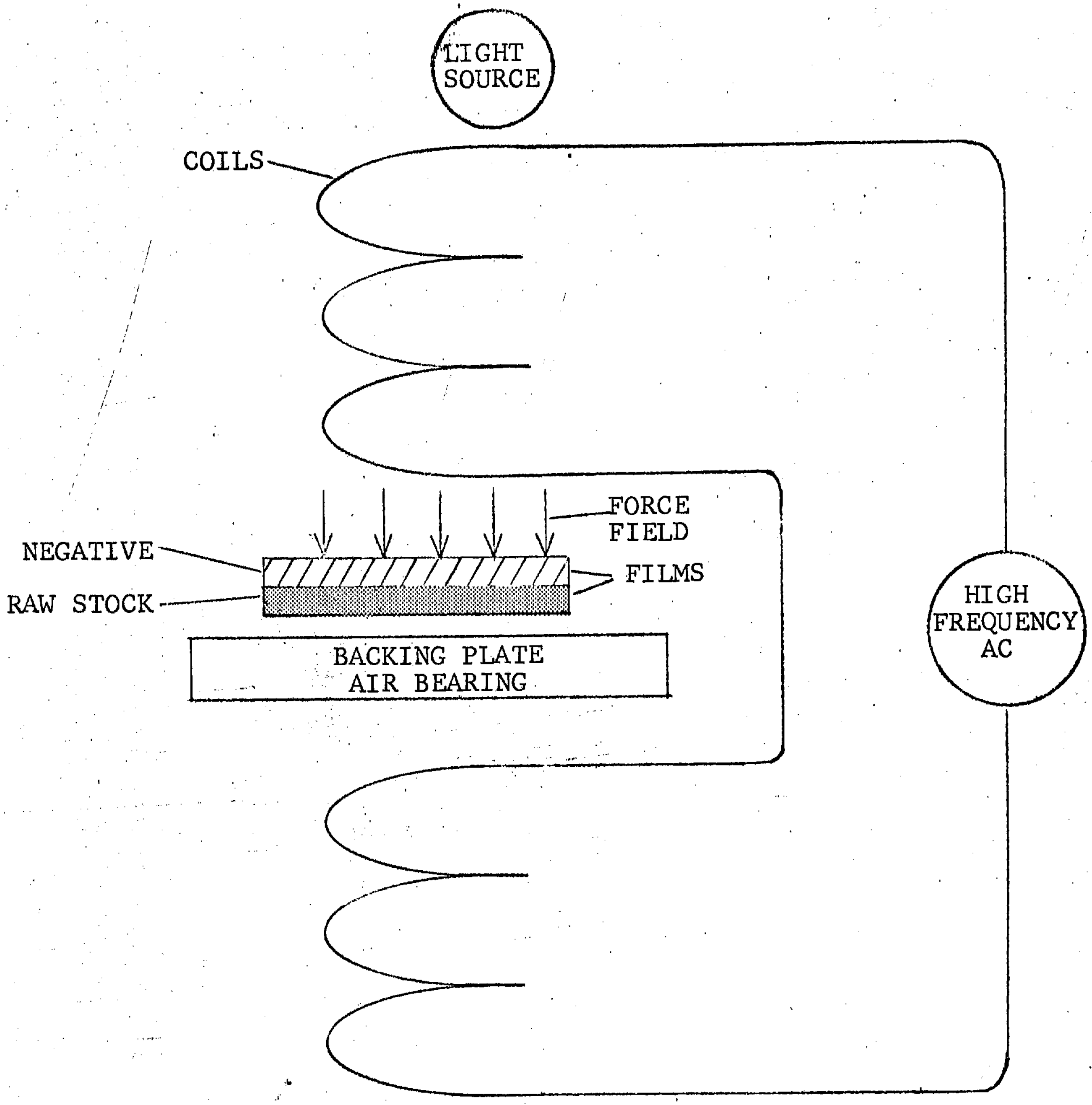

FIGURE 2.11 Electromagnetic Repulsion

(3) Optimizing optical characteristics for maximum information transfer.

(4) Obtaining adequate tack to assure contact during the printing operation.

2. Pneumatic System

Another system under consideration was the use of a simple air bearing system, which consists basically of two cylindrical air bearings between which the films travel. The interior of one of the air bearing sections contains the exposure lamp. The system is depicted in Fig. 2.12.

3. Rotating System

Another approach uses centrifugal force for providing the contact force between two films. In the simplest sense, this could be accomplished by rotating the entire film transport at high speeds. Although at first consideration this may sound impractical, a similar technique has actually been used for holding the film flat in a panoramic camera. Entire cameras have been rotated, as for example the series of "whirling dervish" panoramic cameras.

Two methods have been considered: The first places the platen at the end of a long moment-arm. The film supply and take-up spools are at or near the axis of rotation. Calculations of contact force are presented in the appendix.

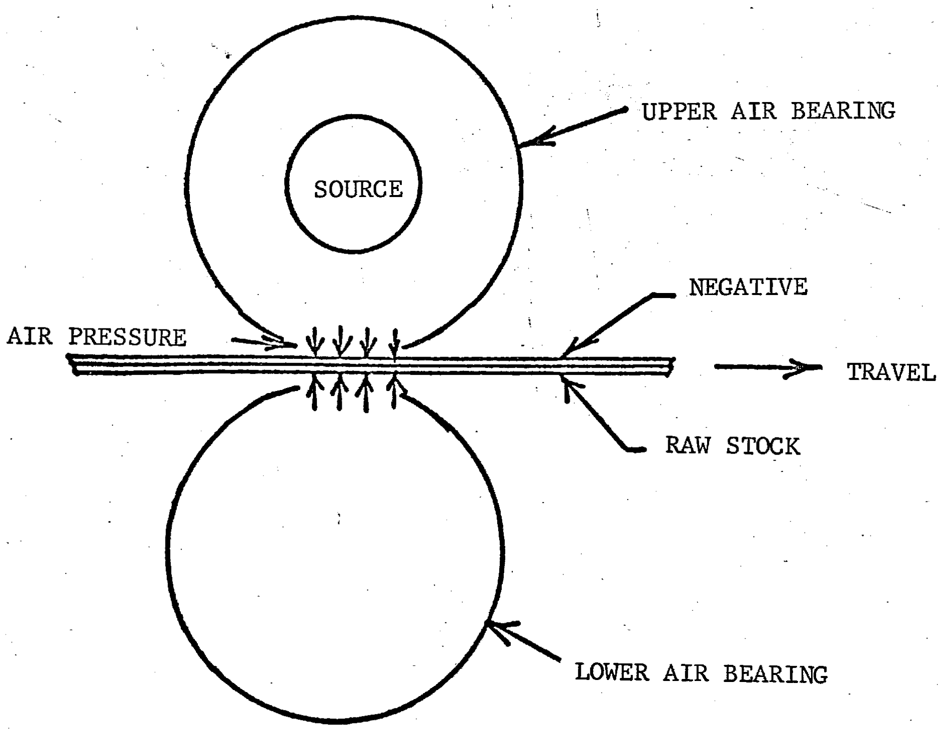

FIGURE 2.12. Air Bearings with Source

The second method employs a centrifuge, introducing a liquid to aid in building up the spin forces. Inert liquids, such as freon or toluene are possible materials. Evenness of liquid distribution over the format and platen-sealing represent two major design problems. Obviously, the problems of minimizing the effects of machine vibration must also be analyzed.

2.2.9 Results of the Open Gate Study - The several open gate techniques that were studied are compared in Table 2.1, which lists the advantages and disadvantages of each technique as well as a short evaluation of each.

3.0 FILM CLEANING

Dirt on aerial film can degrade the quality of information transfer in at least three ways:

1. Dirt can obscure useful information or add noise to confuse the photointerpreter.

2. Dirt particles can produce scratches on the film by abrasive contact or galling.

3. Dirt can prevent intimate film contact and therefore reduce information transfer over substantial areas.

A study has been reported[17] which provides a quantitative measure of the obliterating effect of various size dirt particles. The study concludes that dirt particles below 3.5 micron diameter could not be detected when aerial information is printed in contact on E.K. SO-243.

TABLE 2.1

COMPARISON OF OPEN GATE TECHNIQUES

SYSTEM	ADVANTAGES	DISADVANTAGES	EVALUATION
Liquid Gate	1. Elimination of Newton rings 2. Film cooling 3. Decrease of light scattering 4. Greater resolution 5. Decreases effects of scratches, etc. 6. Excessive roller pressure not required	1. Exacting criteria for liquid selection 2. Removal from films may require recovery equipment if liquids are costly 3. Flammability and toxicity may require closed system 4. Possible hazard to personnel	Advantages outweigh disadvantages. Liquids can be chosen which will not affect films or personnel, or the effects will be small and easily removable. Actual method of application requires careful analysis and design.
Air Bearing	1. Contact nearly equal to that of vacuum frame 2. No friction or rolling action 3. Economy in use of air 4. Cleaning action on films 5. Independent of film thickness on either negative or positive 6. Minimum film tension for driving 7. Predictable and adjustable 8. Bearing life not affected by film contact at any velocity	1. Possible turbulence 2. Limitations on slit or aperture width 3. Relatively complex and expensive 4. Stand-by system required for fail-safe operation	Advantages far outweigh disadvantages. Design of such a system is exacting, and fabrication is to close tolerances. No known effect on films or personnel.
Hydraulics	1. Great contact pressures can be obtained 2. Use of fluid in hydrostatic bearing	1. Closed system for pressurization 2. High pressure seals 3. Not a true open gate 4. Extremely complex supporting system	If a system can be developed for continuous flow, feasibility may be proved. However, at present, disadvantages outweigh advantages.
Vacuum	1. Good contact between films with vacuum printing frame 2. Can be used in conjunction with air jets	1. Vacuum frame difficult in continuous open gate 2. Maintenance of vacuum between films difficult 3. Contamination of evacuated areas is possible 4. Application between films may cause emulsion damage	Because of the continuous flow system, a vacuum system may be difficult to implement. However, if a reliable continuous flow-through vacuum type frame could be developed this might be the best system although a vacuum is not a true open gate
Electrostatics	1. All charged bodies in an electric field exert mutual mechanical forces on each other 2. Good contact is theoretically possible	1. Sensitization of raw stock 2. Possible film damage 3. High voltage requirements to achieve adequate force 4. Attraction of dust 5. RFI 6. Close control of temperature and humidity	Cursory tests do not show a positive answer. Possibility of remote corona charging, but extensive development and study are required in order to provide an answer
Electromagnetic Repulsion	1. Great forces produced by magnetic field in conductor 2. Cleanliness of system 3. Minimum film tension	1. Unknown effects on emulsions on raw stock 2. High temperatures due to high currents 3. Conductivity in developed image may not be enough for force development	An adaptation of a system used by industry for metal forming and fastening. This would require extensive testing and development before feasibility could be demonstrated.
Mechanical Systems	1. Simplicity generally consists of drive rollers, tension devices, contact platens 2. Rotating drum usually used as platen	1. Abrasion in roller system 2. Physical distortion in tension system 3. Smoothness and synchronism of drive is an absolute factor to prevent slippage 4. Small radius drum creates optical distortion	Not an open gate system. Resolution limited by mechanical system.
Adhesives	1. Good contact 2. Open gate	1. Unknown effects on emulsions 2. Problem of application and removal 3. Material compatibility	No standard adhesives would probably do the job. Basic research required to produce properties required.
Simple Air Bearing (Light source within bearing)	1. Good contact 2. Simple 3. No friction 4. Cleaning action on films 5. Predictable and adjustable 6. Open gate	1. Stand-by system required for fail-safe 2. Complex supporting systems 3. Limitations on slit width	Minimum effects on films or personnel. Design criteria are exacting. Advantages far outweigh disadvantages.
Centrifugal Force	1. Open gate system 2. Good contact pressure	1. Rotating mass at end of moment arm 2. High rotational speeds for adequate force 3. Whole system requires rotation 4. Uneven forces for flat gate 5. Uneven lengths for cylindrical gate	Dynamics of system with high inertia forces of film spools, motion, etc., with all the disadvantages, far outweight any advantages.

Film cleaning techniques are available which remove particular dirt above sub-micron particle size. Five techniques were analyzed and include the following:

a. Ultrasonic cleaning

b. Electrostatic cleaning (with static removal)

c. Air knife cleaning

d. Solvent washes

e. Vacuum cleaning

f. Detergent foam cleaning

3.1 Ultrasonic Cleaning

Ultrasonic film cleaning is now capable of removing particles as small as 0.5 micron. Ultrasonics has been used as a standard in the laboratories since 1957[18]. The cost of cleaning solvents is high but recovery systems eliminate most of the losses in the system.

Films never contact the ultrasonic transducers or guide rollers on the emulsion side. Maximum vibration occurs closest to the dirty surface of the films for easy particle removal.

In general. ultrasonic cleaning is a fast, clean method of particle removal. The high cost of proprietary cleaning solvents and initial equipment investment are the only disadvantages noted in the literature.

System parameters[18] of a safe and efficient ultrasonic cleaner are:

a. High speed, fully automatic operation

b. No mechanical contact of film.

c. No dried solvent marks on the film

d. Solvents available which do not react with the film

e. Does not require heater drying likely to cause emulsion distortion

f. Static free

The action of an ultrasonic cleaner is described in detail in the appendix of this study.

3.2 Electrostatic Cleaning

The patent literature[19] describes a method in which electrostatically charged dirt particles are removed from unwinding film. An electrostatic charge accumulates during the film unwinding operation and is transferred to particulate dirt on the film surface. Oppositely charged electrostatic brushes and accumulators sweep the particles from film. The accumulators hold the particles to prevent atmospheric contamination within the machine.

Another patent reference[20] describes a method of removing static charges so that free dust particles can be easily removed. A highly charged brush with a discharge point near the sweeping end neutralizes static charges on the film by ionizing an airstream which washes the film and neutralizes the residual charge. According to the claims, the particles are removed by subsequent brushing action.

Other patent references[21,22] describe methods of cleaning films using rotating brushes to remove electrostatic potentials. Air blasts are then used to remove dust particles.

Commercial bulletins[23] describe dust and static removal equipment. The systems described use sweeping brushes, electrical inductors for static elimination, and air jets in conjunction with the brushes.

The systems previously described relate to cleaning of the developed negative stock alone. Simple techniques for charging the raw stock may cause film damage or exposure by arcing or electrostatic discharge[13,24].

A possible method of cleaning raw film stock with electrostatics and air or vacuum is depicted in Fig. 3.1. High voltage AC fields are applied to the film to neutralize the static charges which hold and attract dirt and dust. The center-tapped DC source biases the system and provides, essentially, an even balance of positive and negative charges. The induced AC field removes the static build-up on the film and the particles can then be easily removed by an air knife system or good vacuum system, possibly in conjunction with an air knife.

Because of the unknown elements in electrostatic or AC field dust removal, a test program would be required to evaluate such a system.

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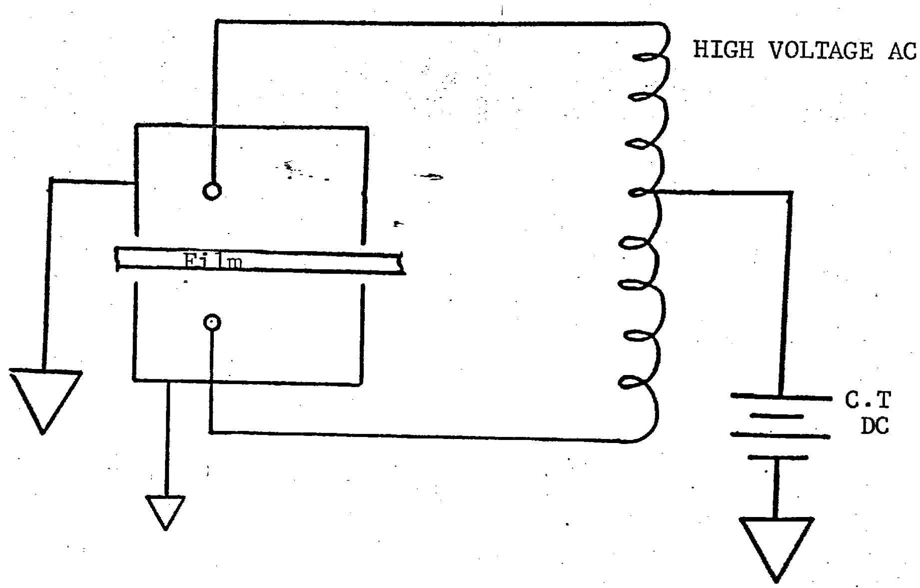

FIGURE 3.1. Static Discharge

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3.3 Solvent Washes for Cleaning

Although there are occasions when film can be cleaned successfully with an air blast, vacuum, brush, or related technique; it may be more effective to use a suitable solvent[25].

The function of the liquid is fourfold:

a. To dissolve dirt

b. To loosen and disperse dirt that does not dissolve

c. To give mobility to possible grit to minimize scratching

d. To discharge static build-up on film.

There are several solvents usually accepted as film cleaners. The most common solvent has been carbon tetrachloride. It is good from the standpoint of evaporation, it is a good solvent for oils, it is inert to film and is incombustible. Although pure carbon tetrachloride meets many of the requirements of a film cleaner, it is a definite health hazard[25]. The fumes are poisonous and excess exposure may be fatal.

Another widely used solvent is based on a small group of hexane related hydrocarbons. However, even though some toxicity may be present, the major drawback is a low flash point and a dangerous potential fire hazard.

Freon 113 is a good cleaner. It is not flammable and only slightly toxic. It has no effect on film base or equipment, but its wide commercial use is limited by its high cost and its extremely high volatility.

Inhibited methyl cloroform (1, 1, 1-trichloroethane) is another solvent in common use.

Most of the solvent washes are mixtures; many of them of proprietary nature. Blending of solvents is usually empirical, but the blends are generally made with high and low flash point materials to control the flash point. Another consideration is the overall toxic effects; blends are made to reduce the toxic effect.

While solvents and their blends are used most advantageously in ultrasonic type cleaners, other cleaning techniques utilize wicks or brushes for film wiping[25]. The operation is usually manual but even if the solvent-wick technique were automated, it is apparent that many problems would arise, such as abrasion, contamination of the wick or brush, solvent contamination, film streaking and possible static charge build-up.

Finally, no information is available to be able to predict the minimum particle size that can be removed by a solvent wick system.

3.4 Air Knife Cleaning Systems

Air blasts or air knives are used primarily for cleaning negatives during the printing cycle in motion-picture film laboratories. The air knife removes dusts whose adhesion to the film is low[25].

During laboratory handling of film a certain amount of room contamination is attracted to the film, even in a clean room environment. Clothing, gloves, and the like, produce lint while additional dust appears as particles scraped from the film by edge guides, gates, etc. These can be removed effectively by the proper use of air blasts or air knives. On the other hand, fingerprints, oils, adhesive marks, and similar materials adhere more tenaciously and are not removed by the purely mechanical action of an air knife.

For dust removal, the momentum of the air stream provides the energy for loosening and removing the particles. Hazards to the film in air blast cleaning include deposition of dirt or "sand-blasting", and possible airborne oil droplets which mottle the film and enhance adherence of dust particles. At times, physical deformation of the emulsion results. Finally, an air stream moving against a poor electrical conductor, such as film, generates static electricity so that controlled high humidity to maintain adequate moisture content in the emulsion is essential in air blast cleaning[25] if other static removal techniques are not employed.

Of course, it is an obvious requirement that any dirt removed by the air be prevented from redepositing elsewhere on the film. This requires adequate air paths so that, once the dirt is suspended in the air, it is removed quickly from the film vicinity to prevent reimpingement and settling onto critical areas as the air velocity drops.

Air blast cleaning partially fills an important need, but has limited objectives and applicability. It is extremely doubtful that a sub-micron maximum dust particle size can be attained.

3.5 Vacuum Dust Elimination Systems

Problems involved in vacuum systems are somewhat similar to those of air blast or air knife systems. Uniformity of vacuum is an important consideration. Generation of a very high vacuum for sub-micron particle size removal is another problem, as is generation of static electricity. Abrasion can occur by entrance of foreign material through the seals of the system. Of course, as in an air knife system, an obvious requirement is that any dirt removed by the vacuum be prevented from redepositing elsewhere on the film. Adequate vacuum paths are required for quick removal of dirt from initial areas. Vacuum will not remove fingerprints, oil, adhesive marks and the like, and it is highly doubtful that a reasonable size vacuum system is sufficient for removal of dust particles as small as the 0.5 micron goal.

3.6 Results of Film Cleaning Feasibility Study

Two systems appear most promising for film cleaning from information available - ultrasonic cleaning and electrostatic cleaning. These conclusions are drawn from a comparison of dust elimination techniques, listed in Table 3.1.

TABLE 3.1

COMPARISON OF FILM CLEANING TECHNIQUES

SYSTEM	ADVANTAGES	DISADVANTAGES	EVALUATION
Air Knife	1. Effective removal of loose dust 2. Air momentum provides energy for loosening and removing particles	1. No removal of finger-prints, oils, etc., by air blast 2. Air moving against unde-veloped films causes static charges 3. Limitations on dust particle size	Partially fulfills re-quirements of good cleaning, but is far from 100% effective. Dis-advantages are obvious.
Vacuum	1. Removal of loose dust 2. Momentum creates energy for particle removal	1. No removal of fingerprints, etc. 2. Static charges generated 3. Limitations of dust particle size 4. Generation of very low vacuum to remove small particles	Disadvantages outweigh advantages. Not com-pletely effective for good cleaning.
Solvent Washes	1. Dissolving and removal of fingerprints, oils, etc. 2. Loosening and disper-sion of particles it does not dissolve 3. Discharge static build-up 4. Mobility to possible grit to minimize scratching	1. Usually a manual operation with solvent and wicks 2. Film streaking 3. Abrasion quite possible 4. Contamination of solvent 5. No information on minimum particle size	Because of the apparent disadvantages, this sys-tem cannot be recommended for a continuous operation, but only for small sections of strips.
Ultrasonics	1. Fully automatic 2. Reasonably fast speed 3. Static free 4. No dried solvent marks 5. No harm to picture area 6. Sub-micron particle removal 7. Oil, grease, etc., removal	1. Critical choice of solvent cleaner 2. High cost of cleaning sol-vents dictates use of solvent recovery system	Advantages far outweigh disadvantages. Present systems clean to 0.5 micron particle size.
Electrostatic Cleaning and Static Removal	1. Neutralization of static charges which attract and hold dust 2. Simple system 3. Possibility of usage on raw stock	1. Careful protection of film from spark breakdown in static field 2. High voltage requirements 3. Close control of tempera-ture and humidity	Induced AC field neutral-izes static build-up. Particles can then be removed by air knife or vacuum.

4.0 TEST PLANS

4.1 Open Gate Evaluation

Liquid gates and air bearing techniques will be evaluated as applied to a continuous film contact printer. The object of these tests is to establish a means by which photographic data contained on good quality aerial negatives can be transferred to duplicating stock at speeds up to 50 feet per minute at a resolution of 300 lp/mm or better. So-267 film, having widths of 70 mm, 5.5 inches, and 9.5 inches will be used for these tests since normal duplicating stock does not have the desired resolution capability. All exposed film will be processed in accordance with manufacturers' specifications.

An experimental frame and housing will be designed and fabricated to accommodate both a "liquid" gate system and an air bearing system. The housing will be daylight operational and will house the negative and raw stock, the light source, the gates, and the necessary drives.

The test program will initially be focused on generating five foot lengths of test negatives using typical aerial film 70 mm, 5.5 inches and 9.5 inches wide, processed in accordance with manufacturer's recommendations. High resolution (500 lp/mm), high contrast (500-1) targets will be uniformly dispersed over the test area.

4.1.1 Liquid Gates - Design and Fabrication - The liquid gate system will be designed and fabricated to accommodate various types of liquid applicators as total immersion, wick, spray, roller and squeegee.

4.1.1.1 Test Program - The test program will utilize a clean roll of the test negative film and raw stock placed in the housing with provisions for accommodating a specific means of liquid application and exposing the test film. Each distinct test run will expose a five foot length of raw stock. Variations in contact pressure, film speed and source diffusion will be included in the tests. Liquid application and removal will also be studied particularly as applied to the negative film. Resolution measurements will be made visually for each set of parameters.

4.1.1.1.1 Test Procedures

a. Preliminary testing will be done on a sub-system basis to determine the means for liquid application as wick, roller and immersion techniques. The most pertinent will be used in the test program for which liquid removal systems as air, vacuum, and squeegee will be studied.

b. Contact pressure variations in the proximity of the gate will be varied by means of rollers or squeegees.

c. Film speeds will be varied in steps of 10,30 and 50 feet per minute. Intermediate speeds can be selected if necessary. Linear velocity of the films will be measured with a speed indicator. Film tensions will be measured statically by use of an accurate scale at the point where the films leave the gate.

d. Diffused and point source lighting will be used. Light intensity will be held constant and film exposure will be held constant by adjusting the aperture for various film speeds.

4.1.1.1.2 Materials and Equipment

a. Resolution Target

b. Test negatives of 70 mm, 5.5 inch and 9-1/2-inch wide (rolls)

c. Rolls of test film stock (SO-267) same width as (b)

d. Photographic chemicals

e. Light sources, diffused and point

f. Liquids for gates

g. 80X - 100X microscope for resolution readings

h. Light intensity meter

i. Tension measuring devices

j. Accurate speed indicator

4.1.1.1.3 Evaluation of Tests - Each test will be randomly replicated a minimum of 5 times and each of the target resolutions will be read with the 80X - 100X microscope.

Average resolution values will be plotted versus contact pressures for the various film speeds for diffused and point source lighting for each film width.

If any resolution value on the replicated tests varies more than plus or minus one target group, the tests for that particular pressure, film speed, and light source will be repeated.

Effects of contact pressure, types and methods of liquid application, and methods of liquid removal will be evaluated. Long and short term effects of liquids on negatives and raw stock will be studied.

4.1.2 Air Bearing - Design and Fabrication - The air bearing system will be designed to accommodate various means for applying film to film contact pressure at the open gate. Fabrication will start only after a careful engineering analysis of nozzle and pad configuration has been made.

Air Bearing System Tasks:

a. Design air bearing system to accommodate various means for applying film to film contact pressure.

b. Fabricate air bearing system.

4.1.2.1 Test Program - This test program will utilize a clean roll of the test negative film and raw stock placed in a housing with provisions for varying air pressure on the film sandwich consisting of negative and raw stock. Film speed will be changed in discrete steps as before with exposure from a diffuse and a point source. Resolution measurements will be made visually for each set of parameters.

4.1.2.1.1 Test Procedures -

a. Preliminary testing will be conducted on a subsystem basis to determine a suitable nozzle configuration for varying and controlling film to film pressure at the aperture. Only those configurations offering promise will be tested at varying film speeds.

b. For chosen configurations contact pressure at the gate will be varied by adjusting the clean air supply pressure and possibly by controlling air layer thickness.

c. Film speeds will be varied in steps of 10, 30, and 50 feet per minute. Intermediate speeds can be selected if necessary. Linear velocity of the films will be measured with a speed indicator. Film tensions will be measured statically by use of an accurate scale at the point where the films leave the gate.

d. Diffused and point source lighting will be used. Light intensity will be held constant and exposure will be held constant by adjusting the aperture for various film speeds.

4.1.2.1.2 Materials and Equipment

a. Resolution Target

b. Test negatives of 70 mm, 5.5-inch and 9-1/2-inch wide (rolls)

c. Rolls of test film stock (SO-267) same width as (b).

d. Photographic chemicals

e. Light sources, diffused and point

f. Pressure gauges

g. 80X -100X microscope for resolution readings

h. Light intensity meter

i. Tension measuring devices

j. Accurate speed indicator

4.1.2.1.3 <u>Evaluation of Tests</u> - Each test will be randomly replicated a minimum of five times and each of the target resolutions will be read with the 80X - 100X microscope.

Average resolution values will be plotted versus contact pressures for the various film speeds for diffused and point source lighting for each film width.

If any resolution value on the replicated tests varies more than plus or minus one target group, the tests for that particular pressure, film speed, and light source will be repeated.

Effects of contact pressure for the selected type of air bearing systems will be evaluated.

4.2 <u>Film Cleaning Evaluation</u>

Much effort has already been devoted to the cleaning problem by both government agencies and private industry for which some successful operating machines now exist.

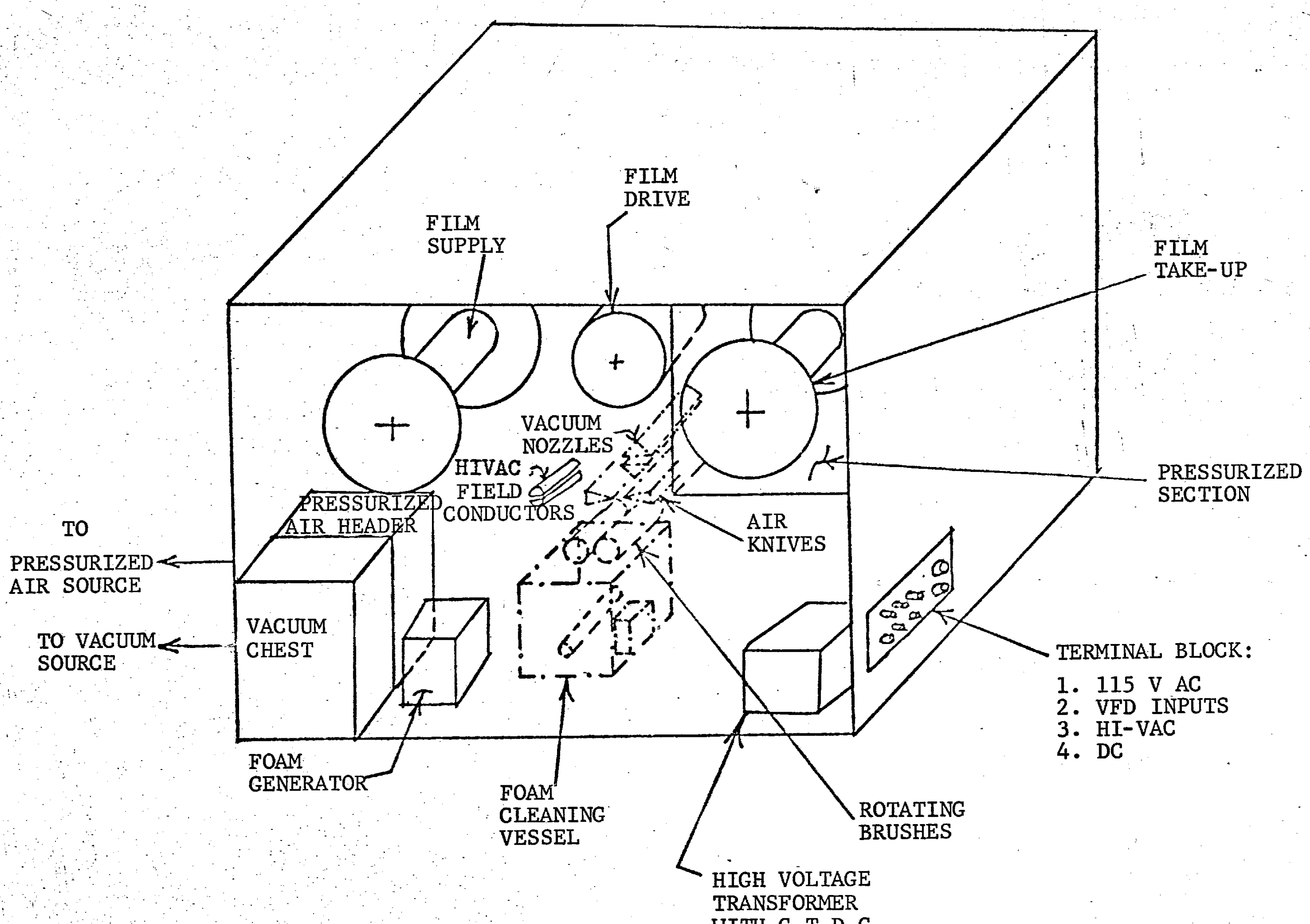

FIGURE 4.0 Universal Film Cleaning Enclosure

Ultrasonic liquid cleaning as used in the Richards CT-11R (.5) machine appears to be one of the more satisfactory methods for removing all types of film contaminants but operation and initial cost are high. Fortunately, film does not often become contaminated with more than dust or film fragments to require cleaning by this method. Therefore, the proposed test plans will be concerned with exploration of other cleaning methods.

The object of the proposed tests is to evaluate other applicable cleaning techniques for film widths of 70 mm, 5.5-inches, and 9.5-inches wide using both typical processed negative and typical duplicating raw stock materials. The negative film will be under exposed and developed in accordance with manufacturers' recommendation so as to have uniform low density. Testing will be done on film which is purposely made dirty with dust and finger prints (on negative film only) then cleaned at speeds of 10,30 and 50 feet per minute. Preliminary tests will be conducted at the low speed of 10 feet per minute for a given film width and only the most promising methods will be evaluated at higher speeds and other film widths. Short and long time effects on emulsion and base will be studied. Cleaning effectiveness of the proposed methods will be observed with a microscope to determine remaining particle size and population density plus removal of fingerprints. Evolution criteria will be generated as a part of the test program. The universal film cleaning enclosure shown in Fig. 4.0 will be designed and fabricated to accommodate various film cleaning methods such as vacuum cleaning (Fig. 4.1), detergent foam cleaning (Fig. 4.2), and electrostatic cleaning techniques. Each system may be tested singularly or in any combination for all widths of film to be tested. Internally, the cleaned film will be spooled in a positive pressure, filtered air input chamber to prevent contamination.

4.2.1 Vacuum System for Film Cleaning - The vacuum system for film cleaning shown in Fig. 4.1 appears to be a good system for particle removal. Rotating fine camel hair brushes will remove particles adhering loosely. It is intended that the ultrasonic transducers further loosen particles which are attracted with greater adhesion. The air knives will essentially separate the particles from the film and the final vacuum will remove all loosened particles.

4.2.1.1 Test Program - Ten foot lengths of developed negative film having a uniform low density will be made dirty by dust particles of 3 micron size and larger. Excess particles will be lightly shaken off and a visual examination made, using a microscope to determine particle size and population density. The film will then be cleaned using various combinations of methods.

4.2.1.1.1 Test Procedures

a. Ten foot lengths of 70 mm film will be coated with fingerprint smears and made dusty.

b. Dust particle size and population density will be noted.

c. Film will be cleaned at 10 ft. per minute using various combinations of cleaning methods

d. Remaining dust particle size and population density will be recorded

e. For the best combination of methods, film speeds of 30 and 50 ft/mm will be tried as well as film widths of

5.5-inches and 9-1/2-inches. Typical raw stock will also be tested with observations made before and after test using safe light so as not to expose the emulsion.

4.2.1.1.2 <u>Material and Equipment</u>

a. Test housing with cleaning methods

b. Pan of dust

c. Test negatives of exposed and developed film of low density or 70 mm, 5.5-inch and 9-1/2 inches wide.

d. Typical duplicating stock of widths as in C above.

e. 50X - 100X microscope

f. Accurate speed indicator

4.2.2 <u>Detergent Foam Cleaning</u> - Detergent foam cleaning appears to possess some advantages over vacuum cleaning techniques since it may also remove fingerprints. Further, the foam is low cost material and is not toxic as are the liquid cleaners used in the Richards machine. The proposed system configuration is shown in Fig. 4.2. The dirty film will pass only through the foam and not be subjected to the liquid so as to keep moisture content of film as low as possible. Rotating camel hair brushes will aid in the cleaning operation and any residue of foam will be removed by the air knife. It is expected that air at 80°F and about 20% relative humidity will provide satisfactory results.

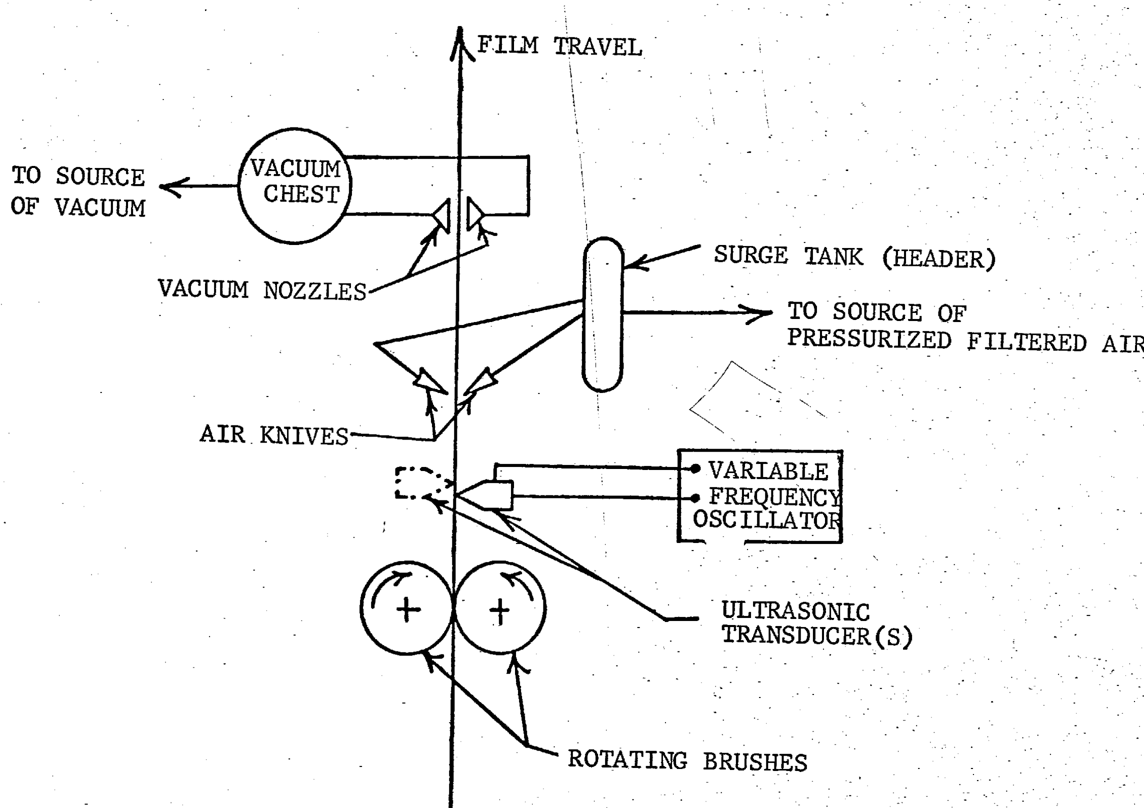

FIGURE 4.1. Vacuum System for Film Cleaning

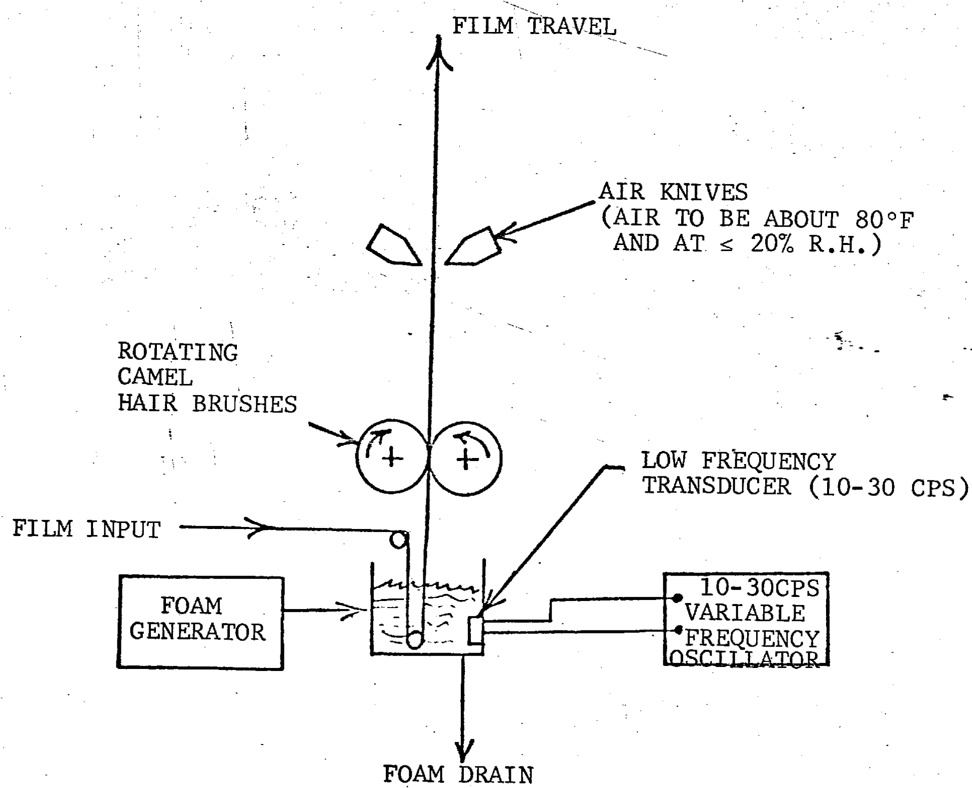

FIGURE 4.2 Foam Cleaning System

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4.2.2.1 Test Program - Ten foot lengths of developed negative film having a uniform low density will be made dirty by dust particles of 3 micron size and larger. Excess particles will be lightly shaken off and a visual examination made, using a microscope to determine particle size and population density. The film will then be cleaned using various combinations of methods.

4.2.2.1.1 Test Procedure -

a. Ten foot lengths of 70 mm film will be coated with fingerprint smears and made dusty.

b. Dust particle size and population density will be noted.

c. Film will be cleaned at 10 ft. per minute using various combinations of cleaning methods.

d. Remaining dust particle size and population density will be recorded.

e. For the best combination of methods, film speeds of 30 and 50 ft/mm will be tried as well as film widths of 5.5-inches and 9-1/2-inches. Typical raw stock will also be tested with observations made before and after test using safe light so as not to expose the emulsion.

f. Short and long time effects of foam on emulsion and base will be studied.

4.2.2.1.2 Material and Equipment -

a. Test housing with cleaning methods

b. Pan of dust

c. Test negative of exposed and developed film of low density, and unexposed duplicating film of 70 mm, 5.5-inches and 9-1/2-inches wide.

d. Typical duplicating stock of widths as in C above

e. 50X - 100X microscope

f. Accurate speed indicator

4.2.3 Electrostatic Cleaning - The Electrostatic method of cleaning of negative and unexposed duplicating film appears to offer some advantages in that dust and film fragments generally adhere to the film by electrostatic attraction. Special attention will be given to corona and AC field generation, static removal and vacuum or air knife particle removal. Ionization effects on film and Radio Frequency Interferences will be studied.

4.2.3.1 Test Program - Ten foot lengths of developed negative film having a low density will be made dusty by dust particles of 3 micron size and larger. Excess particles will be lightly shaken off and a visual examination made, using a microscope, to determine the remaining particle size and population density. The exposed duplicating film as received from the manufacturer will be put through the cleaning operation to determine any effect as fogging, on such film. Cleaning film of other widths at speed of 30 and 50 ft/in will be attempted only if the preliminary tests prove successful.

4.2.3.1.1 Test Procedure

a. Ten foot lengths of 70 mm negative film will be made dusty.

b. Dust particle size and population density remaining on film will be noted.

c. Film will be cleaned at 10 ft/min. at various levels of corona, AC field and air flow.

d. Remaining particle size and population density will be recorded.

e. At the best cleaning condition, unexposed duplicating stock will be put through the cleaning operation to determine any detrimental effects to the emulsion.

f. For the best combination of conditions, providing satisfactory results are achieved, film speeds of 30 and 50 ft/min. as well as film widths of 5.5-inches and 9-1/2-inches will be tried.

4.2.3.1.2 Materials and Equipment

a. Test housing with cleaning methods

b. Pan of dust

c. Test negative of exposed and developed film of low density, and unexposed duplicating film of 70 mm, 5.5-inches and 9-1/2-inches wide.

d. Typical duplicating stock of widths as in C above.

e. 50X - 100X microscope

f. Accurate speed indicator

g. Regulated DC power supply to 5,000 volts

h. Regulated AC power supply to 1,000 volts.

APPENDIX

Exhibit | Page No.

EXHIBIT A

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EXHIBIT C

CONTACT PRINTING
EXPERIMENT

by

[redacted] STATINTL

Optical Technology Department

September 15, 1964

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ABSTRACT

Multiple transparency prints of a 40 x 60 mm array of nine resolution targets were prepared; final resolution values were within the range of 120 - 160 lp/mm. Printing conditions included point and diffuse illumination, several dry and liquid-raw stock interfaces, and variation of interface separation as represented by mechanical pressure.

Results indicate that with liquid interfaces image quality was consistently high regardless of pressure; on the other hand, dry interface images improved with increases in contact pressure, occasionally approaching the quality of liquid interfaces. Resolution at pressures >0.3 lb/in.^{2} was about the same for both point and diffuse light sources; the only difference apparent was that mottle, fringing (Newton rings and particle diffraction) and the reproduction of minor abrasions were more pronounced with point source light.

I. EXPERIMENTAL OBJECTIVES

The purpose of this investigation was to determine, by visual resolution measurement, the influences of light source, original-duplicate separation, and original-duplicate interface medium on print quality. Resolution of at least 300 lp/mm was desirable. The number of tests was rather limited; thus, results are also limited to the conditions of test, and results under other conditions should not be inferred.

II. EQUIPMENT AND PREPARATION

The experimental printer is shown in Fig. 1. The two 1/4-inch glass plates were selected for absence of scratches, bubbles and striae as determined by 25X shadowgraph projection. One of the plates was used as the fixed platen resting on three pads on the horizontal chassis plate. The combined thickness of the target array original and the raw stock was 8.8 mils so, for a free "no pressure" condition, the upper platen was spaced 11.5 mils from the fixed glass by pads outside the film area. During the exposure sequence, the upper platen and auxiliary weight were removed for loading and unloading of raw stock chips. Exposure was controlled manually and timed by stopwatch. Time of day, barometric pressure, humidity and temperature were recorded for each exposure.

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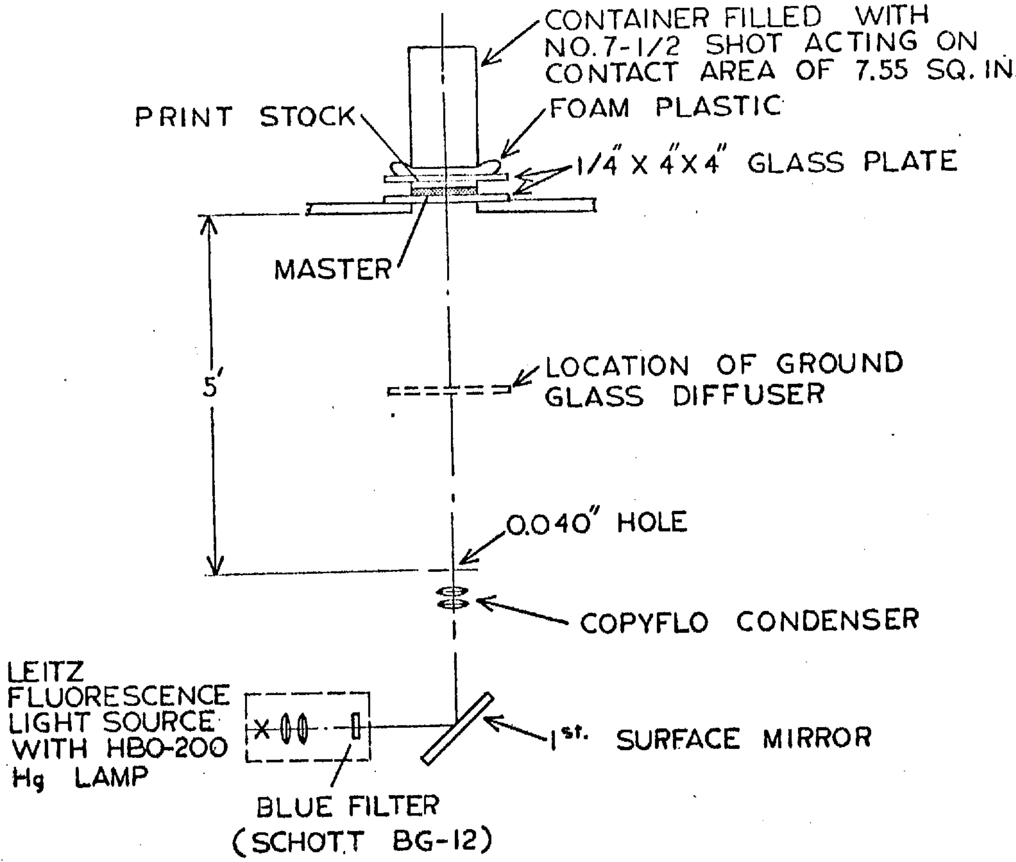

FIGURE 1. Experimental Printer

The materials selected as representative of high resolution operational materials were Kodak Type 4404 (formerly SO-132) as the input, or original, and Type 8430 (SO-278) as the reproduction stock. The 4404 is a panchromatic, 2.5 mil base film which Eastman Kodak reports as capable of 475 lp/mm high contrast threshold resolving power while 8430 is orthochromatic with 5.6 mil base and 335 lp/mm capability.

To surpass the 300 lp/mm reproduction level, an array of high contrast targets was positioned within a 70 mm format area so that each individual target on the 4404 material was identical to the others in its maximum visual resolution threshold. Thus, it would be possible to assess local variations in contact with the reproduction material.

Known suppliers of very high resolution targets were contacted for such an array printed on 4404 material, or lacking this specialized requirement, on any transparency stock. Unfortunately, no arrays were located and it was impossible for any supplier to produce and deliver a special master in the two-week period allotted.

However, a single 650 lp/mm target image was available, so the array was produced in-house. This target, printed on SO-105 material, was a 45.5X reduction, by a special microscopic instrument, of a USAF 1951 high contrast target. The visual threshold--the combination of contrast modulation and line and space dimension degradation--was 650 lp/mm. The target was a positive image (black lines on clear surround); thus, to obtain a positive image array on the 4404 master print, it was necessary to make an intermediate negative. Kodak High Resolution Plate Emulsion (formerly Spectroscopic 649-GH) on 35 mm material was chosen as the submaster stock to assure that the intermediate quality would contribute a minimum degradation in the transfer process. The single SO-105 original was multiple printed, using the equipment assembled for the experimental program (Fig. 1), so that each target image was located within a nine hole mask (Fig. 2). No liquid interface material was used and the local pressure on the SO-105 target area was 4 $lb/in.^2$. The final master was printed on the 4404 material with a single exposure through the 649-GH negative by a similar technique, but with 0.7 $lb/in.^2$ exerted through the top platen area.

The values of resolution for 649-GH and 4404 materials, observed with a [redacted] Ortholux microscope at 80X, are presented in Table I. The array locations refer to the positions in Fig. 2.

TABLE I.

VISUAL RESOLUTION OF 649-GH AND 4404 MATERIALS

649-GH (4404)	649-GH (4404)	649-GH (4404)
Visual Resolution (lp/mm)		
364 (290)	325 (258)	290 (230)
364 (290)	325 (290)	364 (290)
364 (290)	325 (258)	290 (230)

For additional qualification of the target preparation sequence, microdensitometric scanning, with the [redacted] Model 4 instrument and an effective slit dimension of 0.3 x 9.0 microns, resulted in the micro contrast data of Table II for the corresponding visual resolution thresholds.

TABLE II.

CONTRAST DATA

Kodak Film Type	Visual Resol. (lp/mm)	Contrast ΔD	Visual Resol. (lp/mm)	Contrast ΔD	Visual Resol. (lp/mm)	Contrast ΔD
SO-105	650	0.02	650	0.02	650	0.02
649-GH	364	0.02	325	0.02	290	0.06
4404	290	0.10	290	0.10	230	0.18

It should be noted that at the visual threshold level all contrasts were in the "low" category, demonstrating the characteristic contrast reduction which, unless specifically qualified in a target description, must be assumed when the general term "high contrast target" is used. While the lower frequencies of such a target may present line and space contrasts (density differences) exceeding 2.0, the expectation that the high frequencies offer similar characteristics cannot be valid without microdensitometric qualification. High contrast, high resolution image transfer must be initiated with a truly high contrast target image, not merely the image of a high contrast target.

III. EXPERIMENTAL PROCEDURE AND RESULTS

The 4404 Master exhibiting the resolution values given in Table I at the locations shown in Fig. 2, was contact exposed within the twelve element matrix outlined in Table III.

TABLE III.

EXPERIMENTAL MATRIX

			Top Platen Auxiliary Weight	
Source	Contact	No Pressure	2-1/2 lbs.	16 lbs.
Point	Dry	x	x	x
	Liquid	x	x	x
Diffuse	Dry	x	x	x
	Liquid	x	x	x

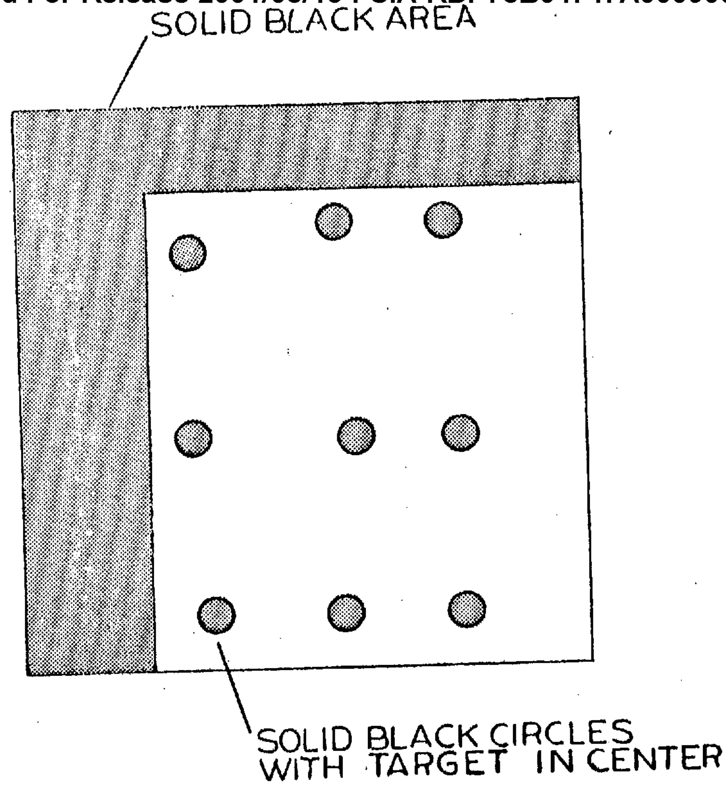

FIGURE 2. Schematic Showing Target Locations on 4404 Master

Two exposures were made for each condition of the matrix, randomly distributed within the matrix. Dry samples were made in a group prior to those involving liquid, to prevent intermingling of effects from residual liquid or cleaning damage influencing dry conditions.

The liquid was a mixture of 90% toluene, 10% Freon 113. It was applied at the center of the interface area by pipette in quantities such that excess did not penetrate to the film-platen surfaces.

Film chips were processed in one batch on each day of exposure, under conditions of controlled agitation, temperature and drying. Chips were identified by random number. Resolution readings were made by two observers the same day as exposure and processing, and were recorded by each observer only with reference to the chip identification number. This technique was used so that observers were not influenced by the pressure, source or interface condition. All reading was done with a [redacted] Ortholux microscope at 80X, with 400X available for checking of visual magnification threshold detail. A total of 450 resolving power readings (including the 4404 Master) was recorded.

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Resolution values were first plotted, with reference to target array location, for each chip to establish graphic trends of the raw data. Values for the nine locations were next averaged by three techniques.

a. readers and replication (four readings/location/condition),

b. readers (two readings/location/chip),

c. replications (two readings/location for one observer condition).

Examination of these data showed:

a. observer agreement to within one $\sqrt[6]{2}$ target element.

b. replication agreement to observation tolerance.

As a result the resolution data corresponding to the locations of maximum value in the 4404 Master array (i.e., the five locations read as 290 lp/mm) were used in final evaluation of the twelve element matrix. The readers and replications for the 8430 chips were numerically averaged for each condition and the resulting values are inserted in the matrix as Table IV and plotted in Fig. 3.

TABLE IV.

SUMMARY OF AVERAGED DATA:
RESOLVING POWER VS PRINTING CONDITION

Source	Contact	No Pressure	Top Platen Auxiliary Weight: 2-1/2 lbs. (0.33 #/in.^{2})	Top Platen Auxiliary Weight: 16 lbs. (2.12 #/in.^{2})
Point	Dry	71 lp/mm	135 lp/mm	122 lp/mm
	Liquid	145 lp/mm	155 lp/mm	167 lp/mm
Diffuse	Dry	76 lp/mm	108 lp/mm	130 lp/mm
	Liquid	145 lp/mm	142 lp/mm	145 lp/mm

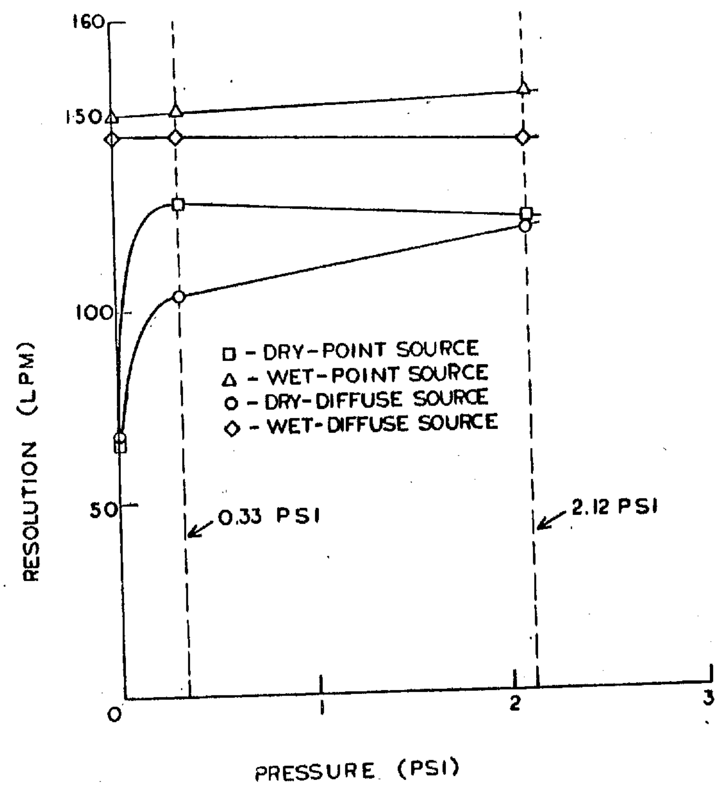

FIGURE 3. Effect of Contacting Pressure on Output Resolution

Figure 3 shows that, at the maximum pressure, all data fall within a three target element range ($\sqrt[6]{2}$ sequence). At this resolution level the spread is 40 lp/mm. Should this resolution spread at maximum pressure hold true for higher input values, any discrimination between the four conditions would not be detectable at stepped $\sqrt[6]{2}$ target frequencies exceeding 400 lp/mm. On the other hand, the three element range might extend to the higher values as well, so that, at 800 lp/mm, the spread would correspond to a 300 lp/mm differential.

IV. CONCLUSIONS

Quantitatively, the resolution data indicate that maximum reproduction fidelity occurs at maximum pressure for all four source and interface conditions. The spread of data at the 0.3 $lb/in.^2$ test point is not appreciably greater than that at maximum pressure, and only when the master-duplicate materials were free within a 11.5 mil spacing was a distinct advantage of the liquid interface over the dry condition apparent. The liquid usage produced high resolution with all source dimensions and pressures.

On a qualitative basis, the following observations were made:

a. A distinct mottling background was apparent in the target region under 80X magnification, with point source illumination, at all pressures, and with both liquid and dry interface media. The effect did not appear when the diffuse source was used.

b. One Newton fringe structure ("L" shaped rather than closed) appeared with no pressure, dry interface and point source. The widest dark band width was measured as 20 microns.

c. Randomly distributed Airy disk-like formations of relatively uniform size (diameter of third ring = 200 microns) appeared with the point source, both liquid and dry interfaces and with increasing pressure. The visual impression was that of a diffraction image.

All these effects were most pronounced when the point source was used, but the resolution targets were not masked detectably in the few cases in which the locations were coincident. The mottling effect can be largely attributed to the gel backing supplied on the 4404 material.

In Fig. 2 it can be seen that only the immediate areas surrounding the targets were exposed through the master; thus, large-area defects, if any, were obscured. This was also true in the case of liquid interface bubbles, which were observed as distinct differences in density, with sharp borders but less definable in diffuse light.

It is concluded that in the reproduction of 70 mm area material, the maximum information is transferred under conditions of a diffuse illumination source, with contact mating pressures exceeding 0.3 $lb/in.^2$. The use of a liquid resulted in very consistent resolution data for all conditions of illumination and pressure.

APPENDIX

This section presents material pertinent not only to the experimental procedure but also to the extension of the conditions to other potential contact printing applications, particularly in the areas of light source characteristics, sensitometry and resolution extrapolation considerations.

1. Light Source Characteristics

Figures 4 and 5 were compiled from manufacturers' literature for comparison of the radiance and spectral sensitivity characteristics of the mercury source and filter used in the experimental equipment, the photographic materials included in the target preparation and test, and the data associated with the use of zirconium. The zirconium arc source exhibits a more general long wavelength peak typical of tungsten and xenon sources and was used for exposure tests to broaden the base of the experimental analysis. In addition, it was observed that the use of the toluene-Freon mixture effected 30% absorption of the mercury-filter radiation (300-500 mμ).

2. Sensitometry

Figure 6 combines experimentally measured absolute D-Log E curves of the 8430 material used with filtered mercury light and unfiltered zirconium. A speed increase of 9.45X and a gamma increase from 1.0 to 1.4 is apparent in the use of the mercury as compared to the zirconium. This order of increase over Kodak tungsten radiation sensitometric data is also evident:

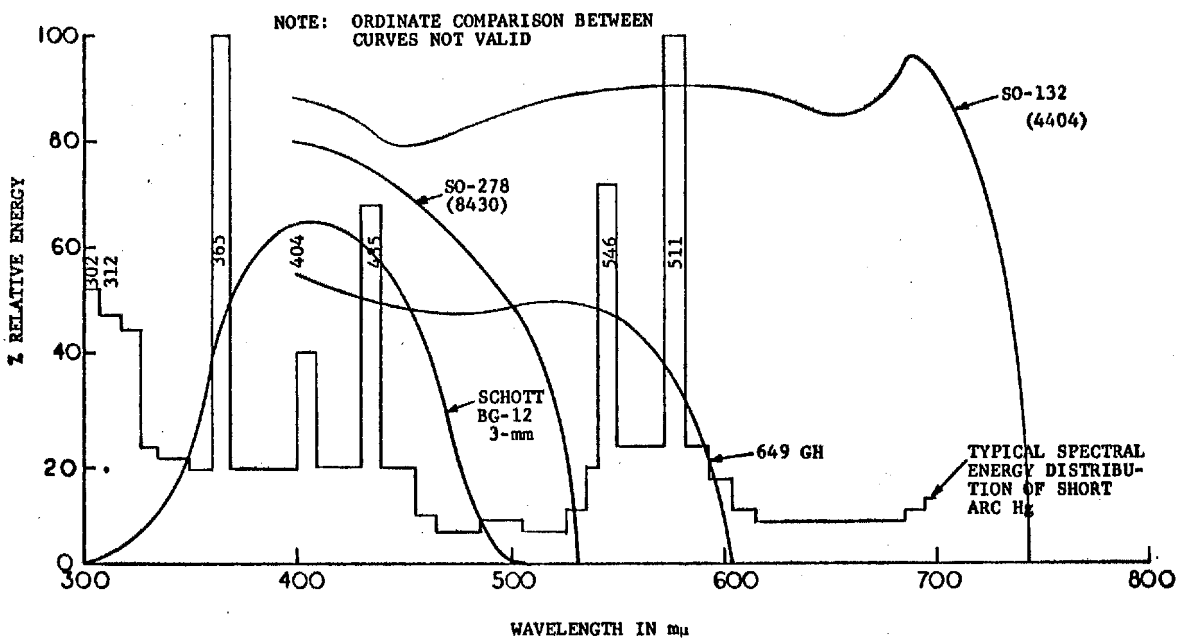

FIGURE 4. RELATIVE RADIANCE AND SPECTRAL SENSITIVITY OF PHOTOGRAPHIC MATERIALS WITH SHORT ARC MERCURY SOURCE.

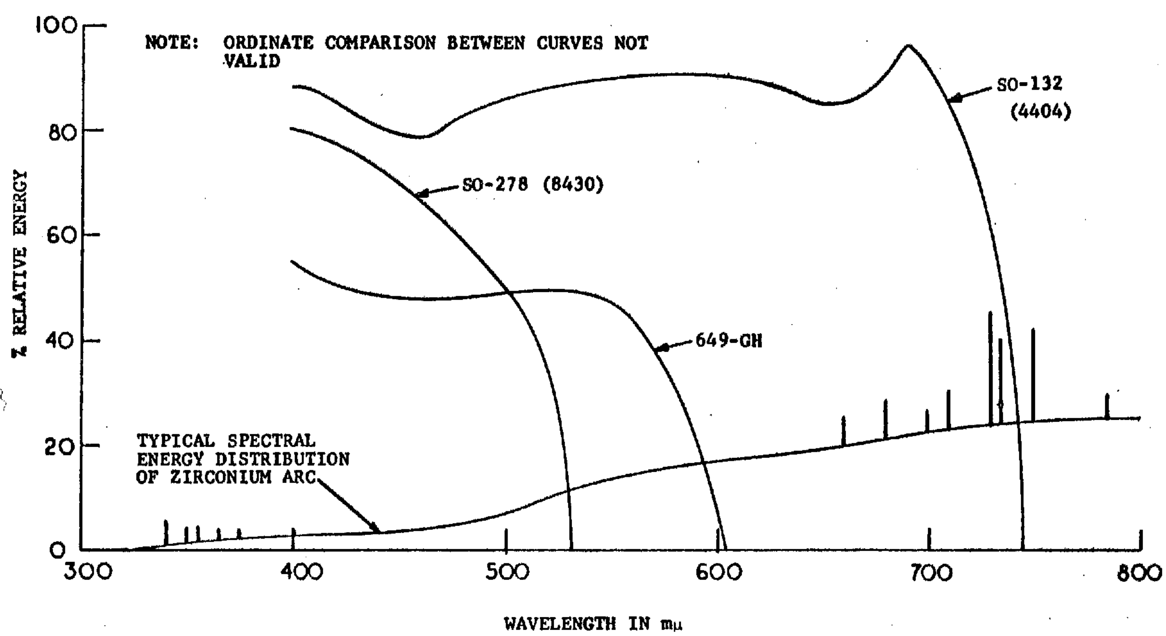

FIGURE 5. RELATIVE RADIANCE AND SPECTRAL SENSITIVITY OF PHOTOGRAPHIC MATERIALS WITH ZIRCONIUM ARC.

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	Speed (1/E) at 1.0 above fog	Gamma
Kodak* (tungsten)	0.06	0.9
[redacted] Mercury	7.95	1.4
Zirconium	0.84	1.0

*Manual of Physical Properties; Aerial and Special Materials.

Also included in Fig. 6 are the data resulting from contact printing with changing exposure of an [redacted] 750 lp/mm target STATINTL (acquired after completion of the basic experiment) on 8430 using a zirconium point source and liquid interface. Note that the resolution maximum generally follows the straight line portion of the D-Log E curve, with a maximum at a log E of 0.025 mcs.

In the process of this exposure-resolution measurement under dry contact conditions image halation occurred, but introduction of the liquid eliminated the effect. Halation did not occur in the exposures with the filtered mercury source. It is understood that 8430 stock has a yellow dye added to the emulsion to minimize halation in the blue region; however, the continuous spectral nature of the zirconium may result in a residual spectral component at the long wavelength region of emulsion sensitivity.

3. Resolution Extrapolation Considerations

Figure 7 was plotted to evaluate the experimental data in terms of theoretical resolution limits. The linear input-output relationship is approached by the four test materials with decreasing target frequency. The maximum value end points

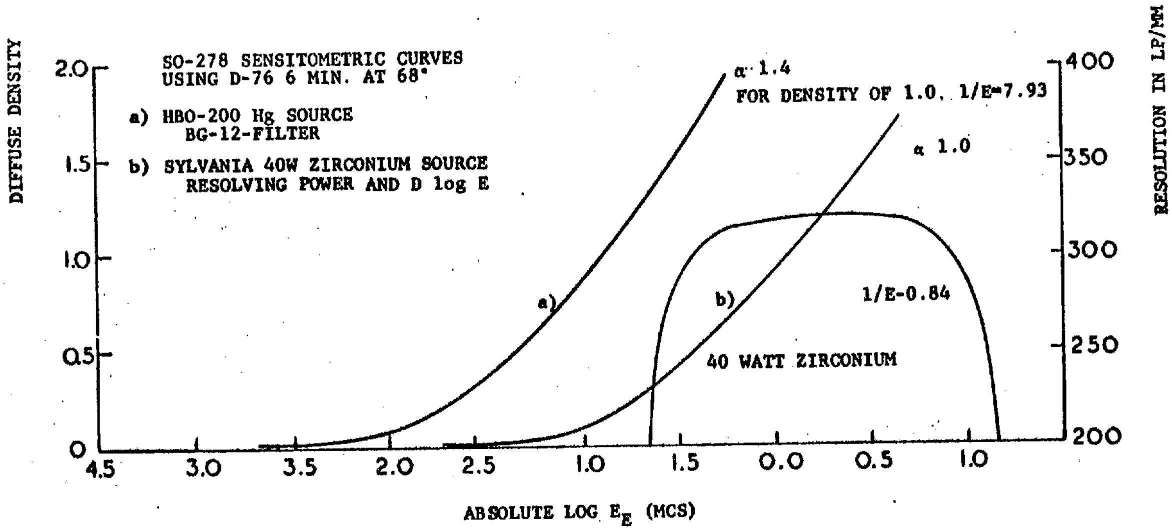

FIGURE 6. Sensitometric Curves for 8430 Material with Filtered Mercury and Unfiltered Zirconium Sources

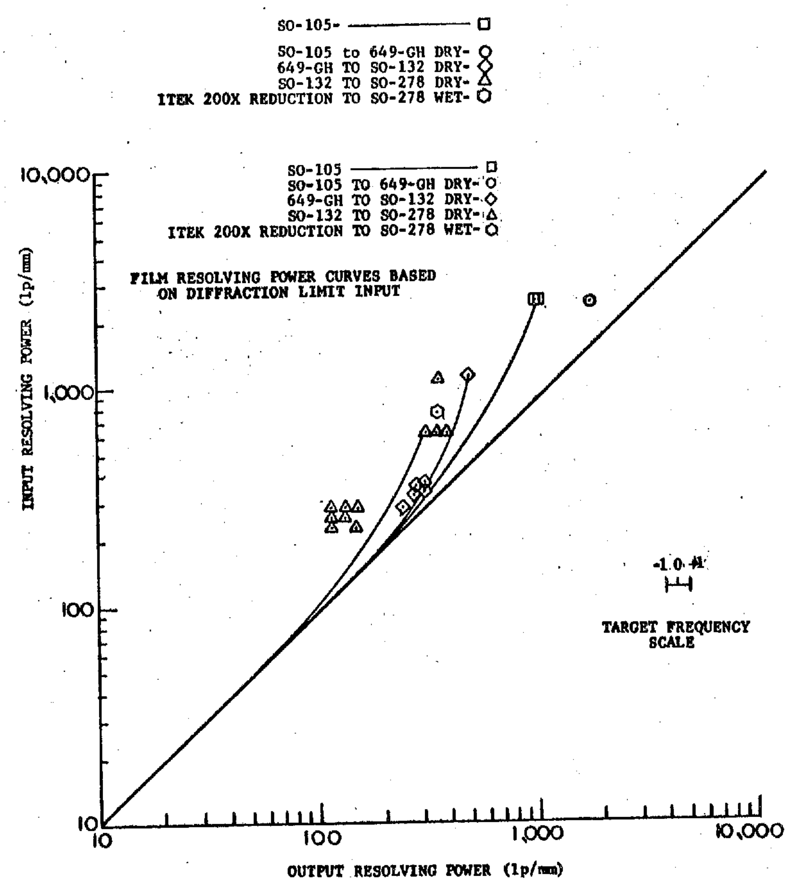

FIGURE 7. Film Resolving Power Curves Based on Diffraction Limit Input

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were plotted using Kodak data, which in terms of input, are the diffraction limits of the reduction optics used. The observations made during target preparation, experiment, and the use of the [redacted] target mentioned above are entered. All but the [redacted] target data are the result of cascading the micro-contrast characteristics of a single image specimen such that the output of the first generation becomes the input of the second and so on. Also, the target frequency scale suggests the order of data scattering that may be expected at all frequency levels.

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EXHIBIT "D"

RESEARCH & ENGINEERING DIVISION

CURSORY INVESTIGATION
OF ELECTROSTATIC ATTRACTION
BETWEEN CHARGED FILMS

November 14, 1963

STATINTL [redacted]

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I. INTRODUCTION

At the request of a government agency a cursory investigation was made to determine the feasibility of employing electrostatic forces in a high resolution film to film contact printer. These tests were conducted employing unsophisticated equipment in the interest of expediency and economy.

II. OBJECTIVES

To perform a cursory examination of the potential application of electrostatic attractive forces between film strips in a film to film contact printer. The effects of several charging methods on silver halide film base materials were also evaluated.

III. TECHNICAL DISCUSSION

A. GENERAL

The investigation was carried out in four parts. Part I was an analytical examination of the anticipated forces. Part II was an attempt to verify the predicted forces empirically on a 10" x 10" parallel plate capacitor. Part III was to examine the shear force characteristics generated by liquid gate and electrostatic attractive forces applied by metal rollers. Part IV was an examination of corona and metal roller charging applied to Eastman Kodak high speed panchromatic film.

B. NORMAL ATTRACTION ON PARALLEL PLATE CAPACITOR

Equation for a parallel plate capacitor:
Eshbach, p. 8-45, eq. 24

$$F = \frac{V^2 K A}{8 x} \qquad \text{where } C = \frac{K A}{4 x}$$

$$\therefore F = \frac{V^2 C}{2x}$$

In MKS system:

F = newtons
V = Volts
C = farads
x = meters
A - square meters

On the 10" x 10" parallel plate aluminum jig plate capacitor, the measured C was:

$C = 9500 \times 10^{-12}$ farad

$x = .003"$ (2 - .0015" Thicknesses of "Mylar")

$$\therefore F_{newtons} = \frac{v^2 (9500 \times 10^{12})}{2 (.003 \times 2.54 \times 10^{-2})}$$

$$F_{newtons} = \frac{V^2 (9500 \times 10^{-12})}{.015 \times 10^{-2}} = \frac{V^2 (9500 \times 10^{-10})}{.015} = \frac{V^2 (9500 \times 10^{-8}}{1.5}$$

$$= V^2 (6330 \times 10^{-8}$$

$$\text{or } F_{newtons} = V^2 (6.33 \times 10^{-4})$$

1 newton = .224 lb.

$$\therefore F_{lbs.} = .224\ V^2 (.663 \times 10^{-4})$$

$$F_{lbs.} = V^2 (.149 \times 10^{-4})$$ (For results, see Table I)

CALCULATIONS FROM EXPERIMENTAL SHEAR TESTS

Tests were run on 2 "Mylar" sheets charged between rollers operating at 2.5 KVDC.

On a charged area of 24 square inches, the median shear stress on a series of replicated tests was about .17 lbs./square inch = τ

Section 8 of the Kodak handbook gives the coefficient of friction of aerial films including Estar base as variable between .2 - .6.

The friction force is

$$F = \mu N$$

where F = lbs.
N = normal force (#)
μ = coefficient of friction

or in terms of stress

$$\tau = \mu P$$

where τ = shear stress (#/sq. inch)
μ = coefficient of friction
P = normal stress (#/sq. inch)

If we assume μ = .2 and solve for P, then

$P = \frac{\tau}{2} = \frac{.17}{2}$ = 185 lbs./sq.in. normal stress as compared to calc. P = .931 lbs./sq. in.

At μ = .6, $P = \frac{.17}{6}$ = .283 lbs./sq.in. (calc. P = .931)

At μ = .4 (average), $P = \frac{.17}{.4}$ = .425 lbs/sq. in. (calc. P = .931)

These values are all close considering that the dielectric thickness does not account for air, cement, etc.

C. NORMAL ATTRACTIVE FORCE ON PARALLEL PLASTIC SHEETS

1. Purpose

To determine the order of magnitude for forces normal to parallel capacitor plates when subjected to charge potentials.

2. Conclusion

A force on the order of .08 lbs./sq.in. was observed with 200 volts dc applied to 10 x 10 inch metal plates coated with 1.5 mil "Mylar: and placed in contact. This force was observed to be monotone increasing with voltage up to 2000 volts beyond which the force reduced sharply, probably due to breakdown of the "Mylar" materials. The measured time constant for decay of the applied charge was observed to be approximately .8 seconds, attributed to conductive leakage through faults in the plastic film.

3. Factors and Measurements

This was intended to be a simple experiment designed to determine the magnitude of the attraction force between parallel plates separated by dielectric material. The response of such forces to a change in charge potential was of some interest so that several levels of voltage (500, 1000, 1500, 2000 and 2500 vdc) were used. A separation force normal to the plane of contact was measured using a 0-80 lb. spring scale.

4. Test Design and Procedure

Two replications of a single factor, 5 level design, conducted in randomized sequence was employed. Test plates were 1/4" aluminum "Jig Plate" 10 x 10 inches square and coated with 1.5 mil "Mylar" sheet. In testing, one plate was placed in physical contact with the other, a voltage applied, and the force required to separate the plates was measured.

5. Data and Analysis

Test results are tabulated in Table II. Experimental error was quite small with the exception of the results at 1500 volts. Valued entered as * are greater than 0 but less than 4 lbs. and were not measured due to the equipment available. A maximum of .08 lbs. per sq. inch was observed at 2000 volts dc. Higher voltage resulted in less force suggesting some sort of change in the electrical properties was taking place. The cause for this was not completely determined.

D. SHEAR FORCE BETWEEN PLASTIC FILMS

1. Purpose

To determine the shear force between two pieces of "Mylar" plastic when charged electrostatically.

2. Summary

With 2.5 KV applied to the plastics, a median force of .18 lbs. per sq. in. was obtained. Another series of tests were performed using a water film layer between the plastics and without charge. In this case, a median force of .23 lbs. per sq. inch was recorded.

3. Factors Studied and Measurements

The tests were conducted so as to measure shear force between films. Since it was expected that area and applied voltage would have the most pronounced effect on the shear force, these were chosen as the variables. The voltage levels applied were 0.5 KV, 1.5 KV and 2.5 KV on either 12 or 24 square inches of contact area.

4. Test Design

A randomized two by three full factorial was used. Voltage was applied between steel rollers supported in a suitable dielectric framework. A controlled contact area was passed through the charging rollers, and specimens were pull tested. The "Mylar" was .0015 inches thick. As a standard, a thin water film was used between the plastics, with 36 square inches of contact.

The measurements were made in all cases by application of dead weights.

5. Analysis

Test results are tabulated in Tables III and IV. At 1.5 KV and .5KV, the forces between the two plastics were insignificant. At 2.5 KV, attractive forces were of the order of .14 lbs. per square inch. There was some lack of repeatibility of measurements from test to test.

E. CHARGING OF FILMS

1. Objective

To charge silver halide film both with positive and negative corona and between conductive rollers to study charging effects on the emulsion.

2. Equipment

STATINTL [redacted] Model A Processor

2500 VDC NJE power supply

2 roller charging unit*

Tri-X pan film (ASA - 400)

3 mil "Mylar" sheet

D-72 developer solution and normal fixants

3. Results

Positive and negative corna fogs the film, both with and without a 3 mil "Mylar" protective sheet.

The roller charging unit both covered and uncovered with 3 mil "Mylar" produced fogging.

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*Two 1-1/4-inch diameter steel rolls 4-inches long held in non-conducting bracket.

IV. CONCLUSIONS

1. Very exotic charging methods would have to be used.
2. Theoretical forces obtainable from electrostatic attraction (see Fig. 1).
3. The liquid gate in itself provides clamping forces that greatly exceed those theoretically obtainable with electrostatics.

V. RECOMMENDATIONS

1. Evaluation of actual clamping forces required.
2. The forces should exceed those existing at the liquid gate. An evaluation should be made of techniques offering greater potential forces.

TABLE I

V	V^2	F lbs.	P(#/in²)(100 in² plate)
500	25×10^4	3.7	.037
1000	10^6	14.9	.149
1500	2.25×10^6	33.5	.335
2500	6.25×10^6	93.1	.931

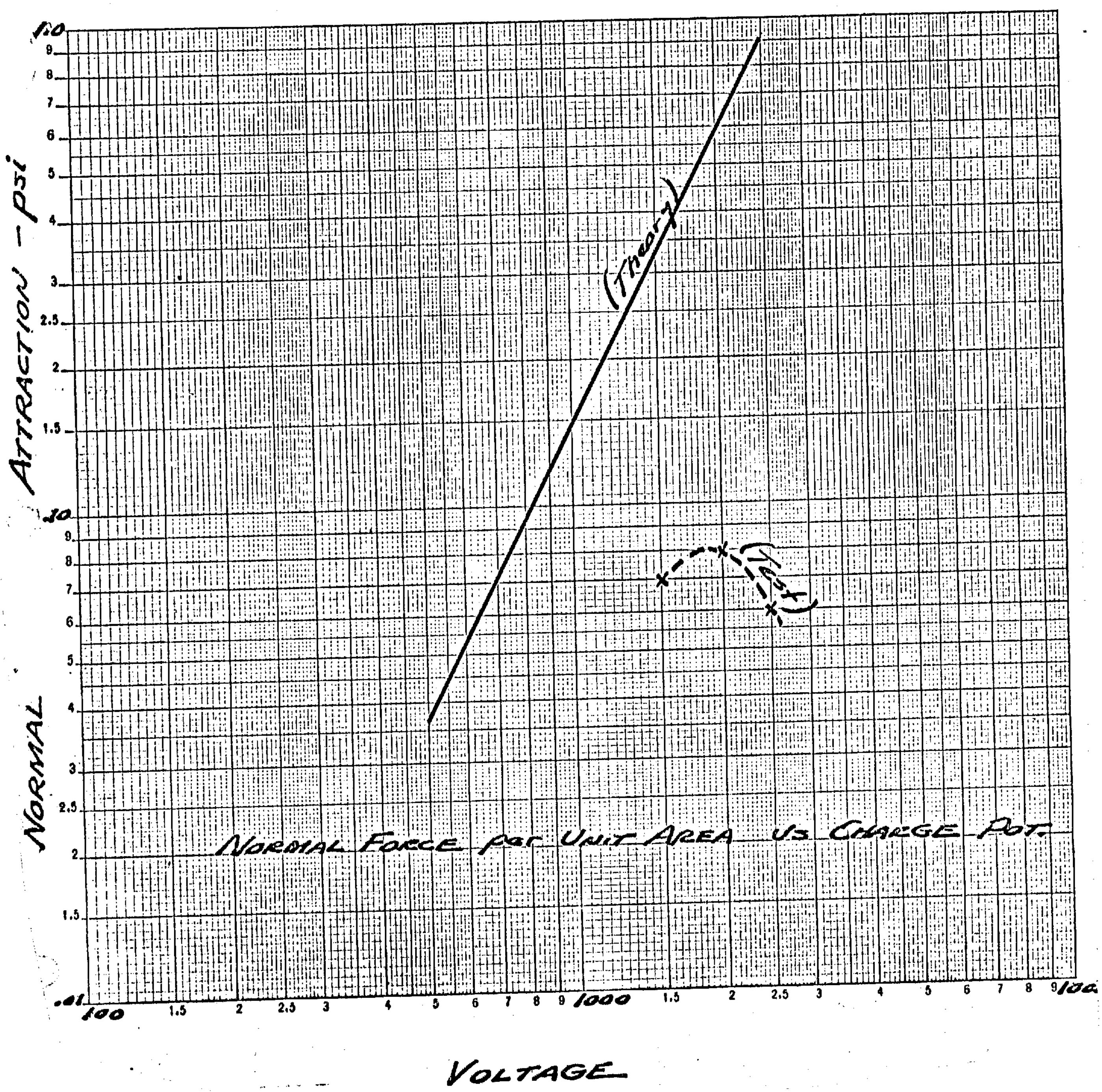

FIGURE 1.

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TABLE II

APPLIED POTENTIAL Volts DC	TEST SEQUENCE	SEPARATION FORCE - LBS (Normal)
500	9 3	* *
1000	2 10	* *
1500	5 7	7 *
2000	8 1	8 8
2500	6 4	6 6
Measured Capacitance		7500 pf Start 9500 pf Finish

TABLE III

Contact Area	APPLIED VOLTAGE 2.5 KV		1.5 KV		0.5 KV	
4" x 3"	2.1 lbs.	(3)	0.5 lbs.	(7)	0	(5)
	0 lbs.	(13)				
	2.2 lbs.	(14)				
	2.4 lbs.	(6)	0	(10)	0	(8)
4" x 6"	3 lbs.	(11)	0	(4)	0	(1)
	4.8 lbs.	(15)				
	4.3 lbs.	(16)				
	1.5 lbs.	(12)	0	(2)	0	(9)

TABLE IV

Order of Test	Shear Lbs.	Force lbs./in^2
1	8	.2
3	9	.3
2	12	.3

Conditions: Water Film used between plastic sheets
Contact area 36 in.^{2}