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KC-TECHNOLOGY AND TWO POSSIBLE APPLICATIONS IN PHOTOGRAMMETRY

Abstract:

KC-coatings are wholly inorganic, crystalline, photoconductive coatings with panchromatic response, high resolution and the sensitivity of high-resolution silver halide emulsions. Production, characteristics and the use of KC-coatings are described with emphasis on their use as a photographic recording medium. Some applications of the KC-technology are mentioned, and two intended applications in photogrammetric operations are described briefly.

KC-TECHNOLOGIE UND ZWEI MÖGLICHE ANWENDUNGEN IN DER PHOTOGRAMMETRIE

Zusammenfassung:

KC-Beschichtungen sind vollkommen inorganische, Kristall- und lichtelektrisch leitende Schichten hoher Auflösung mit einer panchromatischen Empfindlichkeit ähnlich der von Silberhalogenidemulsionen mit hoher Auflösung. Herstellung, Eigenschaften und Verwendung von KC-beschichtetem Material werden beschrieben, insbesondere im Hinblick auf dessen Verwendung für photographische Zwecke. Es werden einige Anwendungen der KC-Technologie erwähnt und zwei beabsichtigte Anwendungen im photogrammetrischen Bereich kurz beschrieben.

LA TECHNOLOGIE KC ET DEUX POSSIBILITES EN PHOTOGRAMMETRIE

Résumé:

Les enduits KC sont complètement inorganiques, crystallins et photoconducteurs; ils ont une réaction panchromatique, une haute résolution et la sensibilité des émulsions de halogérure d'argent à haute résolution. On décrit la production, les charactéristiques et l'usage des enduits KC en appuyant sur leur usage en tant que véhicule de reproduction photographique. On mentionne certaines applications de la technologie KC et deux applications tentatives en photogrammétrie sont examinés.

1. INTRODUCTION

Most photogrammetrists are used to handle photographic products and are, therefore, well aware of a number of ground rules for handling such products, such as

- keep the photographic product from light before exposure and development
- store the photographic product in a cool place to prevent emulsion decay
- expose and process the photographic product carefully because either process cannot be repeated on the same piece of material
- observe rules pertaining to toxicity and disposal

In addition, photogrammetrists know that silver molecules are an essential ingredient to any photographic emulsion and are, or should be, well aware that silver is not only becoming scarcer but also, because of its depletion and as a result of increasing distrust in money as a means to conserve wealth, more expensive. These factors and the inconvenience of operating for extensive periods of time in a darkroom, have forstered the desire for a different type of emulsion free of the mentioned drawbacks, for quite some time.

An "emulsion" which is less expensive to produce and use and does not require as many ground rules for handling and as many darkroom operations, will be discussed in this paper with some of its characteristics. In addition, two possible applications in photogrammetry will be described.

2. REVIEW OF KC-TECHNOLOGY

KC-Technology, named for the inventor M. R. Kuehnle and his partners in harnessing the invention, W. and J. Coulter, is a totally novel technology. It combines properties of photographic materials to be discussed in section 3, magnetic recording media, offset printing plates, photocells and transistors. We shall sketch in this section the production of KC-coatings, their physical and electrical characteristics, and their use.

2.1 Production of KC-Coatings

KC-coatings are manufactured with a sophisticated proprietary radio-frequency sputtering process which causes the deposition of certain chemical elements on a suitable substrate. A series of cathodes surround for this process a central anodic cylinder. This cylinder transports the substrate past the cathodes. The interim space is filled with an intense and uniform gas plasma. The plasma ions bombard the cathodes, removing from them molecules of photoconductor material by kinetic energy. These molecules are then driven towards the anode, where they impact on the substrate web. The molecules position themselves under the influence of an intense field, gas pressure, temperature, secondary ion bombardment, electrical energy density and specially induced eddy currents in a crystal lattice structure shown to be a very uniform formation of tiny, essentially monocrystalline vertical towers with a hexagonal cross section.

The substrate can be of a wide variety of materials but only two have thus far been used in greater amounts, polyester film and stainless steel plates.

The polyester film used is of the same kind and thickness (100 µm) as that used as substrate for silver halide emulsions for films for aerial photography. Prior to exposing the film to the intense environment within the sputtering chamber, it is heat-treated to remove residual stresses and to control dimensional changes. During the first pass through the chamber, the film is coated with a very thin conductive (or ohmic) layer. The photoconductor crystals are grown during a second pass through the same chamber. Fig. 1 shows a cross section through KC-film.

KC-film is presently produced in 1500 m long rolls up to 1 m in width.

Stainless steel does not require a conductive layer because it can assume its function. At present, 300 m long rolls up to 1 m in width are coated in a single pass through a special coating machine.

The photoconductor crystals are typically cadmium sulfide crystals.

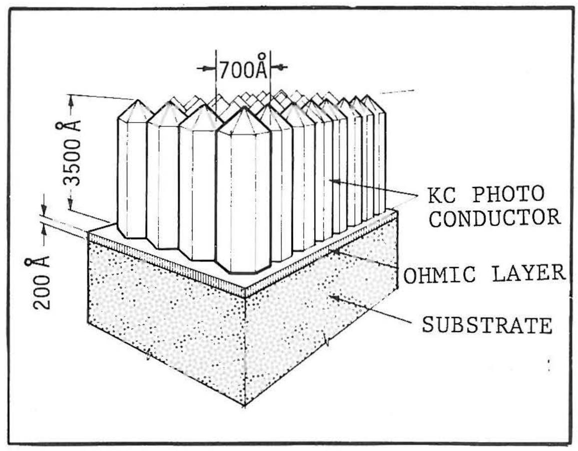

Fig. 1 Construction of KC-film showing the morphology of a perfect cadmium sulfide layer

2.2 Physical Characteristics

Fig. 1 gives the dimensions of the two coating layers: the conductive layer is 0.02 µm thick, and the hexagonal crystals are 0.35 µm high and 0.07 µm thick. Hence, the entire coating is less than 0.4 µm thick. The linear density of the crystals is about 14 000 / mm which results in having available about 196 000 000 elements / mm^2. It is difficult to imagine the tremendous information storage potential of KC-coatings, or the resolution potential of about 7000 lp / mm (if each crystal could be separately exposed, for example with an electron beam), in particular since photogrammetrists work today with emulsions having resolutions of about 30 to 50 lp / mm and with lenses having up to 200 lp / mm resolution on axis but only about 10 to 20 lp / mm in the corners of the 23 cm x 23 cm format (f = 15 cm).

KC-coatings have, in addition to the high resolution and the low raw material cost, other physical characteristics of interest to photogrammetrists; they are

- transparent
- panchromatic (see section 3)
- hard and abrasion resistant because of the crystalline structure
- inorganic and thus invariant in their original composition and unaffected by environmental changes, bacteria and fungi
- reusable until purposely fixed because exposing and processing do not change the nature of the photoconductive layer
- inactive until charged and can therefore be stored in any reasonable environment without protection from light heat, cold or humidity

2.3 Electrical Characteristics

KC-coatings consist of crystals; each of these is a semiconductor and acts as an individual image element. The behaviour of KC-coatings can therefore be described precisely. Elemental composition (stoichiometry) and structure (morphology) of the crystals are so nearly perfect that electronic charges are evenly distributed over the whole coating. The crystals are anisotropic; they display significantly different (uncharged) resistivities along and across the crystals: in the dark about 10^{11} and 10^{13} ohm cm respectively, and in light about 10^6 and 10^8 ohm cm respectively. This is a most important property since it results in a significant barrier to lateral signal diffusion and, therefore, protects against loss in resolution in both binary and analog form, and against loss in contrast.

The resistivity can be increased to 10^{14} ohm cm with the deposition of a uniform electronic charge. This deposition requires the application of a closed electrical circuit connecting the thin conductive (ohmic) layer of the film, or the metal substrate, with a high-voltage source which terminates above the other side of the semi-conductor crystals in a thin wire or needle positioned close to the surface. When voltage is applied, the air surrounding the wire (or needle) becomes ionized. The ions move rapidly towards the film surface where they dispose of their extra electrons which instantly fill the available trapping sites within the surface.

Electrons begin to leak away immediately upon charging, causing a slow decay of the surface charge in the dark. The maximum charge attainable, about 32 V, is self-limiting when charge current and leakage become equal, and can only be deposited with specific relationships between charge current and charge time. Extended charging suppresses maximum charge acceptance and accelerates dark decay, whereas insufficient charging does not provide the necessary number of electrons needed to assemble the optimum number of charges on the surface. A lesser charge than maximum results in a slower rate of leakage. Since the decline is such that percentage levels remain virtually constant, charged coatings remain in readiness for exposure for a relatively long time.

A typical dark decay curve is shown in Fig. 2. This curve is an expression of the equation

$$V(t) = V_o - K \cdot \ln\left(1 + \frac{t}{T}\right)$$

where V_o is the surface voltage upon completion of charging, $V(t)$ the surface voltage at the time t, and K and T are material constants dependent on V. The figure shows a rather fast decrease from 32 V to about 15 V after 60 seconds and indicates that the further decrease is rather slow. The constants have in this case values of $K \sim 1.57$ and $T \sim 0.000\,02$. The fully charged surface supports a charge of about $8 \cdot 10^{-7}$ coulombs / cm^2 which corresponds to about $5 \cdot 10^{12}$ electrons / cm^2 or about 250 electrons / crystallite. This charge imposes a field of $E \geq 10^6$ V / cm across the length of the crystallite. The internal profile of the field produces, because of this high surface charge density, electron acceleration energies which result in impact ionization and quantum yields greater than one; this is the main factor responsible for the high light sensitivity of KC-coatings.

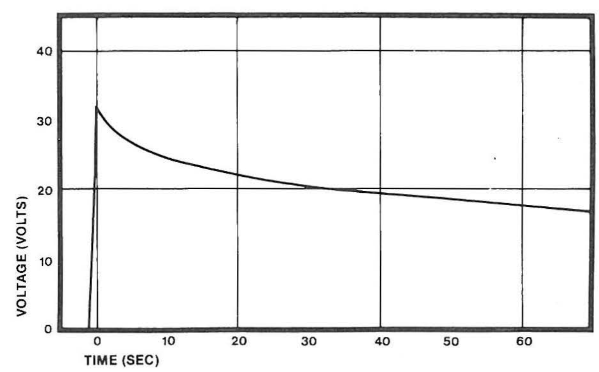

Fig. 2 Diagram of surface voltage decrease with time. The voltage falls from 32 volts to 15 volts in 60 seconds. The exposure and toning should be completed during this period. Decay is slow after this period reaching 4 volts in 15 hours.

Exposure causes an instantaneous reduction of the surface charge in precise relation to the incident light. A certain finite amount of light discharges the coating totally to zero background, while intermediate exposure energies reflect intermediate surface voltages. The response of KC-coatings to light is practically instantaneous since the transit time of an electron is only about 10^{-10} seconds. There is practically no persistence when illumination ceases since the lifetime of an electron is only about 10^{-5} seconds. A continuous-tone picture contains areas which may be fully exposed, or not exposed at all, with many image areas corresponding to intermediate voltages. It was already pointed out that the latent images do not "bleed" laterally because of the anisotropy of the coating; in other words, crystals retain their respective voltages. Moreover, the nature of the dark decay is such that all voltage levels decline with the retention of fixed percentage relationships, thus retaining total image fidelity. This means that an image can be developed, for example, after 1 second or after 30 seconds, to reproduce the entire range of grays.

Fig. 3 shows the spectral sensitivity of two KC-coatings. The undoped coating (KC-101) covers the entire visible spectrum, extending far into the short wave-lengths. The decrease in sensitivity towards the near infrared helps to avoid unwanted heat effects within the coating. Dopents can be used in the manufacture of the coatings to increase the red and near-infrared sensitivity, as demonstrated by an experimental coating (KC-103) in Fig. 3, without appreciably affecting temperature sensitivity. KC-coatings work exceptionally well with low energy lasers of the Argon ion class as well as with HeCd types. Experimental coatings of the KC-103 variety can work with HeNe or solid state lasers operating at the red end of the spectrum.

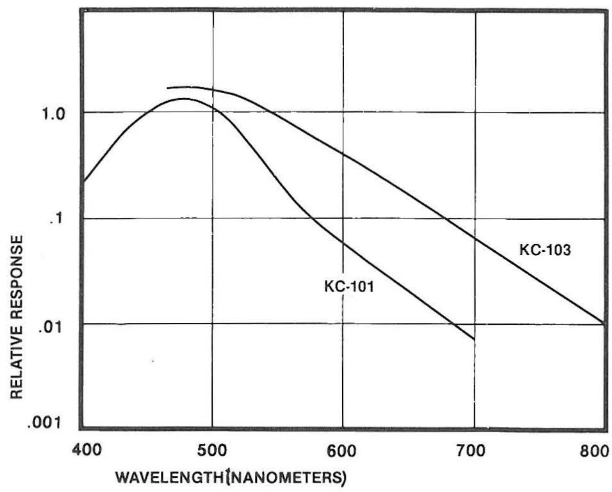

Fig. 3 Spectral sensitivities of KC-101 (undoped) and KC-103 (doped) coatings.

2.4 Procedures for Using KC-Coatings

KC-coatings must be activated to receive data (they must be charged), must receive, remember and store data during and after exposure, and must make these data processable by development (by toning).

Some aspects of charging have already been discussed in the preceeding section. Typically, a corona source passing at a few millimeters distance over the crystals at a speed of about 26 to 37 cm / sec will activate the crystals to become photoreceptive. KC-coatings can operate over a rather wide range of temperatures and are affected in their charge acceptance only relatively little by changes in relative humidity. Experiments have shown that temperatures up to 70°C and relative humidities between 0% and 90% are acceptable.

Some aspects of exposing were also already discussed in the preceeding section. Although it is not possible to compare KC-coatings directly with silver-halide emulsions in regard to their sensitivity, it can be stated that their sensitivity corresponds to that of high-resolution lithographic emulsions. Contact exposures require only the energy of a 75 Watt incandescent bulb for one to five seconds at 0.5 m distance to complete the exposure of any black & white or color original.

Toning, that is the conversion of latent electron imagery to visible imagery, is achieved by depositing a small amount of liquid containing toner particles on the coating surface. The liquid must be trapped between a developing electrode and the coating surface to create an electrical field between the electrode and the internal field of the photoreceptor layer. The entrapped liquid contains small particles of opposite electrical polarity which migrate rapidly towards the coating surface and become deposited on this surface in a layer. The amount of attracted toner is about proportional to the charges on each crystal. More about toning will be said in the following section.

Although a toned image can be viewed and will not change, it is very sensitive to touch and can easily be wiped off. If is therefore desirable to fix the image by fusing the toner to the crystal layer through heat application or chemically. Self-fixing toners are presently under development.

A basic KC-system for data recording comprised of a charge station, an exposure station, a toner applicator and a fuser, is shown in Fig. 4.

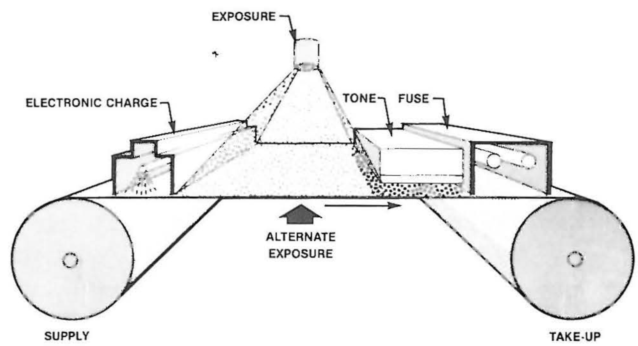

Fig. 4 Diagram of a basic KC-data recording system

Instead of fusing the toner to the crystal layer, it can be transfered to a different medium. The transfer of a toned image onto uncoated paper or film is relatively simple: toned image and uncoated material are run through transfer rollers; a voltage is applied to these rollers as the sandwich of the two materials passes through, and this transfers the toner from the coated to the uncoated surface. Since very little dispersant is used, a printed copy on paper can be handled immediately, because the tiny toner particles imbed themselves so well into the paper surface that neither drying nor fusing are necessary.

3. PHOTOGRAPHIC CHARACTERISTICS OF THE KC-IMAGING PROCESS

It has already been pointed out that KC-coatings can record tonal graduations of an original image without lateral signal diffusion in a manner equivalent to high-quality silver-halide emulsions. A KC-image does not, therefore, evidence the contrast distortions and edge effects commonly found with other photoconductive imaging materials. Neither occurs within the coating light scattering.

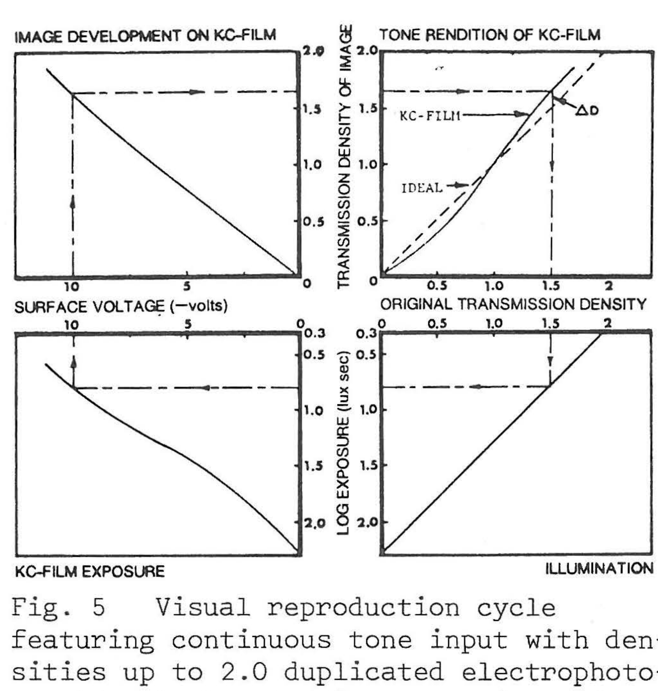

Fig. 5 Visual reproduction cycle featuring continuous tone input with densities up to 2.0 duplicated electrophotographically by charging, exposing and toning, resulting in a minimum density deviation (ΔD) at the final image.

KC-coatings require the application of specially developed toners which respond to the high charge densities, low surface voltages, tonal rendition needs and extreme resolution requirements. Since the coatings can be discharged to zero backgroud by a certain finite amount of light, the toners must be capable to show virtually zero fog which is particularly difficult to achieve. KC-toners respond to less than 0.5 V increments and conform linearly proportionally to surface voltage and toning time, rendering long scale continuous tone images (Fig. 5). Suitable toners can be selected for specific applications, for example

- black & white high resolution continuous tone toners
- black & white binary toners
- color toners
- fusible lithographic halftone toners
- transfer toners

The KC-imaging technology works normally without image reversal but inverse (or reversed) images, as they result often in silver halide emulsion photography, can be produced by the use of special toners in combination with an electrical manipulation during the toning process. This is important for photogrammetric applications where a negative original needs to be reversed.

The individual toner particles are extremely small. The pellets making up the toner have diameters of less than one tenth of a micrometer, or one in the same order as the crystals. However, it is for several reasons physically impossible to achieve toned resolution equivalent to that represented by the crystal structure. Not only is there at present no optical imaging source available which could address each crystal separately, but also, a certain amount of image spread results during the piling-up of toner particles. While silver halide grains are suspended within gelatin, toner particles are required to stack in a tapered form. This has several consequences such as lowering the maximum density and the number of distinguishable levels, and the already mentioned slight image spread. The total number of stacked particles will deviate from the number expected for a certain charge the more, the thicker the tonal layer becomes, and it will always be smaller. Hence, a density lower than the expected will always result.

Typically, a toner layer of less than 2 μm thickness will result in a transmission density of 4.0; it can be deposited in about 4 seconds. Half the thickness will yield slightly more than half the density (Fig. 7, next page) and can be deposited in about half the time. These linear relationships hold in spite of the observations made earlier.

The reduction of modulation transfer values with increasing resolution is minimal as expected because of the anisotropy of the crystals. The MTF curve for toned images on a KC-coating (Fig. 6) declines only when toner particle size limitations become apparent. Also shown in Fig. 6 are two curves representing the MTF's for a photogrammetric mapping lens with a 15 cm focal length, on axis and near the corner of the 23 cm x 23 cm format. Although imaging and toning limitations do not allow full use of the information recording potential of KC-coatings, it has been possible to demonstrate high toned resolution values (Fig. 8, next page).

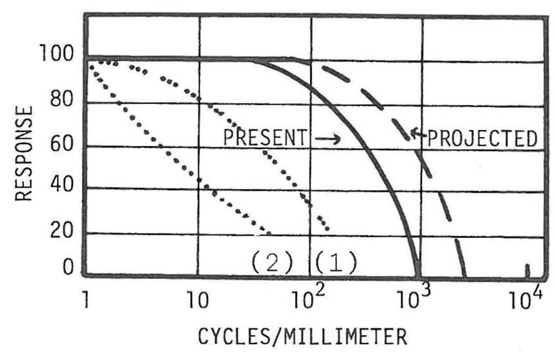

Fig. 6 MTF curves for toned KC-material, and for a mapping lens with f = 15 cm, on axis ($\tau = 0^o$) (1) and off axis ($\tau \sim 45^o$) (2).

The significant improvement in image definition achieved with the KC-imaging process can be demonstrated, for example, by generating the same irregular pattern of well defined dots on a conventional silver halide emulsion and on KC-material. This has been done using a drum printer, a one milliwatt HeNe laser at 6.2 MHz generating dots with a diameter of 40 μm, and a silver

10,000X Density 2.1

Fig. 7 Scanning electron beam photomicrograph of toned KC-film. The photoconductor and toner layers have been chemically separeted from the substrate for illustrative purposes.

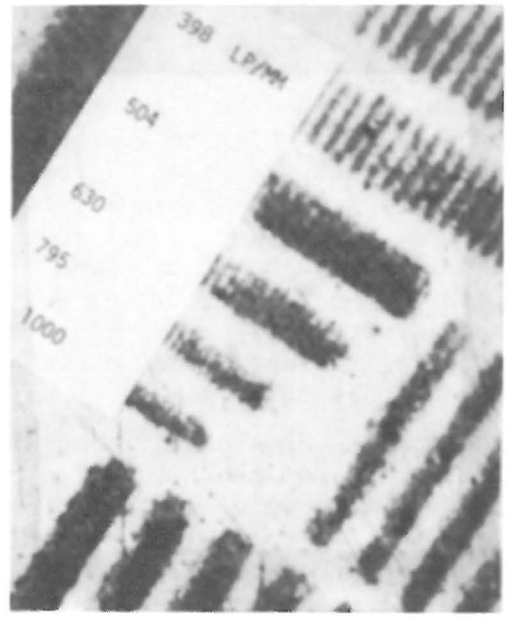

Fig. 8 Photomicrograph (1200X) of an Ealing resolution target contact printed onto KC-film. The 1000 lp / mm target is resolved.

halide emulsion with a sensitivity similar to that of KC-coatings (Fig. 9, top); a better definition of the dots could have been achieved with an emulsion having a higher resolution at the expense of a lower sensitivity. The lower half of Fig. 9 shows the same point pattern imaged on a KC-coating and toned; the dots are not only much better defined but even display a slight elongation due to the velocity of the laser beam relative to the coating.

The characteristic curves (density vs log exposure) associated with the KC-imaging process are similar to those typical of a black & white continuous tone silver halide emulsion reversal film, since the electrophotographic process is normally direct or positive working. By modifying either the exposing or the toning process it is feasible to achieve the low γ-values that might be desirable in pictorial work, or the high γ-values needed in halftone or line work. The parameters most generally varied to control the γ-values are initial surface charge (Fig. 10, next page), time from charging to exposure,

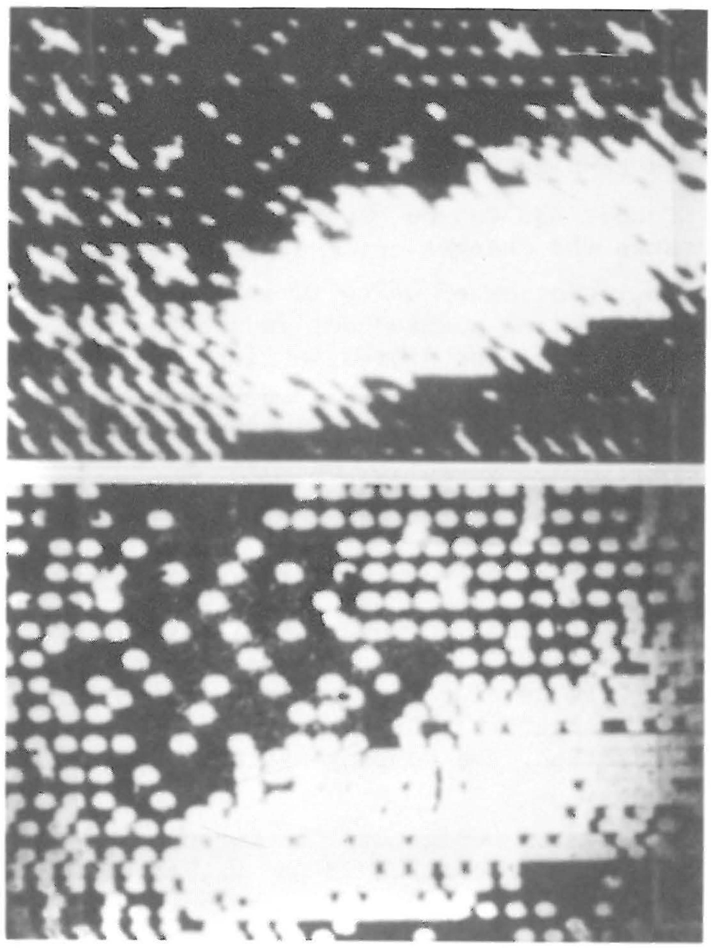

Fig. 9 Laser dots with a diameter of 40 μm imaged on a KC-coating (bottom) and on a silver halide emulsion with comparable sensitivity (top).

time from exposure to the start of toning, toning period, toning concentration, or a combination of these. Because the dark decay is strongest for high initial charges in the first few seconds, frame photography exposed simultaneously over the entire format area should use KC-coatings charged to less than maximum voltage, and should not be exposed until the slope of the dark decay curve has become reasonably low.

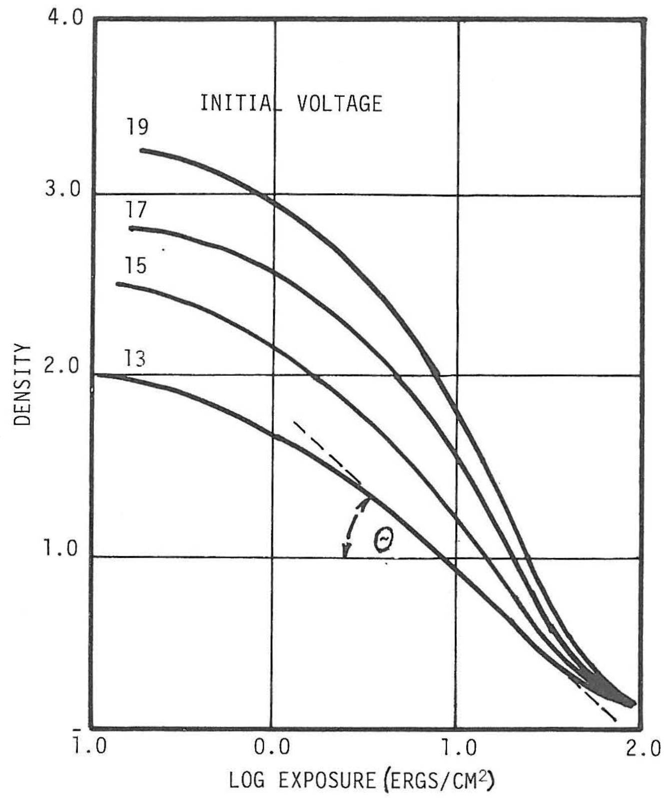

Fig. 10 Variation of γ(= tan Θ) via change in initial toning voltage.

The imaging and toning process does not alter the KC-coating. It is therefore possible to either transfer the toner to a different medium or to wipe it off, and to then use the coated material again. Assuming proper procedures are used, hundreds (thousends?) of images can be made on the same piece of material without loss of quality. This enables experimentation with exposure times and toning procedures without any significant loss in material. Only when the desired type of image has been achieved and is to be conserved will an image be fixed.

KC-coatings can be exposed either by contact exposure or by projection, because the charges are trapped in either case in the crystal layer surface.

The logistics of using KC imaging products are very attractive. The coatings are, as pointed out in section 2.2, non-silver and inorganic. Coated material can be stored in light and is not affected by ambient temperature or humidity. The toner is a single non-toxic solution; whatever remains of it after toning can be reused. Therefore, there are no effluent disposal problems, and high purity water is not needed in large quantities. Finally, the imagery is available in a very short time since charging, exposing and toning can each be accomplished within seconds.

4. INTENDED PHOTOGRAMMETRIC APPLICATIONS

There are many different applications of the KC-technology. Coulter Systems Corporation in Bedford, Massachusetts, have thus far concentrated their efforts to develop applications in the field of graphic communications, also of interest to photogrammetrists concerned with map production and map reproduction. The company has also experimented with various other applications.

Mega System Design Ltd. in Toronto have begun, in cooperation with Coulter Computer Corporation in Dayton, to develop for the National Research Council in Ottawa two products designed to test KC-film for its usability in photogrammetric operations, and to utilize KC-technology in connection with digital processing for the production of orthophotos.

4.1 Contact Copier

In order to test the response of KC-coatings, the image transfer and the repeatability of the KC-image transfering process, and the influence of fixing by heat application on the metric behaviour of exposed film, it was decided to develop a contact copier using KC-film. The instrument is to be capable to produce

- direct and inverse copies of transparent originals
- in fixed or unfixed state
- on coated film
- or, after toner transfer, on clear transparent material or on paper.

Density adjustment using an unsharp, underexposed (or underprocessed) unfixed copy of the original transparency will be incorporated as well.

The instrument will be invaluable in providing us with experience in the handling of the various steps of the KC-imaging process. It will enable us to determine whether the expected improvement in the metric fidelity of film diapositives materializes; the improvement is expected since the processing of the exposed diapositive does not require the immersion into any liquid bath, and since the inhomogenity of film consisting of a substrate and a gelatin emulsion no longer exists. However, we will at the same time be confronted with material effects thus far unknown to photogrammetrists: the behaviour of a film substrate coated with a thin crystal layer and the influence of fixing by heat application, both in view of dimensional stability.

The instrument will also be used to verify or disprove the expectation that original and copy will not differ in resolution; in other words, that the two will be identical in information content.

No results are available for reporting at the time of writing.

4.2 Digitally-Controlled Orthophoto Production

The utilization of the KC-technology for digitally-controlled orthophoto production requires the development of a digitizer / processor / printer system capable of

- digitizing black & white or color photographic images on transparent or opaque, conventional or KC-coated materials, and of storing the resulting data for later processing in a memory unit integral to the system,
- performing a variety of digital processing tasks on the data set to modify the appearence of the imagery, such as contrast enhancement, edge sharpening, signal-to-noise-ratio increase, density modification and slicing, and image restoration,
- performing all transformations necessary to derive an orthophoto from the digitized image data,
- data compression,
- playback of the processed data onto KC-coated materials to obtain either transparent or paper images, or printing plates for the offset printing of photomaps.

This system will benefit from developments in regard to the application of the KC-technology in other areas, for example in the graphic communications field, and from experiences gained with the contact copier. We are anxiously awaiting results from the contact copier and from the digitally-controlled processing of suitable aerial photography on the presently available scanner / printer equipment to finalize the specifications for this instrument, for example in regard to the use of modular or binary-coded area manipulation, scanning and printing pixel sizes, maximum and minimum desirable densities, number of desirable gray scale steps, scanning and printing speeds and formats, and accuracy requirements.

It is intended to use, to the extent possible, standard hardware items and software modules with a minimum of customizing and, where appropriate, commercially available system components such as computers, disc memories, CRT displays and magnetic tape systems. Coulter Computer Corporation has presently under development a digital plate making system incorporating into a modular design a small format and a large format flatbed scanner, a drum scanner and a drum printer. The scanners are designed to use white light and to sample red, blue and green components; the printer will use a laser. The flatbed scanners will be used to scan transparent material, the drum scanner for reflective material. Scanning resolutions are for the flatbed scanners somewhat format dependent and range from 100 samples / mm to 20 samples / mm, and for the drum scanner from 16 samples / mm to 2 samples / mm; the printer will print 12 pixels / mm. The flatbed scanners will accept a density range from 0 to 3.0, the drum scanner a range from 0 to 2.0; all will sample 8 bits / color. The KC-Digital Platemaker was first announced at the IMPRINTA 1979 in Düsseldorf, Federal Republic of Germany, where a prototype of a reversible drum scanner / printer was exhibited.

5. CONCLUSION

A photographic process has been described which is relatively simple, requires only a single solution which is completely used up, does not require any water for processing, is free of effluents or other ecologically undesirable by-products, and is based on inexpensive raw materials. The inorganic coating replacing the conventional silver halide emulsion is insensitive to changes in storage temparature and humidity and, until charged just prior to an exposure, also to light; hence, protection and handling of the material are very simple and do not require large storage and darkrooms.

Some uses of the material have been indicated, and two intended applications in photogrammetric operations were described. There is no doubt, however, that the KC-technology may cause the development of a photogrammetric processing chain quite different from those being observed today, possibly completely free of the need to use silver halide emulsions. In order for this to materialize, scanning and printing resolutions must be further improved.

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POSTSCRIPT

The KC-technology has been demonstrated in North America for the first time publicly at the PRINT 80 exhibit helt recently in Chicago. The following pamphlets were distributed there:

Coulter Systems Corporation, 1980a: KC-technology

Coulter Systems Corporation, 1980b: KC-camera platemaking system

Coulter Systems Corporation, 1980c: KC-digital litho system