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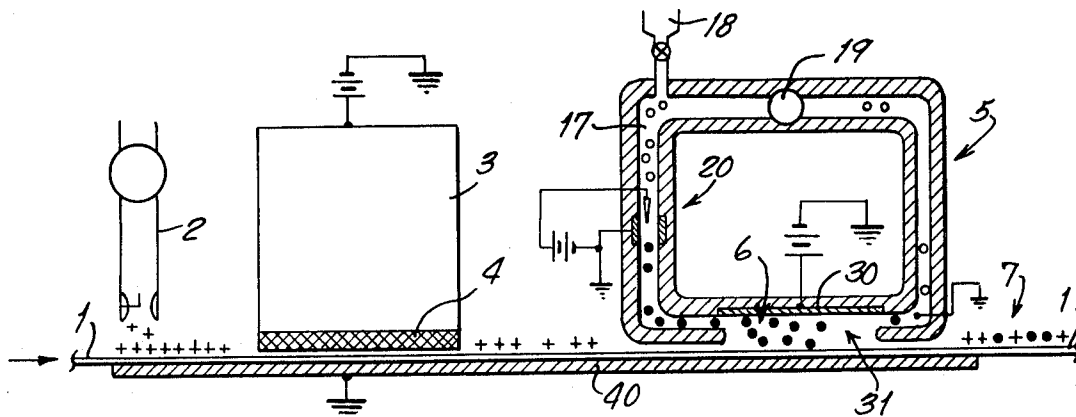
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[54] **IMPROVED ACOUSTIC IMAGE REPRODUCTION  
 SYSTEM USING A PIEZOELECTRIC PRINTER  
 AND ELECTROGASDYNAMICS**  
**10 Claims, 4 Drawing Figs.**

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 179/100.1, 310/8.1  
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 H01v 7/00, G11b 9/00  
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 100.1 (B); 310/8.1; 73/(Inquired)

**ABSTRACT:** An apparatus and method for printing an image of a pattern of sound waves on a dielectric sheet, such as paper or the like, comprising the use of a space charge cloud of ionized ink from an electrogasdynamic generator to develop an electrostatic charge image of the sound pattern which has been formed on the dielectric sheet using an acoustic image converter plate. By virtue of the high charge on the ink, a high quality image is developed on the sheet even though the sound wave patterns resulting from ultrasonic scanning of a test object or from the energizing of an acoustical transducer may be comparatively weak.



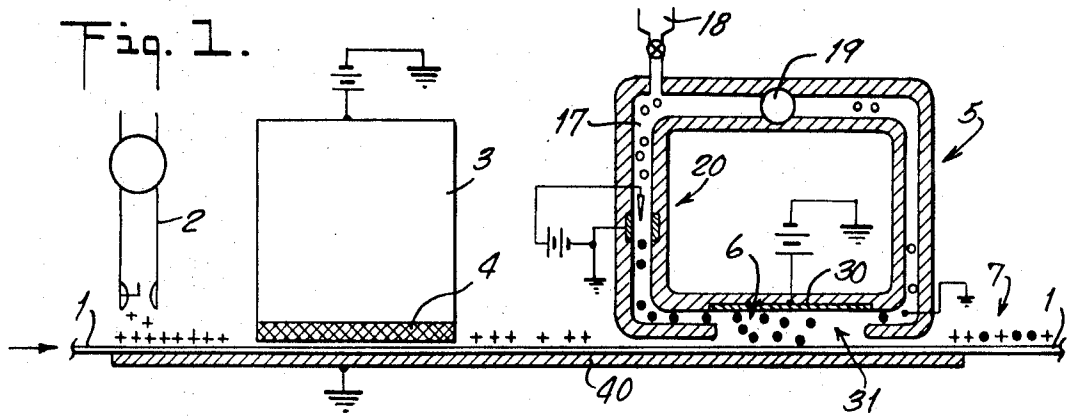
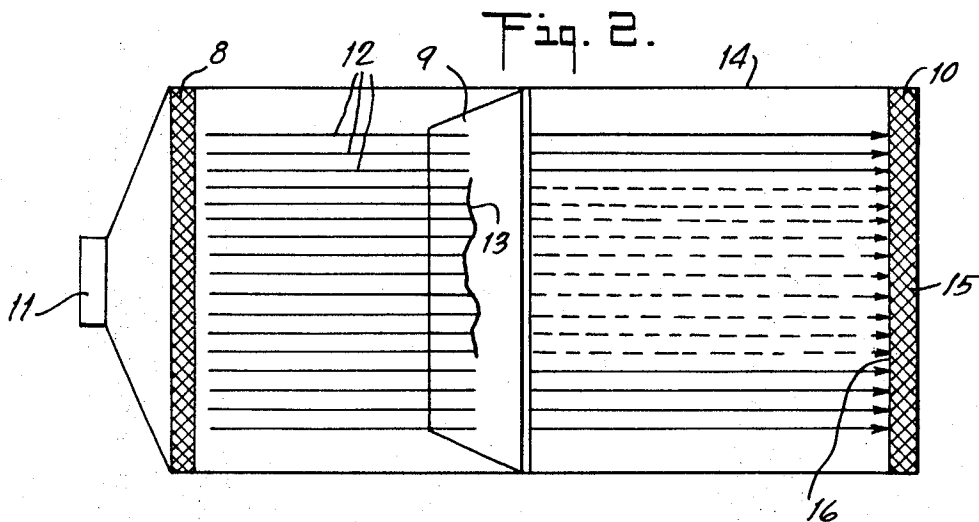
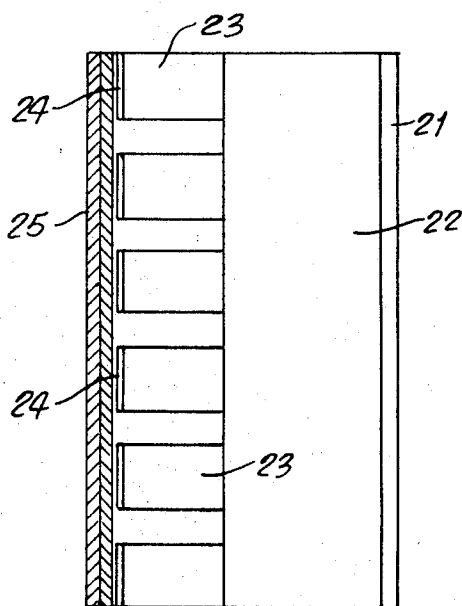
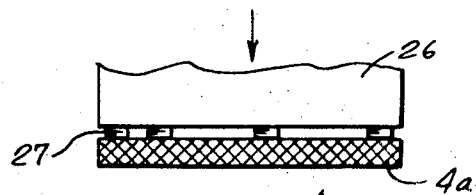


Fig. 3.

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# IMPROVED ACOUSTIC IMAGE REPRODUCTION SYSTEM USING A PIEZOELECTRIC PRINTER AND ELECTROGASDYNAMICS

## BACKGROUND OF THE INVENTION

The present invention relates to the image reproduction art and more particularly to an image producing apparatus and method using an electrogasdynamic generator in cooperation with an acoustic or other pressure image converter.

Sound waves, and particularly those in the ultrasonic region having frequencies above 20,000 cycles per second, have been used for many purposes in industry such as for cleaning, heating, machining, gauging thickness and a number of other diversified applications. In recent years sound waves have been found particularly useful in nondestructive testing as a replacement for x-rays, since sound waves can be used to penetrate and scan the interior structure of opaque materials just as x-rays, but also they have the particular advantage of being attenuated far less by most materials than are x-rays or other electromagnetic waves. In addition, sound is far more sensitive to structural discontinuities such as cracks, microseparations or the like and may be completely reflected by an air gap larger than  $10^{18}$  centimeters.

With the growing use of sonic test equipment has come the problem of achieving adequate acoustic image reproduction and the need for suitable image converter systems. Accordingly, acoustic image converter plates have been developed which are constructed of piezoelectric crystal or semiconductor material. A sound wave pattern striking a surface of such a plate causes mechanical distortion at each point on the surface, which distortion results in the generation of a charge across the thickness of the plate. An electric charge picture of the sound wave pattern is thus produced on the opposite surface of the plate. This charge image may then be scanned such as with a conventional television iconoscope or otherwise detected and a visual image may be reproduced by conventional techniques.

A major problem in connection with such acoustic image converters is the production of sufficient power to obtain a reasonably clear image, since a sound power density in the range of  $10^{17}$  to  $10^{19}$  watts/cm.<sup>2</sup> is required presently to obtain a clear picture. It is therefore quite desirable to provide a system which will produce a high quality visual image from a converter image which has been produced by a sound pattern of minimum power density.

The present invention provides such a system with the added advantage of accomplishing the high quality image reproduction with a minimum of mechanical operations and at high speed.

## SUMMARY OF THE INVENTION

The apparatus and method of the present invention comprises the use of an electrogasdynamic, or EGD, generator in combination with an acoustic or other pressure image converter for reproducing a sound pattern or the like as a printed image. More particularly, the EGD generator is used as a spray gun to produce a space charge cloud of ionized ink particles that are deposited on the surface of a dielectric sheet to develop a latent electrostatic charge image thereon, which image has been derived from a charge pattern produced by a sound wave on a piezoelectric plate converter or similar semiconductor arrangements.

It has been observed that it is a peculiar quality of charges in an electrogasdynamically produced cloud to tend to become uniformly distributed over a dielectric surface and the amount of surface charge that can be acquired by the surface has a particular limit under given conditions. The ion concentration in the cloud determines the maximum potential of the dielectric surface and the maximum surface charge. An explanation of this phenomenon is more fully set forth in my copending application Ser. No. 763,854, filed Sept. 30, 1968, and assigned to the same assignee as the present application. As a result of

this phenomenon, if a patent electrostatic image is produced on a sheet of paper by selectively discharging a uniform layer of charge on the sheet using the charge pattern produced by a sound wave on a semiconductor element, such as a piezoelectric or piezoresistive plate, the latent image may be developed to a high quality by the highly charged particles which are selectively distributed eliminating fringing effects and achieving greater resolution in the halftone areas. This improved process in addition provides a high speed permanent image reproduction.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a system embodying the apparatus of the present invention;

FIG. 2 shows a test system which produces an input for the system of the present invention;

FIG. 3 shows the structural detail of an acoustic image converter which may be used with the present invention; and,

FIG. 4 shows an optional piezoelectric recording plate setup which may be used with the present invention.

## DETAILED DESCRIPTION

The method and means of the present invention may be best understood by first briefly describing the operation of the system shown in FIG. 1 which indicates all the steps to be used in producing a printed image of a sound wave pattern. A dielectric sheet 1, such as paper or other media, on which the image is to be reproduced is passed over a grounded plate 40 along by three essential operating components which are positioned in sequence. The first component is a charge producing device, such as an EGD ionizer 2 or corona discharge device, and uniformly coats the surface of the sheet 1 with charged molecules. The charged surface is then brought into contact with the surface of the acoustic image converter 3, a piezoelectric transducer which may be in the form of a plate of crystalline material such as quartz or one of the electrostrictive ceramics such as barium titanate. The piezoelectric transducer surface 4 is charged in the pattern of an impinging acoustic wave, in a manner which will be more fully explained, and thus discharges the charge layer on the dielectric surface in accordance with this charge pattern. The resulting latent charge image on the dielectric surface is then passed to an EGD developer 5 which produces a space charge cloud 6 of electrogasdynamically produced ink or toner particles that develop the charge image producing a printed image 7 on the dielectric sheet 1.

FIG. 2 shows a particular test system which may be used in connection with the system of the present invention. This system comprises a sound transmitter 8, a test object 9 and an acoustic image converter 10. The sound transmitter 8 may comprise a piezoelectric plate driven by an electric oscillator 11 at the mechanical resonant frequency of the plate for example, in the range from 1 to 10 megahertz, that is,  $10^6$  c.p.s. The sound waves 12 produced by the plate irradiate the test object 9 with a focused parallel beam of ultrasound. Any inconsistencies or defects, such as the line 13, in the test object 9 intercept part of the beam and cause a sound shadow-graph on the face of the image converter 10, which is in the form of a piezoelectric receiving plate made of natural quartz or, as previously mentioned, one of the electrostrictive ceramics such as barium titanate. This plate may be constructed of any suitable piezoresistive material sensitive to pressure, for example, semiconductors of the lead metaniobates, lead zirconate-lead titanates and the like.

As air has an excessive attenuation effect on ultrasound, the receiving plate 10 along with the transmitting crystal 8 and the test object 9 may be immersed in a tank 14 of water or oil for better propagation.

The rising sound wave pattern causes a mechanical distortion at each point on the receiving plate surface 16. This distortion results in the generation of a charge across the thickness of the plate 10. The high intensity of the unob-

structed portions of the sound beam results in a large electric charge on the outer surface 15 of the plate 10 in the areas affected while the low intensity portions of the beam, corresponding to the defect 13 in the test object 9, results in a smaller charge pattern on the face 15 of the plate 10. Since the surface 15 is clean quartz or a ceramic with a high lateral surface resistance, each point of the plate with its associated charge can be considered as independent of all its neighbors. Consequently the acoustic shadow-graph falling on the inner face 16 of the receiving plate 10 is transformed into an electric charge picture on the opposite face 15.

Referring again to FIG. 1, it will be seen that this electric charge picture may be developed by the system shown therein. The detailed steps of the development are as follows. The dielectric sheet 1 on which the image is to be printed is first coated with a uniform layer of charged particles by means of the EGD ionizer 2, or a corona discharge device or a similar device known in the art. The dielectric sheet 1 may be a single piece of paper or may be a continuously fed web depending upon the use to which the image is to be put. The charged sheet is supported on the grounded member 40, which may be a metal plate, and is then brought into contact with the charged surface 4 of the piezoelectric transducer 3. The surface 4 is charged in accordance with an impinging sound wave pattern in a manner such as described in connection with FIG. 2. The uniform charge layer will be discharged in the appropriate areas in accordance with the charge image on the surface of the piezoelectric plate leaving a latent electrostatic image of the sound wave pattern. This charge image is then developed by means of the electrogasdynamic developer 5.

In the developer 5, the ink or toner to be used for printing the image is sprayed into an atomizing chamber 17 from an appropriate reservoir 18. The droplets of ink or particles of toner in the chamber are circulated in a counterclockwise direction by a fan 19. An EGD gun 20 is positioned in the chamber 17 and ionizes the passing ink droplets to produce an electrogasdynamic space charge cloud 6. An accelerator electrode 30, located at chamber opening 31, sets up an electrostatic field which urges the charged particles in the cloud 6 toward the grounded plate 40 when reaching the region of the opening. The ionized ink will tend to distribute itself evenly over the charged surface of the sheet 1 clinging to the uncharged areas and being repelled by the oppositely charged particles in other areas until a uniform potential and evenly distributed charge layer is reached. The electrogasdynamically produced ink particles which are highly charged tend to concentrate themselves in the uncharged areas and will not adhere to the highly charged areas so that an ink image is produced which directly corresponds to the distribution of the charge image produced by the piezoelectric plate 4.

As a result of the even distribution of charged ink, fringing effects are avoided at the areas of greatest contrast and as the highly charged particles will avoid those areas already charged to maximum potential, an image with improved definition and resolution is developed. A variety of inks, toners or paints may be used in this process due to the versatility of the EGD spray gun in charging aerosols and the use of water based inks is particularly of advantage in avoiding air pollution problems during the subsequent fixing step if one is desired.

FIG. 3 shows an alternate form of image converter utilizing semiconductors and thin films. This converter comprises a thin conductive metal film 21, a layer of piezoelectric and possibly rectifying semiconductor material 22 exhibiting highly lateral resistivity, dots of independent, electroluminescent material 23 and another thin transparent metallic coating 24. A sound wave picture striking the conductive film 21 is converted to a pattern of electric currents moving through each tiny area of the semiconductor 22. These currents may be intrinsically amplified by various arrangements. Arriving at the luminescent dots 23, the currents cause each dot to glow with an intensity proportional to the strength of the exciting current. Ultimately this current strength is determined by the sound strength of each small area of the arriving

sound wave pattern. Thus, the sound pattern is converted to a visual picture without the use of complex cathode ray tubes or other devices. The resulting visual picture may be printed in the manner of the present invention by using it in combination with a xerographic plate 25 to produce a corresponding charged surface image. The xerographic plate 25 may then be substituted for the piezoelectric plate 4 in the system of FIG. 1. Other methods and apparatus for developing the charge image on the surface of the xerographic plate 25 are more fully disclosed in my copending application, Ser. No. 763,722, filed Sept. 30, 1968, and assigned to the same assignee as the present application.

While the present invention has been described for use with acoustic images, it will be seen that the piezoelectric plate can reproduce many types of pressure images in the form of a charge pattern on the face opposite the one on which the pressure is applied. For example, as shown in FIG. 4, a printing mat 26 having type face 27 on its surface may be impressed against a piezoelectric plate 4a and a charge image of the type 27 will be produced on the opposite face of the plate 4a. This charge image may accordingly be used to produce the latent electrostatic image in the system shown in FIG. 1.

Thus an improved image reproduction system is presented for printing an acoustical or other pressure type pattern using a piezoelectric transducer in combination with an electrogasdynamic developer to achieve high resolution and high speed image printing.

I claim:

1. A printing apparatus comprising:

- a. means for depositing a layer of electrostatic charge on the surface of a dielectric sheet;
- b. piezoelectric means for producing patterns of electrically conductive areas on a surface in response to impressed pressure patterns;
- c. means for bringing the dielectric sheet in contact with said conductive surface so that a latent electrostatic image of the pressure pattern is formed on said sheet; and
- d. means for electrogasdynamically producing and directing a cloud of ionized particles against a surface of said sheet to develop said latent electrostatic image.

2. Apparatus as claimed in claim 1 wherein said piezoelectric means comprises a member of piezoresistive semiconductor material.

3. Apparatus as claimed in claim 1 wherein said piezoelectric means comprises a quartz plate.

4. Apparatus as claimed in claim 1 comprising:

- e. electroluminescent means for producing light patterns in response to the patterns produced by said piezoelectric means; and
- f. xerographic means for producing patterns of electrically conductive areas on its surface in response to light patterns produced by said electroluminescent means.

5. Apparatus as claimed in claim 1 wherein said piezoelectric means comprises a plate having one surface in contact with a sound conducting medium and its other surface producing electrically conductive areas thereon in response to sound patterns impinging on said one surface.

6. Apparatus as claimed in claim 5 wherein said sound conducting medium is contained in an enclosure.

7. A method of printing, comprising the steps of:

- a. depositing a uniform layer of charge on the surface of a dielectric sheet;
- b. bringing the charge layer in contact with the face of a piezoelectric member having a voltage pattern thereon resulting from the impressing of a pressure pattern on its opposite face thereby producing a latent electrostatic image of the pattern on the dielectric sheet; and
- c. developing the latent electrostatic image by means of an electrogasdynamically produced cloud of ionized particles.

8. The method as claimed in claim 7 wherein the pressure patterns are sound waves.

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9. The method as claimed in claim 7 wherein the piezoelectric member is composed of a piezoresistive semiconductor material.

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10. The method as claimed in claim 7 wherein the pressure pattern receiving face of said piezoelectric member is contained in an enclosure.

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