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(54) **A system and method for high-speed, reliable ink jet printing**

(57) An ink jet printing method is disclosed wherein an ink jet print head and an ink jet ink are provided. The ink jet print head has an ink channel and electrically actuable means to eject a number of successive droplets (d1,d2). The method includes the steps of (i) applying a number of successive electrical drive signals to the electrically actuable means, each electrical drive signal for ejecting a corresponding droplet, each electrical drive signal inducing in the ink channel an underpressure pulse (51_2) followed by a pressure pulse (52_2) for ejecting the corresponding droplet and each electrical drive signal is unipolar and of the same polarity; (ii) after applying the last electrical drive signal for ejecting the last droplet of a maximum number of successive droplets, applying a electrical cancel signal for reducing residual acoustic pressure waves in the ink channel. The electrical cancel signal induces in the ink channel an underpressure pulse (51_c),and a pressure pulse (52_c), and at least one of the underpressure pulse or the pressure pulse is applied in antiresonance with the pressure pulse of the last electrical drive signal.

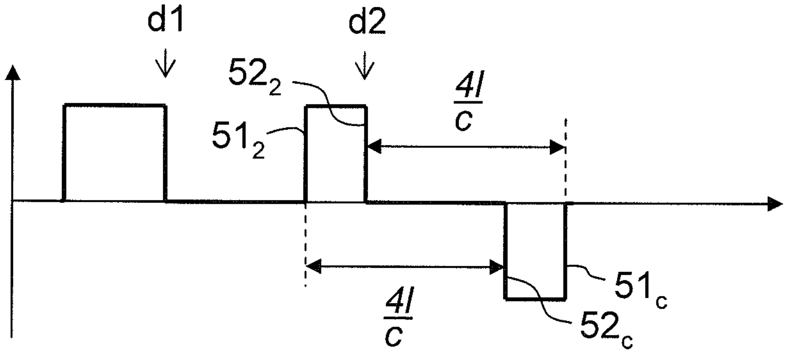

FIG. 7

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Description

Technical Field

[0001] The present invention relates to an ink jet printing method which has excellent ink ejection stability and outputs high definition images at a high printing speed. Particularly, this invention relates to an ink jet printing method for increasing the fire frequency of the ink jet print head without introducing reliability problems.

Background Art

[0002] Various research and development has been conducted in ink jet printing to improve its functionality and expand its applicability. Improvements have been made in the field of ink jet fluids, both in the area of the carrier fluids (e.g. water, solvent, radiation curable compounds, wax, etc.) and in the area of the functional particles (e.g. coloured pigments, metal particles, organic light emitting polymers, adhesion promoting additives, etc.). Non-aqueous ink jet inks are often employed for large format and industrial ink jet applications. Non-aqueous inks may be oil based inks, solvent based inks or radiation curable inks, for example UV-curable inks and electron beam curable inks. The design of such inks today is typically based on a carrier fluid (e.g. UV-curable carrier compounds), a specific particle dispersion, and a number of additives to improve the jetting performance of the ink and the physical properties of the ink when printed. Because of this plenum of compounds and additives, these inks often show a higher viscosity than the known 'small office and home' (SOHO) aqueous ink jet inks, and they typically have a smaller operating window within which reliable drop ejection is guaranteed. Aqueous SOHO ink jet inks typically have viscosities between 2 and 6 mPa.s at 25°C and low shear rate (e.g. measured with a Brookfield viscometer with 4 - 15 RPM). The viscosity of ink jet inks for large format and industrial printing applications can vary in a wide range from about 2 to 100 mPa.s at 25°C and low shear rates, and even up to solids at room temperature for hot melt inks.

[0003] Meanwhile, ink jet print heads have developed towards devices for jetting smaller ink droplet volumes, offering increased greyscale capability, increased ejection frequencies and thus productivity, having higher ink ejection accuracy and reliability, increased ink compatibility, etc. For example, EP 0422870 B (XAAR) 1995-01-11 discloses a technology called "multi-pulse greyscale printing", wherein a variable number of ink droplets is ejected from a single nozzle within a short period of time such that the resulting "packet" of droplets merge in flight and/or on the paper to form a correspondingly variable-size printed dot on the paper. Ink jet print heads incorporating this technology are now commercially available from Xaar (OmniDot 760/GS80), Toshiba Tec (CA3), Agfa Graphics (UPH) and others. Each nozzle in these print heads communicates with an individual ink channel having side walls which extend in the lengthwise direction of the channel. In response to electrical signals, the channel walls can be displaced transverse to the channel axis. This generates acoustic waves that travel along the channel axis, causing droplet ejection from the nozzle located at one end of the channel, as well-known in the art. The electrical signals displacing the channel walls, and driving the droplet ejection process, are referred to in the art as "drive waveforms" or simply "waveforms". In US 6402282 B (XAAR) 2002-06-11 a waveform for use with a multi-pulse greyscale print head is disclosed. The waveform is presented as a bipolar electrical signal applying (positive) electrical pulses for increasing the volume of the ink channel, thereby drawing ink into the ink channel, and (negative) electrical pulses for decreasing the volume of the ink channel, thereby squeezing out a droplet of ink from the ink channel through the open nozzle. Waveform design is very much linked with the design of the print head architecture. Waveforms are therefore often embedded in the electronics of the multi-pulse greyscale print heads and considered 'standard' for that print head. They are not supposed to be changed by end-users of the print head.

[0004] The combination of higher viscosity inks (at 25°C and low shear) with small droplets and high ejection frequencies of state of the art ink jet print heads may cause a problem regarding the stability of the ink ejection process. Particularly, this combination may cause many satellite drops to be generated that separate from the main ink drop and create an ink mist which is airborne just above the receiving medium. One way of solving this problem is lowering the viscosity of the ink during ejection. When printing UV-curable ink jet inks, this approach generally implies jetting the ink at an elevated temperature, e.g. ≥ 40°C.

[0005] Although a lower ink viscosity during jetting reduces the formation of satellite drops, it creates another problem of overfill or pooling at the nozzle plate. Overfill or pooling is a phenomenon wherein the ink meniscus is not completely retracted into the nozzle after ejecting a droplet from the nozzle, causing the nozzle plate to be wetted. Although overfill or pooling is only a post factum phenomenon after the droplet has been ejected, it influences the starting conditions for a next ink droplet to be ejected from that nozzle. Especially in combination with the above described multi-pulse greyscale print heads, wherein a number of droplets are ejected in one burst and wherein the end of a previous droplet ejection process determines the starting conditions for a next droplet ejection, overfill and pooling cause an unpredictable ink meniscus position and introduce energy losses in the ink pool at the nozzle plate during the ejection of subsequent ink droplets. Overfill and pooling of the nozzle plate therefore are troublesome for creating and maintaining a reliable ink jet printing process.

[0006] In the prior art, wetting of the nozzle plate has been counteracted by application of an ink-repellent coating on the surface of the nozzle plate, which accelerated the retraction process of the meniscus into the nozzle after pinch off of the ink droplet. The advantage of ink-repellent coatings towards pooling is unfortunately countered by their vulnerability. During nozzle plate cleaning and maintenance, which often includes wiping the surface of the nozzle plate with a wiper blade, debris in the form of deposits of solidified ink mist, paper fibres, etc. may scratch the ink-repellent coating when wiped off and deteriorate its ink-repellent properties. As nozzle plate maintenance is a well-known and regularly used method for preventing as well as recovering drop ejection failures and increasing the overall printing reliability, ink-repellent coatings are only a last resort.

[0007] Another solution to overfill and pooling when printing low viscous inks in a multi-pulse greyscale printing process has been presented in co-pending PCT application N° PCT/EP2007/064362 and co-pending PCT application N° PCT/EP2007/064363. The method described in these applications combines a lower viscosity ink, at jetting conditions, with a print head drive waveform providing only channel expansion periods and no channel contraction periods. In term of electrical signals, the drive waveform is unipolar, consisting of electrical pulses of one polarity only. The drive waveforms provide an improved energy management in the ink channel and an improved balance between the energy that is input in the ink channel by the drive waveform and the energy that is required for the ejection of an ink droplet from the ink channel. This aspect of energy management is more critical for lower viscosity inks than it is for higher viscosity inks. Each unipolar drive pulse of a waveform generates an underpressure pulse (leading edge of the unipolar pulse) and a pressure or jet pulse (trailing edge of the unipolar pulse) in the ink channel. One unipolar drive pulse generally results in the ejection of one droplet from the corresponding nozzle. The unipolar drive pulse of the first droplet is applied in resonance with the acoustic resonance frequency of the ink channel. An unipolar drive pulse for the ejection of a second droplet in a series of successive droplets is either wider than or narrower than the unipolar drive pulse for the ejection of the first droplet in the series of successive droplets. The unipolar drive pulse of a second droplet is therefore applied out of resonance with the acoustic resonance frequency of the ink channel. The drive waveforms disclosed in these co-pending patent applications anticipate on the presence of residual energy from the ejection process of the first droplet to aid in the ejection of the second droplet and therefore reduce the energy input for the second droplet compared to the energy provided for the first droplet.

Disclosure of Invention

Technical problem

[0008] It has also been found that, although the unipolar drive waveforms presented in co-pending PCT application N° PCT/EP2007/064362 and co-pending PCT application N° PCT/EP2007/064363 operate near or at the resonance frequency of the ink channel, they tend to cause jetting instability at high print frequencies.

[0009] It is therefore an object of the present invention to further expand the applicability of greyscale ink jet printing methods and systems into areas of high print throughput and high productivity, where reliability of the printing method and of the printing system is a prerequisite.

[0010] These and other objects of the invention will become apparent from the description hereinafter.

Technical Solution

[0011] The above-mentioned objectives are realized by providing printing systems, printing methods and combinations thereof incorporating technical features as set out in the independent claims.

[0012] The invention provides a balanced combination of electrical signals for ejecting multiple successive droplets from a nozzle, forming a single multi-droplet drop, the balanced combination realizing reliable printing at high fire frequencies of the ink jet print head. Generally speaking, the invention provides a method for driving a multi-pulse print head wherein the drive waveform has unipolar drive signals only, each unipolar drive signal realizing a channel expansion and ejecting one droplet of a number of successive droplets of a multi-droplet drop, and a cancel signal at the end of the drive waveform, the cancel signal introducing pressure events in the ink channel for at least partially cancelling residual pressure waves present in the ink channel after ejecting the last droplet of the number of droplets. The cancel signal may be of a same polarity as the unipolar drive signals or may be of an opposite polarity. In a preferred embodiment, the cancel signal is of a polarity opposite to the polarity of the unipolar drive signals.

[0013] Specific features of preferred embodiments of the invention are set out in the dependent claims.

Advantageous Effects of the Invention

[0014] A main advantage of the invention is that the additional time required to apply the cancel signal is significantly smaller than the time required for the residual acoustic pressure waves in the ink channel to ease off in an 'unforced' way to a level that makes reliable printing at high fire frequencies possible. Therefore an increase in reliable operation of the print head at higher fire frequencies is achieved.

[0015] With the printing method and printing system according to the invention, the upper limit of the fire frequency operation window, for reliable printing with state of the art multi-pulse print heads, is increased with at least 30%. The technical applicability of multi-pulse ink jet technology is therefore broadened towards print frequencies that were previously not attainable, at least not in a reliable way.

[0016] Another advantage of the invention is that the application of a cancel signal, and the effect of cancelling or at least reducing the amplitude of residual pressure waves in the ink channels, also reduces the risk of gas bubble formation in the ink present in the ink channel and subjected to these residual pressure waves by the phenomenon of rectified diffusion. Therefore ink degassing requirements for reliable operation of an ink in a multi-pulse print head may be relaxed or even be rendered superfluous when residual pressure waves in the ink channel are cancelled. In practice, this may show to be an important advantage because it reduces the cost of the ink jet printing system through the elimination of degassing units in the printing system.

[0017] Even if the invention is used without increasing the operating fire frequency of the print head and/or increasing the printing frequency of the printing process, the invention shows a significant increase in printing reliability, e.g. a reduction in failing nozzles.

[0018] Tuning of the leading and/or trailing edge of the cancel signal in or out of resonance with the residual acoustic energy in the ink channel provides a way for tuning the stability and reliability of the ejection process. Stability and reliability of the multi-pulse ejection process is of major importance for high speed printing applications, i.e. use of high fire frequencies.

[0019] Further advantages and embodiments of the present invention will become apparent from the following description and drawings.

Brief Description of Figures in the Drawings

[0020] Drive waveforms may be represented in a voltage-versus-time graph. In these graphs, the voltage of the drive waveform is shown on the ordinate axis "V" and is expressed in volts, and time is shown on the abscissa "t" and is expressed in seconds.

[0021] Fig. 1 shows an exploded perspective view wherein a part of an exemplary multi-pulse greyscale print head is cut away.

[0022] Fig. 2 shows a partial cross-sectional view of the exemplary ink jet print head of figure 1, cut along a line II-II without the substrate.

[0023] Figs. 3A and 3B are views for explaining the droplet ejection process in the exemplary ink jet print head of figure 1.

[0024] Fig. 4 shows an actuating waveform for driving the ejection of a droplet in the exemplary ink jet print head of figure 1.

[0025] Fig. 5 shows a drive waveform sequence for ejecting a multi-droplet drop using the basic waveform of figure 4.

[0026] Fig. 6 illustrates how a satellite-free drop ejection operating window is selected.

[0027] Figs 7 to 10 shows different embodiments of drive waveforms including a cancel signal according to the invention.

[0028] Fig. 11 illustrates the effect of a cancel signal on the drop velocity, as the print head fire frequency is increased.

Mode(s) for Carrying Out the Invention

<u>Multi-pulse greyscale printing</u>

[0029] The invention has been reduced to practice using piezoelectric multi-pulse greyscale print heads and UV-curable ink jet inks. However, the inventors envision that the invention may be applied also to other multi-pulse greyscale print head technologies and other ink jet inks because the basis for the invention is proper energy management in the ink channel, i.e. managing the energy input to the ink channel in relation to the energy requirement for ejection of an ink droplet from the ink channel, a teaching which is transposable to other types of ink jet print head architectures and other ink jet inks. Moreover, the faster the ink jet printing process is operated, the quicker successive ink ejection events in the ink channel occur, and the more important the energy management in the ink channel becomes. As these considerations are not linked to a single type of ink jet actuating principle (e.g. piezoelectric) or a single ink type (e.g. UV-curable), neither is the invention linked to or limited by these.

[0030] Piezoelectric ink jet printers employ the inverse piezoelectric effect, which causes certain crystalline materials to change shape when a voltage is applied across them. In piezoelectric ink jet, a shape deformation of the crystalline material (piezoelectric ceramics) is used to quickly decrease the volume of a channel wherein ink is contained, resulting in squeezing out ink through a nozzle opening in a wall of the channel. Piezoelectric ink jet print heads may be classified into four main categories, depending on the deformation mode of the piezoelectric ceramic used. These categories are: squeeze mode, bend mode, push mode and shear mode. The description will further focus on shear mode piezoelectric print heads, as for example developed and manufactured by Xaar (UK).

[0031] State of the art piezoelectric print heads may be designed to allow high quality greyscale printing wherein multiple small ink droplets are ejected successively in one burst from a single nozzle and within a short period of time, allowing these droplets to merge in flight into a single drop or merge on the receiving medium into a single dot. The number of small ink droplets ejected in one burst and merged into a single drop is variable thereby providing a technology capable of printing variable-size dots onto a receiving medium.

Design

[0032] A detailed description of a multi-pulse greyscale print head using shear mode technology is disclosed in EP 0968822 B (TOSHIBA TEC, XAAR) 2002-11-16. A multi-pulse greyscale print head may have a multitude of closely spaced parallel ink channels having channel separating walls that are displaceable via piezoelectric action. Each channel is actuable by one or both of the displaceable side walls. In a typical arrangement, at least one of the side walls is sandwiched between two electrodes, either partially or entirely. An external electrical connection is provided to each of the electrodes and when a voltage difference is applied between the electrodes, the corresponding wall separating the one channel from its neighbour channel is displaced. This causes the volume of the one channel, depending on the sign of the voltage difference, to expand or to contract creating underpressure respectively pressure waves in the ink contained in the channel, causing an ink drop to be ejected from a nozzle communicating with the channel. Figure 1 is a, partially cut away, exploded perspective view showing a typical ink jet print head incorporating piezoelectric wall actuators operating in shear mode. It comprises two sheets of rectangular piezoelectric members 2 and 3 adhered and fixed at one end of the surface of a substrate 1 made of a ceramics, by an epoxy resin adhesion. A plurality of long grooves 4 which are disposed in parallel at a predetermined interval and have an equal width, equal depth and equal length are formed in the piezoelectric members 2 and 3 by a diamond cotter. Electrodes 5 are formed on the side surface and the bottom surface of the long grooves 4, and lead electrodes 6 are formed from the rear ends of the long grooves 4 to the rear upper surface of the piezoelectric member 3. These electrodes 5 and 6 may be formed by electroless nickel plating. A printed circuit board 7 is adhered and fixed to the other end of the surface of the substrate 1. A drive IC 8 including a drive circuit is mounted on the printed circuit board, and conductive patterns 9, connected to the drive IC 8, are formed on the printed circuit board. Further, the conductive patterns 9 are connected to the lead electrodes 6 through wires 10 by wire bonding. A top plate 11 made of a ceramics is adhered and fixed to the piezoelectric member 3 by an epoxy resin adhesion. In addition, a nozzle plate 13 provided with a plurality of nozzles 12 is adhered and fixed to the front end of each of the piezoelectric member 2 and 3 by an adhesion. In this manner, the top portion of the long grooves 4 is covered by the top plate 11, and the front end thereof is closed by the nozzle plate 13, such that each of the grooves forms an ink channel 15, which can act as a pressure chamber. A common ink chamber 14 is formed in the top plate 11, and rear end portions of the ink channel 15 formed by the long grooves 4 communicate with the common ink chamber 14. Further, the common ink chamber 14 communicates with an ink supply system (not shown). Figure 2 is a partial cross-sectional view showing the ink jet print head having the structure shown in figure 1, cut along a line II-II without the substrate 1. Side walls of the ink channels 15 formed by the long grooves 4 are made of piezoelectric members 2 and 3 which are polarized along the plate-thickness in a direction opposed to each other, as indicated by the arrows.

Unipolar operation

[0033] Next, operational principles of this type of multi-pulse greyscale ink jet print head will be explained as disclosed in co-pending PCT application N° PCT/EP2007/064362 and co-pending PCT application N° PCT/EP2007/064363**,** with reference to figures 3A, 4 and 5. On the condition that each ink channel 15 is filled with ink, attention is drawn to three ink channels 15A, 15B and 15C partitioned by side walls P1, P2 P3 and P4 made of piezoelectric members 2 and 3. Supposing that the electrode 5 of the central ink channel 15B is controlled with a positive voltage and the electrodes 5 of both adjacent ink channels 15A and 15C are set to a ground potential (GND), then both the side walls P2 and P3 of the ink channel 15B are respectively polarized in directions opposed to each other in the plate-thickness direction, and therefore, the side walls P2 and P3 are deformed outwards so as to increase the volume of the ink channel 15B. Through this deformation, a negative pressure is introduced in the ink channel 15B, resulting in ink being supplied to the ink channel 15B from the common ink chamber 14. From this state, the electrode 5 of the central ink channel 15B is reset to the ground potential while the electrodes 5 of both the adjacent ink channels 15A and 15C are maintained at this ground potential resulting in both the side walls P2 and P3 of the ink channel 15B rapidly taking their original position so as to reduce the volume of the ink channel 15B back to its original volume. This volume reduction imposes a positive pressure in ink channel 15B, resulting in the ink meniscus in nozzle 12 bulging out and ejecting an ink filament from the nozzle 12 outward. The tail of the ink filament ejected from nozzle 12 is pinched off at the moment the ink meniscus is retracted into the nozzle 12, and a droplet separates from the nozzle 12 and flies towards the receiving medium. The drop ejection process is thus controlled by temporary channel expansion periods.

[0034] Figure 4 illustrates the unipolar drive waveform applied to the electrode of ink channel 15B, driving the ejection of a 2dpd (droplets per dot) dot from the nozzle 12 of that channel. The magnitude of the actuating voltage is indicated on the ordinate and normalized time is indicated on the abscissa. The waveform shows two drive pulses, each controlling the ejection process of one droplet from the nozzle. The waveform is extendable for ejecting more droplets per dot by applying additional drive pulses. A 5dpd waveform sequence (not shown) would include in total 5 drive pulses, each controlling the ejection of one droplet from the nozzle within corresponding time slots d1 to d5. Each of the drive pulses correspond with a channel expansion. In terms of pressure events in the ink channel, the following relation exists between these drive pulses and pressure events. Each drive pulse, also referred to as channel expansion pulse, of the waveform introduces one underpressure pulse, as a result of leading edge 51_1, 51_2 of the drive pulse, and one pressure pulse, as a result of trailing edge 52_1, 52_2 of the drive pulse, in the ink contained in the ink channel.

[0035] Each of the pressure and underpressure pulses creates an acoustic pressure wave in the ink channel. Pressure and underpressure pulses may reinforce or counteract each other, depending on the timing of the pulses relative to the acoustic properties of the ink channel, and may therefore reinforce or counteract existing acoustic pressure waves in the ink channel. The timing of pressure and underpressure pulses may or may not be linked to an acoustic resonance frequency of the ink channel. An acoustic resonance frequency is the reciprocal of an acoustic resonance period, for acoustic pressure waves travelling in an ink channel filled with an ink, and equals *4l/c*, wherein the parameters *l*and *c*are defined as follows. "*c*" is the speed of sound, in the ink jet ink, at which acoustic pressure waves propagate in the ink channel. "*l*" is the Active Length which is the length of the ink channel along which the pressure waves can propagate. The time it takes for a pressure wave to travel from one end of the ink channel to the other end, e.g. from the common ink chamber 14 to the nozzle 12, equals *l/c* and the acoustic resonance period of the ink channel consequently equals *4l/c*. These definitions are similar to the definitions relating to acoustic waves propagating and reverberating in a single-ended cavity. A drive waveform operated at the acoustic resonance frequency of the ink channel has pressure and underpressure pulses reinforcing each other so as to require a minimum energy input to eject droplets from the ink channel. In figure 4, the drive waveform is a unipolar waveform comprising only channel expansion pulses. The under-pressure and pressure pulse for ejecting a first droplet are applied in resonance, preferably with a time between both pulses of ½ of the acoustic resonance period of the ink channel, so that they reinforce each other. For a second droplet, the underpressure and pressure pulse are preferably applied with a time difference substantially smaller than ½ of the acoustic resonance period of the ink channel, wherein the underpressure pulse or the pressure pulse of the second droplet is applied in resonance with the underpressure pulse respectively pressure pulse of the first droplet. This reduces the resonant coupling between the first and the second droplet while printing at the resonance frequency of the print head and therefore provides improved control of the ejection process. This effect may also be achieved by applying both the underpressure pulse and the pressure pulse of the second droplet out of resonance with the underpressure respectively pressure pulse of the first droplet. Figure 5 illustrates an alternative drive waveform wherein the underpressure and pressure pulse for the second droplet are preferably applied with a time difference substantially lager than ½ of the acoustic resonance period of the ink channel. The underpressure pulse or the pressure pulse of the second droplet is, as in the drive waveform illustrated in figure 4, applied in resonance with the underpressure pulse respectively pressure pulse of the first droplet.

[0036] The above described multi-pulse greyscale drive waveforms may be operated with ink jet inks that are degassed to a level of total gas content below the reference total gas content of the ink at ambient atmospheric conditions. One of the reasons for this is to avoid the generation of gas bubbles in the ink through rectified diffusion as a result of the extreme pressure variations applied to the ink at or close to the acoustic resonance frequency of the ink channel. Although ink jet inks may be degassed during the production of the ink and/or during the filling of ink containers/cartridges with the ink, it is preferred to degas the ink jet ink in the printing system. Various methods to at least partially degas ink jet inks in the ink supply system of an ink jet printer are described in the prior art. One particularly suitable method for application in industrial ink jet printing system is disclosed in WO 2006/064040 A (AGFA GRAPHICS) 2006-06-22 . In this publication there is referred to a through-flow ink degassing unit having a semi-permeable membrane to control the dissolved gas level of the ink in a continuous ink circulation system.

Bipolar operation

[0037] Another way operating the type of multi-pulse greyscale ink jet print head discussed above is explained in US 6402282 B (XAAR) 2002-06-11 . It will briefly be repeated hereinafter with reference to figures 3A and 3B and figure 6. On the condition that each ink channel 15 is filled with ink, attention is paid to three ink channels 15A, 15B and 15C partitioned by side walls P1, P2, P3 and P4 made of piezoelectric members 2 and 3. Supposing that the electrode 5 of the central ink channel 15B is applied with a positive voltage and the electrodes 5 of both adjacent ink channels 15A and 15C are set to a ground potential (GND), as shown in figure 3A, then both the side walls P2 and P3 of the ink channel

15B are respectively polarized in directions opposed to each other in the plate-thickness direction, and therefore, the side walls P2 and P3 are deformed outwards so as to increase the volume of the ink channel 15B. Because of this deformation, an underpressure is introduced in the ink channel 15B, resulting in ink being supplied to the ink channel 15B from the common ink chamber 14. From this position, the electrode 5 of the central ink channel 15B is next applied with a negative voltage while the electrodes 5 of both the adjacent ink channels 15A and 15C are maintained at the ground potential resulting, as shown in figure 3B, and both the side walls P2 and P3 of the ink channel 15B rapidly deform inwards so as to reduce the volume of the ink channel 15B. This volume reduction of the ink channel 15B imposes a positive pressure in ink channel 15B, resulting in bulging out of the ink meniscus in nozzle 12 and ejection of an ink filament from the nozzle 12 at the end of the ink channel 15B. From this collapsed position of the channel side walls, the potential of the electrode 5 of the ink channel 15B is further changed to the ground potential, and the side walls P2 and P3 rapidly take their original position. By this action, the tail of the ink filament ejected from nozzle 12 is pinched off and a droplet separates from the nozzle 12 and flies towards the receiving medium. Following a dwell period, the just described operation may be repeated to eject further droplets in the multi-droplet drop ejection process, as illustrated in figure 6 showing a drive waveform in solid line suitable for ejecting a 2dpd (droplets per drop) drop, extendable to for example a 5dpd (droplets per drop) waveform indicated in dashed line. Each combination of a positive pulse and a succeeding negative pulse, further referred to as a bipolar drive pulse, causes the ejection of one droplet.

[0038] Setting the electrode 5 of an ink channel 15B at a negative voltage may be realised as shown in figure 3B by application of a negative voltage to the electrode 5 of ink channel 15B while keeping the electrodes 5 of the neighbouring channels 15A and 15C to the ground potential, or it can be realised by application of a positive voltage of (the same magnitude) to the electrodes 5 of the neighbouring channels 15A and 15C while keeping the electrode 5 of the ink channel 15B to the ground potential. For the type of multi-pulse greyscale inkjet printheads used to reduce the invention to practice, a single polarity drive voltage may be used to apply a bipolar drive waveform. Other type of multi-pulse greyscale inkjet printhead may require a drive voltage that can switch polarity in order to use bipolar drive waveforms. Both type of multi-pulse greyscale inkjet printheads may benefit from the invention as discussed hereinafter.

[0039] In terms of pressure events occurring in the ink channel, a drive waveform according to figure 6 introduces the following pressure events. Each positive pulse realizes a channel expansion and creates an underpressure pulse as a result of its leading edge 51 and a pressure pulse as a result of its trailing edge 52a. A subsequent negative pulse realizes a channel contraction and creates an additional pressure pulse resulting from leading edge 52b and an under-pressure pulse resulting from trailing edge 53. The induced pressure and underpressure pulses in the ink channel may reinforce or counteract each other, depending on the timing of the pulses and the acoustic properties of the ink channel. That is, this timing may or may not be linked to an acoustic resonance frequency of the ink channel.

Control

[0040] Greyscale mode

[0041] The number of droplets to be ejected successively from an ink channel 15, in order to create one multi-droplet drop, is determined by print tone data provided to the ink jet print head for that ink channel. Print tone data is representative for the grey-value associated with the image pixel that is to be reproduced on the receiving medium by the printed dot. In multi-droplet drop ejection processes, the print tone data that is input to the print head determines the number of droplets in a multi-droplet drop and therewith the drop volume of the multi-droplet drop and the dot size of the printed dot resulting from the multi-droplet drop landing on the receiving medium. Multi-pulse greyscale printhead are driven with a multi-pulse drive waveform wherein each pulse of the drive waveform is designed to eject one droplet of the number of droplets forming the multi-droplet drop. Depending on the print tone data or grey value of the pixel to be printed, the multi-pulse drive waveform is applied in full (i.e. for maximum pixel density - maximum drop volume) or the multi-pulse drive waveform is applied only partially (i.e. for an intermediate pixel density - intermediate drop volume). A multi-pulse drive waveform is a.o. characterised by the maximum number of droplets n it can eject in one burst. Such a multi-pulse drive waveform is referred to as an *n*-dpd waveform. An *n*-dpd waveform applied in full ejects n successive droplets in one burst. An *n*-dpd waveform that is applied only partially ejects only x successive droplets in one burst for creating a multi-droplet drop of x dpd, wherein x ranges from zero to the maximum but one number of droplets the multi-pulse drive waveform can eject in one burst, i.e. $0 \leq x \leq n$. For example a 5dpd multi-pulse drive waveform may comprise 5 drive pulses, each drive pulse for ejecting one droplet. This waveform may eject up to 5 successive droplets for creating multi-droplet drops of variable size. A maximum density pixel will be created by printing a 5dpd drop via application of the full 5dpd waveform. An intermediate density pixel will be created by printing an xdpd drop (x ranging from 0 to 4) via partial application of the 5dpd waveform, i.e. executing the waveform up to and including the ejection of the x^{th} droplet and then ceasing the execution of the waveform.

When describing details of multi-pulse drive waveforms according to the invention, see further discussions, the full waveform is always referred to. More specifically, the terms 'first' and 'last' refer to their position in the specification of the full waveform. For example, the last drive pulse or last droplet of an *n*-dpd waveform corresponds with the n^{th} drive pulse or n^{th} droplet ... and not necessarily with the last drive pulse effectively executed or last droplet effectively ejected in the burst of successive droplets forming the variable-size drop effectively printed, which depends on print tone date. Commercially available print heads that use multi-pulse greyscale technology include the OmniDot 760/GS8 print head from Xaar (UK), the UPH print head from Agfa Graphics (BE), the CA3 print head from Toshiba Tec (JP) and the KM512 print heads from Koninca-Minolta (JP).

[0042] Binary mode

[0043] Greyscale print heads can be operated in binary mode, in which case the print tone date is representative for the 'black' or 'white' value associated with the image pixel. In this context 'black' means 'ink' and 'white' means 'no ink'. A greyscale print head in binary mode thus either ejects an ink drop onto a given pixel on a receiving medium or it does not, wherein the ink drop is always a drop of the same volume. Thus, a greyscale ink jet print head operating in a binary 1 dpd mode prints either no drop or a 1 dpd drop, a greyscale ink jet print head operating in a binary 2dpd mode prints either no drop or a 2dpd drop, etc. The binary 1dpd mode has interesting features including the ejection of very small drops, therefore being highly suitable for high resolution printing, and the use of a very short drive waveform having only one channel expansion period, thereby enabling high fire frequencies and printing speeds. The binary 2dpd mode has an additional advantage over the binary 1dpd mode, in that the drop volume and drop speed of binary 2dpd drops can be better controlled compared to binary 1dpd drops, as will be illustrated later on. The strength of greyscale print heads regarding the printing of very small drops - even a 2dpd binary drop is small compared to the size of a binary drop from a state of the art binary print head - makes these print heads highly suitable for high resolution binary printing at the high fire frequencies and printing speeds typical for these print heads. The combination of high resolution binary printing with halt-tone screening techniques, well known in the graphics art, can deliver high print quality at high printing speeds and can be a preferred printing mode for a number of applications. That is, the advantage of high speed printing at an increased print resolution balances the disadvantage of a reduced image resolution by the half-toning technique and creates an overall system printing at high speed and delivering high image quality.

[0044] Drive system

[0045] An unipolar drive waveform may be represented and stored in the print head electronics as a sequence of bits. This sequence may be obtained by sampling the waveform using a sample clock, and representing and storing each sample in a digital form in the print head electronics. The Sample Clock (Sclk) is the smallest time unit, i.e. the resolution, of the print head drive waveform and may for example be expressed in nanoseconds (ns). One Sclk time unit corresponds with the duration of one sample of the drive waveform, wherein the sample value is represented in a digital format. The drive waveform schematically shown in figure 4 may for example comprise a first channel expansion pulse with a duration of 16 time units (16*Sclk) and a second channel expansion pulse having a duration of 10 time units (10*Sclk). The dwell period between the channel expansion pulses may be 22 time units (22*Sclk) and the dwell period following the second expansion pulse may have a duration of 16 time units (16*Sclk). The time units are relative units, that is, relative to the Sample Clock period, and are used to specify time periods or time durations relative to each other. A total of x Sample Clock time units will be further referred to as x bits. The drive waveform schematically shown in figure 4 may therefore be represented as a "16;22;10;16" bit sequence. The bit sequence defines the "shape" of the drive waveform, whereas the Sample Clock defines the "speed" of the waveform. The bits in the bit sequence have a value of 0 (corresponding with the application of ground potential) or a value of 1 (corresponding with the application of the drive voltage). The digital representation of a waveform, as stored in the print head electronics, is applied to the electrode of an ink channel through waveform drive circuitry. Electrical specifications or limitations of the waveform drive circuitry may require small changes to the waveform implementation of figure 4 to comply with the waveform drive circuitry specifications. For example, a maximum voltage step specification of the drive circuitry may require the use of voltage slopes instead of voltage steps to implement the transition from a normal channel volume to an expanded channel volume or vice versa.

[0046] A bipolar drive waveform may be represented and stored in the print head electronics as a sequence of bit-pairs. This sequence may also be obtained by sampling the waveform using a sample clock, and representing and storing each sample in a digital form in the print head electronics. Each sample can have a value of +V, GND or -V and can for example be represented by a 2bit value (e.g. 01, 00, 10), a signed bit (+I, 0 or -I) or other suitable representation. When storing the sampled waveform in the print head electronics, only digital representation can be used. A representation often used to store waveform data is +V ≡ '10', GND ≡ '00' and -V ≡ '01'. In this representation, opposite voltages have opposite bits in their digital representation. For the purpose of describing the invention in this written disclosure, another representation will be used namely +V ≡ '+', GND ≡ '0' and -V ≡ '-'. A bipolar drive pulse for ejecting one droplet (see the 'd1' part of the waveform shown in figure 6) may for example be represented as a "1(0);9(+);18(-);5(0)" sequence. This way of describing a bipolar drive waveform may of course equally be used for describing unipolar drive waveforms, e.g. the unipolar drive waveform "16;22; 10; 16" discussed in the previous paragraph may be written as "16(+);22(0);10(+);16(0)". The bipolar drive waveform notation using '+', '0' and '-' values will therefore be used throughout the rest of this disclosure to describe both bipolar as well as unipolar drive pulses of waveforms.

[0047] The frequency at which multi-droplet drops are ejected from each of the ink channels of a multi-pulse greyscale print head is referred to as the fire frequency or pixel frequency of the print head. In other words, within one fire period of the print head, (fire frequency)$^{-1}$, each nozzle in the print head may eject one burst of a number of successive droplets to create one multi-droplet drop. The fire frequency depends on a number of operating parameters such as printing speed (relative movement between the print head and the receiving medium in terms of meters per second), print resolution (in term of dots per inch), maximum density (in terms of droplets-per-dot) and others. The frequency at which individual droplets are ejected from a nozzle is referred to as the droplet ejection frequency of the print head and typically is a multiple of the fire frequency. As an example, Omnidot 760/GS8 greyscale print heads have a typical fire frequency of about 6-8 kHz and a droplet ejection frequency of about 100-120 kHz. Whereas it is evident that print heads can operate at fire frequencies lower than the typical fire frequency for that print head, it is preferable to keep the droplet ejection frequency at the typical droplet ejection frequency for which the print head was designed, for reasons of droplet merging. The droplet ejection frequency and the fire frequency are of course related to the Sample Clock. For a UPH greyscale print head, the typical fire frequency relates to the Sample Clock as:

$$\text{Fire frequency} \leq (\text{Sclk} * 32 * \text{max.dpd} * 3)^{-1}.$$

[0048] The print heads used in industrial ink jet printing applications are typically multi-nozzle print heads with 100 to 1000 and more nozzles in a single print head. In the ideal situation, all nozzles and corresponding ink channels are identical and their jetting performance is also identical. This would make the jetting conditions identical for ink channels. In reality, variations exist as a result of manufacturing tolerances, and this would require varying jetting conditions to be installed to obtain identical performance of all of the nozzles. Some print heads allow adjustment of the jetting temperature and allow the use of different drive waveforms nozzle-by-nozzle. This last feature however significantly enlarges the complexity and the cost of the print head and its electronics/drivers. The jetting temperature of the ink has a major impact on the viscosity of the ink during the ink ejection process, and is controlled via the temperature of the ink jet print head near the nozzle and the ink channel. The majority of print heads can operate at a jetting temperature range from 10°C to 70°C, but preferably operate in a range from 25°C to 55°C. The experiments for illustrating the invention have been conducted at jetting temperatures 35°C, 45°C and 55°C.

Application

[0049] Because of the ability to combine high print quality with high printing speed, multi-pulse greyscale print heads are frequently used. In industrial applications, multi-pulse greyscale print heads may be mounted onto a shuttle for traversing across a receiving medium while printing a swath of print data, followed by a forward movement of the receiving medium in a direction orthogonal to the traversing direction of the shuttle and, during a next traversal movement of the print head shuttle across the repositioned receiving medium, printing a next swath of print data adjacent the previous swath. This type of print head setup is for example used in the SOHO (small office and home) printers but also in a wide range of industrial wide format ink jet printers as for example the :Anapurna printers from Agfa Graphics. Print heads can also be arranged in a fixed configuration spanning the entire printing width of the receiving medium. In this case, the receiving medium moves with a uniform speed past the fixed set of print heads, while these print heads eject drops onto the receiving medium, in accordance with print data. Printers incorporating this type of print head setup are often referred to as single pass printers. Examples of single pass ink jet printers are the :Dotrix series of printers from Agfa Graphics. Various hybrid configurations may be thought of as well. The M-Press printers from Agfa Graphics for example include a print head shuttle that substantially covers the full width of the receiving medium but prints non-contiguous swaths, i.e. neighbouring swaths from neighbouring print heads do not join up tightly to form one contiguous swath but leave gaps in between. The gaps need to be filled in with additional swaths interleaving the previously printed swaths to create one interlaced contiguous page wide swath of printed data. The advantage of this setup is an increased throughput compared to the more conventional shuttle printers, because of the increased width of the shuttle, without uncontrollable increase of complexity that may arise from a large amount of print heads, tubing and cabling associated with a full width contiguous page wide shuttle. Although printing throughput of shuttle printers may be expected to be less than that of single pass printers, their setup allows the use of special image quality improvement techniques known as "shingling" or "mutual interstitial printing", not available for single pass printers.

<u>Ink jet inks</u>

[0050] The ink jet ink may be selected from aqueous and non-aqueous ink jet inks. The ink jet ink comprises at least a colorant in a liquid carrier. The colorant may be a dye or a pigment or a mixture thereof. The colorant is preferably used in the ink jet ink in an amount of 0.1 to 20 wt%, preferably 1 to 10 wt% based on the total weight of the ink jet ink. In multi-density ink jet ink sets, a light density ink jet ink preferably comprises the colorant in an amount between 0.1 to

3 wt% and a full density ink jet ink preferably comprises the colorant in an amount between 1 to 10 wt%. When the colorant is very low soluble or insoluble in the carrier liquid of the ink, the colorant has to be dispersed. The pigment may be surface treated to be self-dispersible in the carrier liquid. Without such a treatment, a dispersant is added in the dispersion step. Such a dispersant is a surface-active compound. A polymeric dispersant is preferred. When it is still difficult to disperse the colorant by the polymeric dispersant, use may be made of an extra dispersant synergist. The surface tension of the ink jet ink is preferably below 40 mN/m at 25°C, more preferably below 33 mN/m at 25°C.

Aqueous ink jet inks

[0051] The aqueous carrier liquid comprises water or a mixture of water and water-soluble solvents. The water-soluble solvents can function as humectants and/or penetrants. The amount of the water-soluble solvents in the ink is typically between 5 and 50 wt% of the total ink composition, more preferably 5 to 40 wt%, most preferably 10 to 30 wt% of the total ink composition. Examples of organic solvents include triacetin, 2-pyrrolidone, N-methyl-2-pyrrolidone, glycerol, urea, thiourea, ethylene urea, alkyl urea, alkyl thiourea, dialkyl urea and dialkyl thiourea, alcohols, diols, including ethanediols, propanediols, butanediols, pentanediols, and hexanediols; triols such as propanetriols; glycols, including propylene glycol, polypropylene glycol, ethylene glycol, polyethylene glycol, diethylene glycol, triethylene glycol, tetraethyleneglycol, and mixtures and derivatives thereof. Preferred humectants are triethylene glcyol mono butylether, glycerol and 1,2-hexanediol. The aqueous ink jet ink may further contain at least one surfactant.

Non-aqueous ink jet inks

[0052] The non-aqueous ink jet ink is preferably selected from the group consisting of organic solvent based, oil based and curable ink jet inks, for example UV-curable inks and electron beam curable inks. The non-aqueous ink jet ink is preferably a pigment ink jet ink. The non-aqueous ink jet ink may contain at least one humectant to prevent the clogging of the nozzle, due to its ability to slow down the evaporation rate of ink. The curable ink jet ink may contain as carrier liquid monomers, oligomers and/or prepolymers possessing different degrees of functionality. A mixture including combinations of mono-, di-, tri- and/or higher functionality monomers, oligomers or prepolymers may be used. A catalyst called an initiator for initiating the polymerization reaction may be included in the curable pigmented ink jet ink. The initiator may be a thermal initiator, but is preferably a photo-initiator. The photo-initiator requires less energy to activate than the monomers, oligomers and/or prepolymers to form the polymer. The photo-initiator suitable for use in the curable ink jet ink may be a Norrish type I initiator, a Norrish type II initiator or a photo-acid generator or a combination thereof. The non-aqueous ink jet ink may further contain at least one surfactant.

Colour dyes

[0053] Dyes suitable for the ink jet ink include direct dyes, acidic dyes, basic dyes and reactive dyes.

- Suitable direct dyes for the ink jet ink include:
  - C.I. Direct Yellow 1, 4, 8, 11, 12, 24, 26, 27, 28, 33, 39, 44, 50, 58, 85, 86, 100, 110, 120, 132, 142, and 144
  - C.I. Direct Red 1, 2, 4, 9, 11, 134, 17, 20, 23, 24, 28, 31, 33, 37, 39, 44, 47, 48, 51, 62, 63, 75, 79, 80, 81, 83, 89, 90, 94, 95, 99, 220, 224, 227 and 343
  - C.I. Direct Blue 1, 2, 6, 8, 15, 22, 25, 71, 76, 78, 80, 86, 87, 90, 98, 106, 108, 120, 123, 163, 165, 192, 193, 194, 195, 196, 199, 200, 201, 202, 203, 207, 236, and 237
  - C.I. Direct Black 2, 3, 7, 17, 19, 22, 32, 38, 51, 56, 62, 71, 74, 75, 77, 105, 108, 112, 117, 154 and 195.
- Suitable acidic dyes for the ink jet ink include:
  - C.I. Acid Yellow 2, 3, 7, 17, 19, 23, 25, 20, 38, 42, 49, 59, 61, 72, and 99
  - C.I. Acid Orange 56 and 64
  - C.I. Acid Red 1, 8, 14, 18, 26, 32, 37, 42, 52, 57, 72, 74, 80, 87, 115, 119, 131, 133, 134, 143, 154, 186, 249, 254, and 256
  - C.I. Acid Violet 11, 34, and 75
  - C.I. Acid Blue 1, 7, 9, 29, 87, 126, 138, 171, 175, 183, 234, 236, and 249
  - C.I. Acid Green 9, 12, 19, 27, and 41
  - C.I. Acid Black 1, 2, 7, 24, 26, 48, 52, 58, 60, 94, 107, 109, 110, 119, 131, and 155.
- Suitable reactive dyes for the ink jet ink include:

- C.I. Reactive Yellow 1, 2, 3, 14, 15, 17, 37, 42, 76, 95, 168, and 175
- C.I. Reactive Red 2, 6, 11, 21, 22, 23, 24, 33, 45, 111, 112, 114, 180, 218, 226, 228, and 235
- C.I. Reactive Blue 7, 14, 15, 18, 19, 21, 25, 38, 49, 72, 77, 176, 203, 220, 230, and 235
- C.I. Reactive Orange 5, 12, 13, 35, and 95
- C.I. Reactive Brown 7, 11, 33, 37, and 46
- C.I. Reactive Green 8 and 19
- C.I. Reactive Violet 2, 4, 6, 8, 21, 22, and 25
- C.I. Reactive Black 5, 8, 31, and 39.
- Suitable basic dyes for the ink jet ink include:

- C.I. Basic Yellow 11, 14, 21, and 32
- C.I. Basic Red 1, 2, 9, 12, and 13
- C.I. Basic Violet 3, 7, and 14
- C.I. Basic Blue 3, 9, 24, and 25.

Colour pigments

[0054] The colour pigment in the ink jet ink may be an organic or inorganic pigment or a mixture thereof. The colour pigment for the ink jet ink may be chosen from those disclosed by HERBST, Willy, et al. Industrial Organic Pigments, Production, Properties, Applications. 3rd edition. Wiley - VCH, 2004. ISBN 3527305769.

- Particular preferred pigments are C.I. Pigment Yellow 1, 3, 10, 12, 13 ,14, 17, 55, 65, 73, 74, 75, 83, 93, 97, 109, 111, 120, 128, 138, 139, 150, 151, 154, 155, 180, 185, 194 and 213.
- Particular preferred pigments are C.I. Pigment Red 17, 22, 23, 41, 48:1, 48:2, 52:1, 57:1, 81:1, 81:3, 88, 112, 122, 144, 146, 149, 169, 170, 175, 176, 184, 185, 188, 202, 206, 207, 210, 216, 221, 248, 251, 254, 255, 264, 270, 272 and 282.
- Particular preferred pigments are C.I. Pigment Violet 1, 2, 19, 23, 32, 37 and 39.
- Particular preferred pigments are C.I. Pigment Blue 15:1, 15:2, 15:3, 15:4, 15:6, 16, 56, 61 and (bridged) aluminium phthalocyanine pigments.
- Particular preferred pigments are C.I. Pigment Orange 5, 13, 16, 34, 40, 43, 59, 66, 67, 69, 71 and 73.
- Particular preferred pigments are C.I. Pigment Green 7 and 36.
- Particular preferred pigments are C.I. Pigment Brown 6 and 7.

[0055] Inorganic pigments can also be used in the ink jet ink, especially for white ink and black ink. Illustrative examples of the inorganic pigments include titanium oxide, barium sulfate, calcium carbonate, zinc oxide, lead sulfate, yellow lead, zinc yellow, red iron oxide (III), cadmium red, ultramarine blue, prussian blue, chromium oxide green, cobalt green, amber, titanium black and synthetic iron black.

[0056] Carbon black is preferred as a pigment for the black ink jet ink. Suitable black pigment materials include carbon blacks such as Pigment Black 7 (e.g. Carbon Black MA8™ from MITSUBISHI CHEMICAL), Regal™ 400R, Mogul™ , Elftex™ 320 from CABOT Co., or Carbon Black FW18, Special Black 250, Special Black 350, Special Black 550, Printex™ 25, Printex™ 35, PrintexTM 55, Printex™ 90, Printex™ 150T from DEGUSSA. Additional examples of suitable pigments are disclosed in US 5389133 (XEROX)

[0057] Mixed crystals of pigments, sometimes referred to as solid solutions of pigments, can also be used. For example, mixed crystals of quinacridone pigments, mixed crystals of diketopyrrolo-pyrrole pigments and mixed crystals of quinacridone and diketopyrrolo-pyrrole pigments.

[0058] It is also possible to make mixtures of pigments in ink jet ink. For example, carbon black generally exhibits a warm brownish black tone, while a neutral black tone is generally preferred. A neutral black ink jet ink may be obtained, for example, by mixing carbon black with a cyan, a magenta or a cyan and magenta pigment into the ink, as for example described in pending European patent application EP 1593718 A (AGFA).

[0059] The ink jet ink is typically used in an ink jet ink set. For black and white printing the ink jet ink set may comprise two or more black inks of different densities. For colour ink jet printing the ink jet ink set may comprise yellow, cyan, magenta, black, red, orange, violet, blue, green, brown inks, mixtures thereof, and the like.

[0060] A preferred ink jet ink set comprises at least a cyan ink, a magenta ink, a yellow ink and a black ink. The CMYK ink set may also be extended with extra inks such as red, green, blue, and/or orange to enlarge the colour gamut of the ink set. The CMYK ink set may also be extended by the combination of full density and light density inks of both colour inks and/or black inks to improve the image quality by lowered graininess.

[0061] The ink jet application may also require one or more spot colours, for example for packaging ink jet printing or textile ink jet printing. Silver and gold are often desired colours for ink jet poster printing and point-of-sales displays.

Particular preferred pigments are C.I. Pigment Metal 1, 2 and 3. Illustrative examples of the inorganic pigments include titanium oxide. barium sulfate, calcium carbonate, zinc oxide, lead sulfate, yellow lead, zinc yellow, red iron oxide (III), cadmium red, ultramarine blue, prussian blue, chromium oxide green, cobalt green, amber, titanium black and synthetic iron black.

[0062] Pigment particles in ink jet ink should be sufficiently small to permit free flow of the ink through the ink jet-printing device, especially at the ejecting nozzles. It is also desirable to use small particles for maximum colour strength and to slow down sedimentation.

[0063] The numeric average pigment particle size is preferably between 0.005 and 5 μm, more preferably between 0.005 and 1 μm, particularly preferably between 0.080 and 0.200 μm and most preferably not larger than 0.150 μm. However, the average pigment particle size for white ink jet inks comprising, for example, a titanium dioxide pigment, is preferably between 0.100 and 0.300 μm.

Polymeric dispersant

[0064] The dispersants used in the pigment ink jet ink are preferably polymeric dispersants. Preferred polymeric dispersants are disclosed in the unpublished EP-A 06122098 (filed 11 October 2006) in paragraph [0051] to [0086].

[0065] The polymeric dispersant is preferably used in the pigment ink jet ink in an amount of 2 to 600 wt%, more preferably 5 to 200 wt% based on the weight of the pigment.

Dispersion synergist

[0066] A dispersion synergist may be used for improving the dispersion quality and stability of pigment dispersions and ink jet inks.

[0067] The dispersion synergist usually consists of an anionic part and a cationic part. The anionic part of the dispersion synergist exhibits often a certain molecular similarity with the colour pigment and the cationic part of the dispersion synergist consists of one or more protons and/or cations to compensate the charge of the anionic part of the dispersion synergist.

[0068] The synergist should be additional to the amount of polymeric dispersant(s). The ratio of polymeric dispersant/ dispersion synergist depends upon the pigment and should be determined experimentally. Typically the ratio wt% polymeric dispersant/wt% dispersion synergist is selected between 2:1 to 1000:1, preferably between 2:1 and 100:1.

[0069] Suitable dispersion synergists that are commercially available include Solsperse™ 5000 and Solsperse™ 22000 from NOVEON. In dispersing C.I. Pigment Blue 15:3, the use of a sulfonated Cu-phthalocyanine dispersion synergist, e.g. Solsperse™ 5000 from NOVEON is preferred.

[0070] In dispersing C.I. Pigment Blue 15, the use of a sulfonated Cu-phthalocyanine dispersion synergist, e.g. Solsperse™ 5000 from NOVEON is preferred.

[0071] Suitable dispersion synergists for non-aqueous ink jet inks include those disclosed in pending European Patent Applications EP 05111357 A (AGFA) and EP 05111360 A (AGFA).

Non-aqueous carrier liquid

[0072] In the case of solvent-based ink jet inks the carrier of the non-aqueous ink jet ink consists of organic solvent (s). Suitable organic solvents include alcohols, ketones, esters, ethers, glycols and polyglycols and derivatives thereof, lactones, N-containing solvents such as amides, saturated hydrocarbons and unsaturated hydrocarbons. Preferably mixtures of one or more of these solvents are used.

[0073] Examples of suitable alcohols, ketones, esters, ethers, glycols and polyglycols, glycol and polyglycol derivatives, lactones, N-containing organic solvents and hydrocarbons are disclosed in unpublished EP-A 06122091 (filed 11 October 2006) in paragraph [0088] to [0107].

[0074] Preferred solvents for use in ink jet inks are one or more polyalkyleneglycol dialkylethers represented by the formula (PAG)

$$R_1 - \left[O\text{-}Y \right]_n - O - R_2$$

Formula (PAG)

wherein,

R_1 and R_2 are each independently selected from an alkyl group having 1 to 4 carbon atoms;
Y represents an ethylene group and/or a propylene group; wherein
n is an integer selected from 4 to 20 for a first polyalkyleneglycol dialkylether; and n is an integer selected from 5 to 20 for a second polyalkyleneglycol.

[0075] The alkyl groups R_1 and R_2 of the polyalkyleneglycol dialkylethers according to Formula (PAG) preferably represent methyl and/or ethyl. Most preferably the alkyl groups R_1 and R_2 are both methyl groups.

[0076] Preferrably the polyalkyleneglycol dialkylethers according to Formula (PAG) are polyethylene glycol dialkylethers.

[0077] A preferred solvent mixture is a mixture of 2, 3, 4 or more polyalkyleneglycol dialkylethers, more preferably polyethylene glycol dialkylethers are present in the pigment dispersion or ink jet ink.

[0078] In the case of oil-based ink jet inks the non-aqueous carrier liquid comprises oil types of liquids, alone or in combination with organic solvent(s).

[0079] Suitable organic solvents include alcohols, ketones, esters, ethers, glycols and polyglycols and derivatives thereof, lactones, N-containing solvents such as amides, higher fatty acid ester and mixtures of one or more of the solvents as described above for solvent based ink carriers.

[0080] The amount of polar solvent is preferably lower than the amount of oil. The organic solvent has preferably a high boiling point, preferably above 200°C. Examples of suitable combinations are disclosed by EP 0808347 (XAAR TECHNOLOGY LTD) especially for the use of oleyl alcohol and EP 1157070 (VIDEOJET TECHNOLOGIES INC) for the combination of oil and volatile organic solvent.

[0081] Suitable oils include saturated hydrocarbons and unsaturated hydrocarbons, aromatic oils, paraffinic oils, extracted paraffinic oils, napthenic oils, extracted napthenic oils, hydro treated light or heavy oils, vegetable oils, white oils, petroleum naphtha oils, halogen-substituted hydrocarbons, silicones and derivatives and mixtures thereof.

[0082] Preferred hydrocarbons, silicone oils, white oils, vegetable oils and other oils are disclosed in unpublished EP-A 06122091 (filed 11 October 2006) in paragraph [0112] to [0124].

[0083] If the non-aqueous ink jet ink is a curable ink, the carrier liquid comprises one or more monomers and/or oligomers. Sometimes, it may be advantageous to add a small amount of an organic solvent to improve the dissolution of the dispersant. The content of organic solvent should be lower than 20 wt% based on the total weight of the ink jet ink. In other cases, it may be advantageous to add a small amount of water, for example, to improve the spreading of the ink jet ink on a hydrophilic surface.

[0084] Preferred organic solvents include alcohols, aromatic hydrocarbons, ketones, esters, aliphatic hydrocarbons, higher fatty acids, carbitols, cello solves, higher fatty acid esters. Suitable alcohols include, methanol, ethanol, propanol and 1-butanol, 1-pentanol, 2-butanol, t.-butanol. Suitable aromatic hydrocarbons include toluene, and xylene. Suitable ketones include methyl ethyl ketone, methyl isobutyl ketone, 2,4-pentanedione and hexafluoroacetone. Also glycol, glycolethers, N-methylpyrrolidone, N,N-dimethylacetamid, N, N-dimethylformamid may be used.

[0085] Suitable monomers and oligomers may be found in Polymer Handbook, Vol. 1 + 2. 4th edition. Edited by J. BRANDRUP, et al. Wiley-Interscience , 1999.

[0086] Preferred polymerizable compounds for curable ink jet inks are disclosed in unpublished EP-A 06122091 (filed 11 October 2006) in paragraph [0128] to [0148].

[0087] A combination of monomers, oligomers and/or prepolymers may also be used. The monomers, oligomers and/or prepolymers may possess different degrees of functionality, and a mixture including combinations of mono-, di-, tri-and higher functionality monomers, oligomers and/or prepolymers may be used.

[0088] The ink jet ink may be a free radical polymerizable ink, a cationically polymerizable ink or a combination thereof.

Initiators

[0089] A curable ink jet ink usually contains an initiator. The initiator typically initiates the polymerization reaction. The initiator may be a thermal initiator, but is preferably a photo-initiator. The photo-initiator requires less energy to activate than the monomers, oligomers and/or prepolymers to form the polymer.

[0090] The photo-initiator suitable for use in the curable liquids may be a Norrish type I initiator, a Norrish type II initiator or a photo-acid generator or a combination thereof.

[0091] Preferred initiators are disclosed in unpublished EP-A 06122091 (filed 11 October 2006) in paragraph [0150] to [0163].

[0092] A preferred amount of initiator is 0.3 - 50 wt% of the total weight of the curable ink jet ink, and more preferably 1 - 15 wt% of the total weight of the curable ink jet ink.

Inhibitors

[0093] Radiation curable ink jet inks may contain a polymerization inhibitor. Suitable polymerization inhibitors include phenol type antioxidants, hindered amine light stabilizers, phosphor type antioxidants, hydroquinone monomethyl ether commonly used in (meth)acrylate monomers, and hydroquinone, t-butylcatechol, pyrogallol may also be used.

[0094] Suitable inhibitors are, for example, Sumilizer™ GA-80, Sumilizer™ GM and Sumilizer™ GS produced by Sumitomo Chemical Co., Ltd.

[0095] Other suitable commercial inhibitors are, for example, Genorad™ 16, Genorad™ 18 and Genorad™ 20 from Rahn AG, Irgastab™ UV10 and Irgastab™ UV22 from Ciba Specialty Chemicals, Tinuvin™ 460 from Ciba Specialty Chemicals and CGS20 from Ciba Specialty Chemicals, Floorstab™ UV range (UV-1, UV-2, UV-5 and UV-8) from Kromachem Ltd, Additol™ S range (S100, S110, S120 and S130) from Cytec Surface Specialties.

[0096] Since excessive addition of these polymerization inhibitors will lower the ink sensitivity to curing, it is preferred that the amount capable of preventing polymerization is determined prior to blending. The amount of a polymerization inhibitor is preferably lower than 2 wt% of the total ink.

Surfactants

[0097] The ink jet ink may contain at least one surfactant. The surfactant(s) may be anionic, cationic, non-ionic, or zwitter-ionic and are usually added in a total quantity less than 20 wt% based on the total weight of the pigment ink jet ink and particularly in a total less than 10 wt% based on the total weight of the ink jet ink.

[0098] Suitable surfactants include fatty acid salts, ester salts of a higher alcohol, alkylbenzene sulphonate salts, sulphosuccinate ester salts and phosphate ester salts of a higher alcohol (for example, sodium dodecylbenzenesulphonate and sodium dioctylsulphosuccinate), ethylene oxide adducts of a higher alcohol, ethylene oxide adducts of an alkylphenol, ethylene oxide adducts of a polyhydric alcohol fatty acid ester, and acetylene glycol and ethylene oxide adducts thereof (for example, polyoxyethylene nonylphenyl ether, and SURFYNOL™ 104, 104H, 440, 465 and TG available from AIR PRODUCTS & CHEMICALS INC.).

[0099] For non-aqueous ink jet inks preferred surfactants are selected from fluoro surfactants (such as fluorinated hydrocarbons) and silicone surfactants. The silicones are typically siloxanes and may be alkoxylated, polyether modified, polyether modified hydroxy functional, amine modified, epoxy modified and other modifications or combinations thereof. Preferred siloxanes are polymeric, for example polydimethylsiloxanes.

[0100] When the ink jet ink is a radiation curable ink jet ink a fluorinated or silicone compound may be used as a surfactant, however, a cross-linkable surfactant would be preferred. It is therefore preferred to use a copolymerizable monomer having surface-active effects, for example, polyacrylate copolymers, silicone modified acrylates, silicone modified methacrylates, acrylated siloxanes, polyether modified acrylic modified siloxanes, fluorinated acrylates, and fluorinated methacrylates; these acrylates may be mono-, di-, tri- or higher functional (meth)acrylates.

Other additives

[0101] The ink jet ink may comprise a biocide, especially in the case of aqueous ink jet inks. Suitable biocides for the ink jet ink of the present invention include sodium dehydroacetate, 2-phenoxyethanol, sodium benzoate, sodium pyridinethion-1-oxide, ethyl p-hydroxybenzoate and 1,2-benzisothiazolin-3-one and salts thereof. A preferred biocide in an aqueous ink jet ink of the present invention is Proxel Ultra 5 from ARCH BIOCIDES.

[0102] A biocide is preferably added in an amount of 0.001 to 3 wt.%, more preferably 0.01 to 1.00 wt. %, each based on the ink jet ink.

[0103] The ink jet ink may comprise an antioxidant. As the antioxidant for improving storage stability of an image, various organic and metal complex type fading preventives may be used in the invention. Organic fading preventives include hydroquinones, alkoxyphenols, dialkoxyphenols, phenols, anilines, amines, indanes, coumarones, alkoxyanilines and heterocycles, while metal complexes include nickel complexes and zinc complexes. More specifically, compounds as described in "Research Disclosure, No. 17643, VII, Section I or J, No. 15162, No. 18716, left column on page 650, No. 36544, page 527, No. 307105, page 872, and the patent cited in No. 15162, and compounds embraced in the formula of the typical compounds and compound examples described on pages 127 to 137 of JP 62215272 A (FUJI).

[0104] The stabilizer is added in an amount of 0.1 to 30 wt%, preferably 1 to 10 wt% based on the ink.

[0105] The ink jet ink may comprise an ink binder resin.

[0106] Examples of binder resins include acrylic resins, modified acrylic resins, styrene acrylic resins, acrylic copolymers, acrylate resins, aldehyde resins, rosins, rosin esters, modified rosins and modified rosin resins, acetyl polymers, acetal resins such as polyvinyl butyral, ketone resins, phenolic resins and modified phenolic resins, maleic resins and modified maliec resins, terpene resins, polyester resins, polyamide resins, polyurethane resins, epoxy resins, vinyl resins, vinyl chloride-vinyl acetate copolymer resins, cellulose type resins such as nitro cellulose, cellulose acetopropionate and cellulose acetate butyrate, and vinyl toluene-α-methylstyrene copolymer resin. These binders may be used alone or in a mixture thereof. The binder is preferably a film-forming thermoplastic resin.

[0107] The use of an ink binder resin is particular important for solvent-based ink jet inks.

[0108] The amount of binder resin in ink jet ink is preferably in the range of 0.1 to 30 wt%, more preferably 0.3 to 10 wt %, most preferably 0.5 to 5 wt% based on the total weight of the ink jet ink.
[0109] In addition to the constituents, described above, the ink jet inks may, if necessary, further contain following additives to have desired performance: evaporation accelerators, rust inhibitors, cross-linking agents, soluble electrolytes as conductivity aid, sequestering agents and chelating agents, compounds to introduce security features, etc.
[0110] Compounds to introduce security features include a fluorescent compound, a phosphorescent compound, a thermochromic compound, an iridescent compound and a magnetic particle. Suitable UV-fluorescent and phosphorescent compounds include LUMILUX™ luminescent pigments from HONEYWELL, UVITEX™ OB from CIBA-GEIGY, KEYFLUORTM dyes and pigments from KEYSTONE and fluorescent dyes from SYNTHEGEN.

Preparation of ink jet inks

[0111] A dye-based ink jet ink is prepared by dissolving the dye in the carrier liquid. When the dye is only moderately soluble in the carrier liquid, the dye may be dispersed in the carrier liquid.
[0112] A pigment ink jet ink may be prepared by precipitating or milling the pigment in the dispersion medium in the presence of the dispersant.
[0113] Mixing apparatuses may include a pressure kneader, an open kneader, a planetary mixer, a dissolver, and a Dalton Universal Mixer. Suitable milling and dispersion apparatuses are a ball mill, a pearl mill, a colloid mill, a high-speed disperser, double rollers, a bead mill, a paint conditioner, and triple rollers. The dispersions may also be prepared using ultrasonic energy. A combination of these techniques may be used.
[0114] Many different types of materials may be used as milling media, such as glasses, ceramics, metals, and plastics. In a preferred embodiment, the grinding media may comprise particles, preferably substantially spherical in shape, e.g. beads consisting essentially of a polymeric resin or yttrium stabilized zirconium oxide beads.
[0115] In the process of mixing, milling and dispersion, each process is performed with cooling to prevent build up of heat, and for radiation curable pigmented ink jet inks as much as possible under light conditions in which actinic radiation has been substantially excluded.
[0116] The pigment ink jet ink may contain more than one pigment, the ink jet ink may be prepared using separate dispersions for each pigment, or alternatively several pigments may be mixed and co-milled in preparing the dispersion.
[0117] The dispersion process may be carried out in a continuous, batch or semi-batch mode.
[0118] The preferred amounts and ratios of the ingredients of the mill grind will vary widely depending upon the specific materials and the intended applications. The contents of the milling mixture comprise the mill grind and the milling media. The mill grind comprises pigment, polymeric dispersant and a liquid carrier. For ink jet inks, the pigment is usually present in the mill grind at 1 to 50 wt%, excluding the milling media. The weight ratio of pigment over polymeric dispersant is 20:1 to 1:2.
[0119] The milling time can vary widely and depends upon the pigment, mechanical means and residence conditions selected, the initial and desired final particle size, etc. In the present invention pigment dispersions with an average particle size of less than 100 nm may be prepared.
[0120] After milling is completed, the milling media is separated from the milled particulate product (in either a dry or liquid dispersion form) using conventional separation techniques, such as by filtration, sieving through a mesh screen, and the like. Often the sieve is built into the mill, e.g. for a bead mill. The milled pigment concentrate is preferably separated from the milling media by filtration.
[0121] In general it is desirable to make the pigment ink jet inks in the form of a concentrated mill grind, which is subsequently diluted to the appropriate concentration for use in the ink jet printing system. This technique permits preparation of a greater quantity of pigment ink from the equipment. By dilution, the ink jet ink is adjusted to the desired viscosity, surface tension, Colour, hue, saturation density, and print area coverage for the particular application.

Evaluation methods

[0122] Industrial ink jet printing applications often aim at high productivity and throughput and therefore require high print head fire frequencies to be used. Under these conditions, ink drop speeds of at least 6 m/s are preferred. Higher drop speeds minimize the adverse effect of (nearly unavoidable) drop speed variations in a printing system. Drop speed variations adversely affect the placement of the printed dots on a receiving medium and thus result in image quality degradation as a result thereof. For the printing experiments described further, a drop speed of 6 m/s is considered a favourable condition for running the experiments.
Printing speed is defined as the relative velocity between the receiving medium, upon which the ink drops are printed, and the ink jet print head during printing.
The experiments conducted in the course of this invention used an 8 pL UPH greyscale print head from Agfa Graphics. For the purpose of verifying the invention, the technology of the 8 pL UPH greyscale print head is similar to that of the

OmniDot 760/GS8 greyscale print head from Xaar. There are four important ink jet reliability parameters that have been studied in the framework of the present invention. They are satellite drop formation, overfill or pooling, ink viscosity, and gas content of the ink. It will be explained first how these parameters are measured and quantified or at least qualitatively determined.

Satellite drop formation

[0123] Satellite drop formation is investigated using VisionJet™ Optica equipment, available from Xennia Technology (UK). The VisionJet™ Optica is a high definition stroboscopic visualization instrument that captures live images of ink jetting from print head nozzles. It enables real-time analysis of drop, ligament and satellite formation.

[0124] The visualization and study of the ink ejection process was carried out by evaluating satellite drop formation at different operating conditions using the VisionJet™ Optica. This allowed determination of sensitivity and latitude towards satellite drop formation as a function of the electrical drive signals and the ink characteristics. Satellite drop formation was especially evaluated for single droplet drops, as a satellite-free operation of the single droplet ejection process is a premium condition for ejecting multiple droplet drops. An example is shown in figure 6. A first graph in figure 6 shows the drive voltage (in volts) required to eject a drop from the print head with a velocity of 6 m/s, at different sample clocks or droplet ejection frequencies at which the print head is operated. A second graph shows, for the same range of sample clocks or droplet ejection frequencies, the threshold drive voltage (in volts) at which the ejection process starts creating satellite drops that are visible on the VisionJet™ Optica equipment. Drive voltages below this threshold voltage will generally not cause satellite drop formation, whereas voltages above this threshold voltage will likely cause satellite drop formation. If the drive voltage to reach a drop velocity of 6 m/s is lower than the threshold voltage causing satellite drop formation, it is considered an acceptable operating point. If however the drive voltage to reach a drop velocity of 6 m/s is equal to or higher than the threshold voltage causing satellite drop formation, then reliable drop ejection at 6 m/s can not be achieved and consequently the operating point can not be accepted. This method therefore allows evaluation of the latitude towards satellite drop formation and deduction of the operating window at which reliable drop ejection is possible at 6 m/s. It results in a Sclk window wherein satellite drop formation can be avoided at a drop velocity of 6 m/s.

Overfill and pooling

[0125] Overfill and pooling can, to some extent, also be evaluated using the VisionJet™ Optica equipment, by focussing the optics at the ink meniscus and the nozzle plate. However, overfill and pooling is not only a phenomenon of transient short-lived ink meniscus behaviour but also has a cumulative long-term effect, i.e. the effect of a growing ink pool on the nozzle plate, kinetic energy loss in the ink pool and the influence on the drop formation process. It has been observed that sustained overfill and pooling adversely affects jetting reliability, with increasing number of ejection failures of the print head. Causes of ejection failure may be insufficient energy for drop formation and ejection (energy losses in the ink pool) or insufficient directionality of the ejected drop (undefined "nozzle" or "meniscus"). The presence of overfill and pooling can therefore also be deduced from jetting reliability tests wherein a print head is driven in standard operating conditions at maximum density, i.e. maximum dpd and therefore maximum energy input in the ink channel, for a given period of time, after which the ejection failures are evaluated. In these experiments, the ink is deeply degassed to a total gas content level of ≤ 40% of the reference total gas content of the ink when exposed to ambient atmospheric conditions, in order to guarantee absence of bubble formation as a result of rectified diffusion which also can result in failing nozzles. These jetting reliability tests may be performed to define the operating window for drop ejection solely based on overfill and pooling effects, but it is preferable to limit the scope of these tests to the operating window already defined from the satellite drop formation test above. A criterion for deciding that overfill or pooling is present or not, may be a percentage of failing nozzles, after one hour of printing in a repetitive pattern of 3 seconds full coverage printing and 0.1 seconds non-printing. The percentage of failing nozzles is preferably less than 10%. Jetting reliability tests define a drive voltage window within which no overfill and pooling is observed.

Viscosity

[0126] The viscosity of ink jet inks is not a fixed parameter for a given ink composition. Often the viscosity is measured at room temperature (25°C) and at low shear (≤ 100 s^{-1}). This viscosity measurement is less relevant for ink jet inks for two reasons. Firstly, room temperature and low shear conditions are not relevant for real operating conditions where the ink is ejected through a nozzle. Real operating conditions generally include a higher operating temperature and a higher shear rate. Secondly, a viscosity value at room temperature and low shear, for a given ink composition, can not unambiguously be linked to a viscosity value at real operating conditions. Therefore the viscosity value at room temperature and low shear can not serve as an entry in a look-up table for finding the viscosity of the ink jet ink at real operating conditions. A hybrid UV-curable ink jet ink, sometimes referred to as a semi-solid ink, may for example have a much higher viscosity (60 to 1000 mPa.s) at room temperature and low shear than a standard UV-curable ink jet ink (20 to 30 mPa.s) in the same conditions, and nevertheless may have a similar viscosity at real operation conditions in the ink jet

print head. Moreover, two ink jet inks with similar viscosity at room temperature and low shear rate can have different viscosities at 1000 s^{-1} and at jetting temperature.
Therefore, the viscosity of the inks used in the experiments verifying the invention is always measured at the jetting temperature and at a shear rate of 1000 s^{-1}, with an AR1000 rheometer from TA Instruments. The measurement cell is a steel core cell with a cone - plate architecture; the cone has a diameter of 40 mm and an angle of 2°. The measurement cell is filled with the ink jet ink and the ink is heated to a desired temperature during 5 minutes without pre-shear. The desired temperature is adjustable and may for example be set to 25°C, 35°C, 45°C or 55°C, being the evaluated jetting temperatures. The shear rate is then increased at a steady state flow step from 1 to 1000 s^{-1} during 20 minutes. The viscosity is measured at a shear rate of 1000 s^{-1}.

Gas content

[0127] The total gas content of the ink jet inks is measured using gaschromatography according to the DIN norm EN 60567. It is important that the total gas content in the ink is measured and not only the oxygen content. Especially with UV-curable ink jet inks, that tend to 'consume' oxygen during there shelf life, while leaving other dissolved gasses at their reference concentration level, measuring the oxygen content only may not be relevant.
[0128] The measurement method provides a quantitative value for the total gas content contained in the ink. By comparing this value with the value for the total gas content contained in the ink at reference conditions, a % value representing the total gas content of a degassed ink relative to a reference total gas content is calculated. The reference condition is the ink exposed to ambient atmospheric conditions.

Embodiments for carrying out the invention

Preliminary considerations

[0129] According to the Merriam-Webster dictionary, resonance is a vibration of large amplitude in a mechanical or electrical system caused by a relatively small period stimulus of the same or nearly the same period as the natural vibration period of the system. Elaborating on this definition, it is considered that stimuli are applied in resonance with a resonant acoustic pressure wave in an ink channel if they sustain or amplify the resonant acoustic pressure wave at the acoustic resonance frequency, and stimuli are applied in antiresonance with a resonant acoustic pressure wave in the ink channel if they minimize the amplitude of the resonant acoustic pressure wave at the acoustic resonance frequency. A first stimulus generally induces the acoustic pressure wave in the ink channel. Subsequent stimuli either amplify the acoustic pressure wave (when applied in resonance), minimize the acoustic pressure wave (when applied in antiresonance), or have a less pronounced effect on the acoustic pressure wave (when applied out of resonance).
[0130] Rendering the above teaching in the present invention, the natural vibration period of the system is the acoustic resonance period of the ink channel which is $4l/c$, wherein l is the length of the ink channel and c is the speed of sound in the ink. For two pulses of the same polarity to be applied in resonance with a resonant acoustic pressure wave in the ink channel, e.g. two underpressure pulses or two pressure pulses, the time between both pulses has to be the same or nearly the same as the acoustic resonance period $4l/c$ of the ink channel, or an integer multiple thereof. Then the individual effect of the subsequent pulse amplifies the individual effect of a previous pulse. For two pulses of opposite polarity to be applied in resonance with a resonant acoustic pressure wave in the ink channel, e.g. an underpressure pulse and a pressure pulse or vice versa, the time between both pulses has to be the same or nearly the same as ½ of the acoustic resonance period $4l/c$ of the ink channel, or an odd integer multiple thereof. Then the individual effect of the subsequent pulse also amplifies the individual effect of a previous pulse. Similar considerations can be given to antiresonance phenomena. For two pulses of the same polarity to be applied in antiresonance with a resonant acoustic pressure wave in the ink channel, e.g. two underpressure pulses or two pressure pulses, the time between both pulses has to be the same or nearly the same as ½ of the acoustic resonance period $4l/c$ of the ink channel, or an odd integer multiple thereof. Then the individual effect of the subsequent pulse cancels the individual effect of a previous pulse. For two pulses of opposite polarity to be applied in antiresonance with a resonant acoustic pressure wave in the ink channel, e.g. an underpressure pulse and a pressure pulse or vice versa, the time between both pulses has to be the same of nearly the same as the acoustic resonance period $4l/c$ of the ink channel, or an integer multiple thereof. Then the individual effect of the subsequent pulse again cancels the individual effect of a previous pulse.
[0131] Resonance or antiresonance effects will thus be pronounced when stimuli are applied at specific time intervals as described above and will decay as the application of these stimuli moves away from these prescribed time intervals. For the purpose of this disclosure, the phrase "the same or nearly the same" in the Merriam-Webster definition of resonance is rendered into "the same or within a tolerance window of $\pm 1/8*(4l/c)$", preferably into "the same or within a tolerance window of $\pm 1/16*(4l/c)$". Within these time windows, the effect of resonance or antiresonance will still be apparent. As is evident within the context of a sampling, the term "the same" is to be read as "the same within the time

resolution of the sample clock". A pulse is applied out of resonance with a resonant acoustic pressure wave in the ink channel if it is applied out of the resonance and antiresonance time windows.
So, for the purpose of this description and the understanding of the claimed invention, two stimuli are applied in acoustic resonance if they are applied with a time difference of an odd multiple of ½ of the acoustic resonance period of the ink channel (if the stimuli are of opposite polarity) or an even multiple of ½ of the acoustic resonance period of the ink channel (if the stimuli are of the same polarity), with a tolerance of ±1/8 of the acoustic resonance period of the ink channel, end-points including. Two stimuli are applied out of resonance if they are applied out of this time window.

[0132] The acoustic resonance period of an ink channel mainly depends on the design of the ink jet print head. Some typical values for different type ink jet print heads are: A UPH (3pl) ink jet print head from Agfa Graphics has an acoustic resonance period of about 4000 ns; A UPH (8pl) ink jet print head from Agfa Graphics has an acoustic resonance period of about 6000 ns; A KM512 M (14pl) ink jet print head from Konica-Minolta has an acoustic resonance period of about 12000 ns.

Cancel signal

[0133] According to the invention, an unipolar drive waveform is terminated with an additional cancel signal at the end of the sequence of unipolar drive signal. The sequence of unipolar drive signals generates a corresponding sequence of droplets creating a multi-droplet drop of an appropriate size or volume. The additional cancel signal does not produce an additional droplet. It produces an underpressure pulse and a pressure pulse in the ink channel, of which at least one is in antiresonance with the existing pressure waves in the ink channel. It is to be understood that the term antiresonance in this context is to be interpreted as "within the tolerance window of ±1/8 of the acoustic resonance period of the ink channel" as discussed above. Because the at least one underpressure or pressure pulse of the cancel signal is applied in antiresonance with the existing pressure waves in the ink channel, this at least one pulse is also referred as a cancel pulse as it attempts to cancel the existing pressure waves in the ink channel. The additional signal at the end of an unipolar drive waveform is referred to as a "cancel signal", as opposed to a "drive signal" which is used to eject a droplet. The cancel signal may be either of the same polarity as the unipolar drive signal(s) or it may be of an opposite polarity.

[0134] The invention is further illustrated with a 2dpd unipolar drive waveform of the type wherein the duration t_2 of the channel expansion pulse for ejecting the second droplet is significantly smaller than the duration t_1 of the channel expansion pulse used to eject the first droplet. These type of waveforms, schematically depicted in figure 4, have been described in co-pending PCT application N° PCT/EP2007/064363. It should however be understood that the invention is not limited to 2dpd waveforms. The invention is also applicable to greyscale waveforms capable of using more greyscale levels (e.g. up to 4dpd drops) as well as to binary waveforms using multi-pulse drive waveforms to generate binary multi-droplet drops. As explained before, the cancel signal attempts to cancel the residual acoustic waves present in the ink channel at the end of the ejection of a sequence of droplets, which are mainly dominated by the last drive signal of the multi-pulse waveform. The preferred specification of a cancel signal thus relates to the specification of the last drive signal of the multi-pulse waveform. Therefore, the absolute timing of the cancel signal is of less importance but the relative timing of the leading and/or trailing edge of the cancel signal versus the timing of the last drive signal for ejecting the last droplet will be of importance. For proper reference to the drawings, the "last drive signal" or "last droplet" will be reduced to the "second drive signal" respectively the "second droplet" of the 2dpd multi-pulse waveform used in the drawings. It is however not intended to limit the invention thereto.

Double pulse cancelling

[0135] In one embodiment, both the underpressure pulse 51_2 and the pressure (jet) pulse 52_2 of the last drive signal are cancelled by pulses of the cancel signal. Two examples of this embodiment are shown in the figures 7 and 10. In both examples, the unipolar drive waveform is, by way of illustration only, a 2dpd drive waveform.

[0136] If the cancel signal is of the same polarity as the unipolar drive signals, as in figure 10, pressure wave cancelling is achieved by providing the underpressure pulse 51_c of the cancel pulse in antiresonance with the underpressure pulse 51_2 of the drive signal for ejecting the second droplet. Similarly, the pressure pulse 52_c of the cancel signal is applied in antiresonance with the pressure (jet) pulse 52_2 of the drive signal for ejecting the second droplet. In figure 10, the time between the underpressure pulses 51_c and 51_2, and between the pressure pulses 52_c and 52_2, is defined as ½ of the acoustic resonance period of the ink channel, i.e. ½*($4l/c$). It is however understood that any uneven multiple thereof, e.g. 3/*($4l/c$), will also work.

[0137] If the cancel signal is the opposite polarity as the unipolar drive signals, as in figure 7, double pulse cancelling is achieved by providing the pressure pulse 52_c of the cancel pulse (i.e. the leading edge of the cancel signal) in antiresonance with the underpressure pulse 51_2 of the drive signal for ejecting the second droplet. The underpressure pulse 51_c of the cancel signal (i.e. the trailing edge of the cancel signal) is applied in antiresonance with the pressure (jet) pulse 52_2 of the drive signal for ejecting the second droplet. In figure 7, this is illustrated by applying the leading and trailing edge of the cancel signal about one acoustic resonance period (4*l*/*c*), or an integer multiple thereof, after the corresponding edge of the drive signal of the second droplet.

Jet pulse cancelling

[0138] In a further embodiment, only the pressure (jet) pulse 52_2 of the last drive signal is cancelled by the cancel signal. Two examples of this embodiment are shown in the figures 8 and 9. In these examples, the unipolar drive waveform is, by way of illustration only, a 2dpd drive waveform.

[0139] A first example of jet pulse cancelling is shown schematically in figure 9. A cancel signal of the same polarity as the unipolar drive signals is applied about one acoustic resonance period after application of the pressure (jet) pulse 52_2 of the second droplet. That is, the leading edge 51_c of the cancel signal, which is an underpressure pulse, is applied in antiresonance with the pressure (jet) pulse 52_2 of the drive signal for ejecting the second droplet, that is, at about 4*l*/*c* after that jet pulse. The leading edge of the cancel signal thereby cancels the jet pulse of the second drive signal. The trailing edge of the cancel signal, i.e. the pressure pulse 52_c, is applied about ½ of the acoustic resonance period thereafter, i.e. about 1½ of the acoustic resonance period after the pressure (jet) pulse 52_2 of the drive signal for ejecting the second droplet. The jet pulse 52_2 of the last droplet is therefore cancelled twice.

[0140] In a second example, illustrated in figure 8, a cancel signal of an opposite polarity than the unipolar drive signals is applied. The cancel signal provides a pressure pulse 52_c about ½ of the acoustic resonance period after pressure (jet) pulse 52_2 of the second droplet, and an underpressure pulse 51_c about a full acoustic resonance period after pressure (jet) pulse 52_2 of the second droplet. Again, the jet pulse 52_2 of the last droplet is cancelled twice, by the pressure and the underpressure pulse of the cancel signal applied in antiresonance with the jet pulse of that last droplet.

Further embodiments

[0141] It goes without saying the numerous other embodiments can be envisioned that have the same or similar cancelling effect. For example, the timing between the last drive signal and the cancel signal may be different than described and illustrated examples, but the principle of applying the cancel signal in antiresonance with the last drive signal is preferably. However in a most preferred embodiment, the cancelling effect is pursued with a minimum of additional time to execute the cancel signal. That is, the cancel signal is applied as soon as appropriate after the last drive signal. The term "as soon as appropriate" does not necessarily mean "as soon as possible" ; it is preferred that the drive signal should have exercised its effect on the ejection process of the last droplet before the cancel signal attempts to cancel any residual acoustic pressure waves. If not, the application of the cancel signal may adversely affect the ejection process of that last droplet.

[0142] The invention has been illustrated in the figures with an unipolar 2dpd waveforms as disclosed in co-pending PCT application N° PCT/EP2007/064363, filed by the same applicant. These unipolar waveforms have a channel expansion period for ejecting a second droplet that is significantly shorter than the channel expansion period for ejection a first droplet. However, the invention also works fine with unipolar waveforms as disclosed in co-pending PCT application N° PCT/EP2007/064362, also filed by the same application, wherein the channel expansion period for ejecting a second droplet is significantly lounger than the channel expansion period for ejection a first droplet.

[0143] A waveform according to the invention may also include additional cancel signals, following a first cancel signal, for further reducing the residual acoustic pressure waves in the ink channel. However, experiments have shown that this is not always favourable because subsequent cancel pulses may show to become drive pulses when previous cancel pulses have effectively cancelled the residual acoustic pressure waves in the ink channel. That is, if substantially no residual acoustic pressure waves are left in the ink channel, a subsequent cancel signal effectively becomes a drive signal. It has been shown that a single cancel signal applied "as soon as appropriate" after ejecting the last droplet of a sequence of droplets of a multi-droplet drop, is effective enough for the purpose of reducing the residual acoustic pressure wave in the ink channel so as to have substantially no effect on the ejection process of a next sequence of droplets of a multi-droplet drop from the same or neighbouring nozzle.

[0144] In the embodiments described above, both pressure events associated with the application of the cancel pulse, i.e. a pressure pulse 52_c and underpressure pulse 51_c, are applied to cancel residual acoustic pressure waves in the ink channel. This is however not necessary. One pressure event, for example the leading edge of the cancel signal applied in antiresonance with the jet pulse of the last droplet, may turn out to be effective enough to cancel the residual acoustic pressure waves to a level that shows reliable operating at high printing frequencies. The other pressure event, for example the trailing edge of the cancel signal, is then preferably applied out of resonance (i.e. not in resonance, nor in antiresonance with any of the pulses of the last droplet).

Advantages of the invention

[0145] The main advantage of the invention is that, despite the fact that the application of a waveform according to the invention takes longer to execute, because of the additional cancel signal, the ink channel returns much faster into a relaxed, eased state so that the start of a next waveform for ejecting a next multi-droplet drop may be moved up. Hence the cancel signal provides opportunities to drive the multi-pulse print head at a higher fire frequency or print frequency than usual.

[0146] The reduction of time for the ink channel to move into a relaxed, eased state, is important for starting the ejection of a droplet from a neighbouring ink channel, in a so-called ABC firing scheme used in shared-wall type print head technologies as for example manufactured by Xaar where channel walls effecting a channel expansion or contraction are common to two neighbouring channels, as well as for starting the ejection of a next droplet from the same ink channel, in a so-called AAA firing scheme used with print heads providing autonomous controlled ink channels as for example manufactured by Dimatix FujiFilm.

[0147] In the embodiments described, the cancel signal is applied after application of the unipolar drive signal for ejecting the last droplet, e.g. the second droplet in the figures 7 to 10. It must be clarified that, in these embodiments, the cancel signal is only applied when the maximum number of droplet in a multi-droplet drop ejected with the drive waveform is requested. This feature is linked to the way the drive waveforms are applied in a UPH print head from Agfa Graphics, used to verify the invention. In a UPH print head, the execution of the waveform is cut off when the requested number of droplets (corresponding with the print tone data, greyscale value or dpd-level of the multiple-droplet drop requested) is ejected. Thus, a cancel signal is not applied when a multi-droplet drop having a number of successive droplets less than the maximum number of successive droplets is ejected. This limitation is however not a problem for the following reason. If not the maximum number of droplets is requested from the print head, additional time for the residual acoustic pressure waves to ease off, before the piezoelectric walls start operating again for ejecting a next droplet, becomes available. Within this additional time period, the residual acoustic pressure waves in the ink channel will ease down to a level that they do not substantially impede the proper ejection of a next number of droplets in a next multi-droplet drop. However, if the maximum number of droplets is requested, this additional time period is not available and the cancel signal will then actively reduce the residual acoustic pressure waves within the available (shorter) time period. The invention therefore does not require every dpd-level to be cancelled individually, which would increase the execution time of the drive waveform, as a whole, significantly.

Examples

Ink examples

[0148] Materials

[0149] All materials used in the following examples were readily available from standard sources such as ALDRICH CHEMICAL Co. (Belgium) and ACROS (Belgium) unless otherwise specified.

- PB15:4 is an abbreviation for Hostaperm™ Blue P-BFS, a C.I.Pigment Blue 15:4 pigment from CLARIANT.
- S35000 is an abbreviation for SOLSPERSE™ 35000, a hyperdispersant from NOVEON.
- DPGDA is dipropylene glycol diacrylate monomer available from SARTOMER.
- Darocur™ ITX is a photo-initiator available from CIBA SPECILATY CHEMICALS.
- Darocur™ TPO is a photo-initiator available from CIBA SPECILATY CHEMICALS.
- Genocure™ EPD is an amine synergist available from Rahn AG.
- Byk™UV3510 is a surfactant from BYK CHEMIE GMBH.
- Genorad™ 16 is a polymerization inhibitor form RAHN AG.

[0150] Inks

[0151] The composition and preparation method of the ink jet ink used in the examples is described below.

[0152] The UV-curable inkjet ink INK-1 is of the so-called 100% solids type, meaning that there are no non-reactive solvents presents, thus that all diluents are UV-curable, also the dispersion medium consists of UV-curable compounds.

[0153] The ink INK-1 is a Cyan pigmented ink. The concentrated pigment dispersion was prepared in DPGDA as dispersion medium. The concentrated Cyan pigment dispersion was made in a Dyno-Mill™ ECM Poly from WAG (Willy A. Bachofen AG Machinenfabrik). In a predispersion step the vessel was filled with 6.750 kg S35000 as dispersant, 27.286 kg DPGDA as UV-curable dispersion medium, 0.507 kg Genorad™ 16 and 13.500 kg pigment PB15:4, and stirred for 30 minutes. Then this mixture was milled during 3 hours. Next, to this mixture 6.750 kg S35000 as dispersant, 0.169 kg Genorad™ 16 and 12.539 kg DPGDA as UV-curable dispersion medium were added. This mixture was milled during 1 hour. In the dispersion yttrium stabilized zirconium oxide beads of 0.4 mm were used as beads. The bead mill is filled for 65 % with the grinding beads. The Cyan pigment dispersion composition is given in Table 1.

[0154]

Table 1

Component	Concentration (wt%)
PB15:4	20.00
S35000	20.00
Genorad™ 16	1.00
DPGDA	59.00

[0155] The concentrated cyan dispersion of table 1 was used to prepare the cyan ink jet ink INK-1 by addition of the other ingredients while stirring.

[0156] The final ink composition (in wt%) of the UV-curable ink jet ink INK-1 is given in Table 2.

[0157]

Table 2

Component	INK-1
PB15:4	3.00
S35000	3.00
Darocur™ ITX	5.00
Darocur™ TPO	4.95
Genocure™ EPD	5.00
Byk™UV3510	0.10
Genorad™16	1.00
DPGDA	77.95

[0158] The viscosity of the ink jet ink INK-1 was determined at a shear rate of 1,000 s^{-1} and at a jetting temperature range suitable for the specific type of ink, varying between 25°C and 55°C. The viscosity values in mPa.s for the ink jet ink INK-1 are given in Table 3.

[0159]

Table 3

INK	Viscosity at 25°C	Viscosity at 30°C	Viscosity at 35°C	Viscosity at 45°C	Viscosity at 55°C
INK-1	19.1	15.5	12.4	8.7	6.7

[0160] The total gas content of the ink jet inks needs to be controlled in order to deliver good jetting performance in combination with the waveform of the invention. The ink jet ink INK-1 is degassed by use of an active through-flow degassing unit. The term "active" refers to the ability to control the degassing level of the ink. The through-flow degassing unit is part of a continuous ink circulation system. This circulation system may be operating standalone, only for the purpose of ink degassing, or it may be integrated in an ink supply system for ink jet printers, in which the system supplies inline degassed ink to an ink jet print head. An inline degassing system has been described in WO 2006/064040 (AGFA-GEVAERT) 2006-06-22 . An example of a through-flow degassing unit suitable for ink jet inks is a MiniModule hollow fiber membrane type degassing unit available from Membrana GmbH. The Celgard® hollow fibers are hydrophobic and provide a surface area for a liquid and a gas phase to come into direct contact without the liquid penetrating the pores. Generally, in through-flow degassing units, the percentage of dissolved gas removal is a function of the trough-flow rate of the ink, the type of ink, the applied vacuum, temperature and time. For example, the reference total gas content of INK-1 was 454 mg/L (measured according to DIN EN60567). After circulating one hour through the degassing unit desribed above, at a flow rate of 1 L/hour and a vacuum pressure of - 800 mbar. INK-1 was degassed to a level of 322.5 mg/L or 71% of the reference total gas content of INK-1. All experiments were carried with the INK-1 at this degassing level.

Effect of a cancel signal on maximum fire frequency

[0161] Experiments have been conducted with a UPH (8pL) ink jet print head from Agfa Graphics having an acoustic resonance period of around 5900 ns. The ink jet print head is driven at 22 V and operated at 45°C with a UV-curable ink INK-1, of which the details are provided above, and which was degassed down to a total gas content of 71 % of the reference gas content when exposed to ambient atmospheric conditions. The ink jet print head was driven with a drive waveform WaFo-485CT as illustrated in figure 7, more specifically, and using the notation described supra, a waveform specification of "1(0);25(+);35(0);15(+);35(0);15(-);2(0)". In this specification the "25(+)" represents the drive signal of a first polarity for ejecting a first droplet, the "15(+)" represents the drive signal of the first polarity for ejecting a second and last droplet, and the "15(-)" represents the cancel signal of opposite for cancelling the residual acoustic pressure waves in the ink channel after ejection of the second and last droplet. The same waveform but without the cancel signal is further referred to as WaFo-485 (without suffix). This drive waveform was applied at different Sample Clocks to evaluate the sensitivity of a waveform with cancel signal to Sample Clock variations, i.e. to the timing of the waveform with respect to the acoustic resonance period of the ink channel. The effect of the cancel signal on the reliability of the ejection process, as the fire frequency is increased, is illustrated in figure 11.

[0162] Figure 11 illustrates the stability improvement of the drop velocity with increasing fire frequencies, when using a cancel signal at the end of the drive waveform. At the horizontal axis, the 'rest time' is depicted. The rest time is the time available, after execution of the drive waveform, that the piezoelectric side walls P2 and P3 of ink channel 15B (see figures 1 to 4) are not operated. This time is counted from the pressure (jet) pulse of the last unipolar drive signal onward. It is the time available for the residual acoustic pressure waves to ease off, before the piezoelectric side walls start operating again for ejecting a droplet from a neighbouring ink channel, in a so-called ABC firing scheme used in shared-wall type print head technologies as for example manufactured by Xaar, or for ejecting a next droplet from the same ink channel, in a so-called AAA firing scheme used with print heads providing autonomous controlled ink channels as for example manufactured by Dimatix FujiFilm. The rest time is sometimes also referred to as residual vibration time. Note that, with the above provided definition of rest time or residual vibration time, a cancel signal (if used) is applied within the rest time, which seems a sound conclusion because that's the time period within which active cancelling and/or unforced easing of residual pressure waves occur. It is evident that the print head fire frequency is inverse proportional to the rest time or residual vibration time. That is, as the print head fire frequency increases, the rest time available for the residual acoustic pressure waves to ease off reduces. Figure 11 depicts the drop velocity of the 2dpd drop realized with different drive waveforms (with and without cancel signal) operated at different Sample Clocks. The stability of the drop velocity may be regarded as representative for the stability of the ejection process. In practice it has shown that the first local drop velocity maximum following the operating window of nearly constant drop velocity, i.e. the first local maximum in the direction of reduced rest time or increasing fire frequency, is a fire frequency operating point that still provides reliable operation. These points correspond with a rest time of about 22.5 μs (without cancel signal) and about 15.5 μs (with cancel signal). Taking into account that the 2dpd drive signal part of waveform WaFo-485 or WaFo-485CT takes about 8.5 μs to execute, the reliable maximum operating fire frequency for the UPH print head of Agfa Graphics, operating in an ABC firing scheme shift from 10.7 kHz (without cancel signal) to 13.9 kHz (with cancel signal). Thus for a 2dpd unipolar waveform, the use of a cancel signal provides an achievable fire frequency increase of about 30%.

[0163] It must be clarified that effective rest time or residual vibration time is not a constant for a given waveform and fire frequency. The effective rest time depends on the actual print tone data, greyscale value or dpd-level that is being printed. For example, when 1dpd drops are printed at a given fire frequency, the available rest time will be larger than when 2dpd drops are printed at the same given fire frequency because the execution time of a 1dpd waveform is shorter than that of a 2dpd waveform.

Industrial Application

Alternative greyscale ink jet print heads

[0164] The invention is not limited to the UPH (8pl) greyscale ink jet print head from Agfa Graphics, used to reduce the invention to practice. The invention is also applicable to other type of multi-pulse greyscale ink jet print heads currently available, e.g. greyscale ink jet print heads from Xaar (UK), Toshiba TEC (JP) and Konica-Minolta (JP). Also future multi-pulse greyscale print head designs having other channel lengths, nozzle diameters, nozzle shapes, taper angles, etc. are envisioned to benefit from the invention. Alternative drive electronics

[0165] If the electronics of the print head's drive circuitry so allows, the additional cancel signal may be applied after each sequence of successive droplet forming a single multi-droplet drop, independent on the number of droplets ejected in this sequence. That is, the additional unipolar cancel pulse may be added to each dpd-level of the unipolar drive waveform, a dpd-level of the unipolar drive waveform being the drive waveform applied for ejecting a specific number of droplets to form a specific multi-droplet drop.

[0166] Because of technical limitations of the drive electronics incorporated in the ink jet print head, design options for the cancel signal and unipolar drive pulses may be limited. For example, in the drive electronics currently incorporated in the UPH ink jet print head, sloped leading or trailing edges can not be defined and a voltage polarity switch can not be implemented without an intermediate 'zero voltage' phase. Alternative inks

[0167] The invention is applicable to aqueous and non-aqueous ink jet inks, wherein non-aqueous inks include oil based inks, solvent based inks and curable inks, for example UV-curable inks.

Printing applications

[0168] The present invention can be used in a variety of printing applications and printing apparatus, either using single pass printing techniques or multiple pass (scanning) printing techniques.

Claims

1. An ink jet printing method comprising the steps of:

- providing an ink jet print head and an ink jet ink, the ink jet print head having an ink channel (4) and electrically actuable means (5) associated with the ink channel (4) and actuable in accordance with print tone data, thereby to eject a number of successive droplets of an ink jet ink from the ink channel (4) to form a printed dot of appropriate tone on a receiving medium, the ink channel (4) being **characterised by** an acoustic resonance frequency and corresponding acoustic resonance period, and;
- applying a number of successive electrical drive signals to the electrically actuable means (5), each electrical drive signal for ejecting a corresponding droplet of the number of successive droplets to be ejected in accordance with the print tone data, each electrical drive signal inducing in the ink channel (4) one underpressure pulse (51_1) followed by one pressure pulse (52_1) for ejecting the corresponding droplet (d1), each electrical drive signal being an unipolar signal having a same polarity;

characterised in that the method further comprises the steps of:

- after applying a last electrical drive signal for ejecting a last droplet of a maximum number of successive droplets, applying an electrical cancel signal for reducing residual acoustic pressure waves in the ink channel (4), wherein the electrical cancel signal induces in the ink channel (4) one underpressure pulse (51_c) and one pressure pulse (52_c) and at least one of the underpressure pulse (51_c) or the pressure pulse (52_c) is applied in antiresonance, with a tolerance of $\pm 1/8^{th}$ of the acoustic resonance period of the ink channel (4), with the pressure pulse (52_2) of the last electrical drive signal for ejecting the last droplet (d2) of the maximum number of successive droplets.

2. The method according to claim 1, wherein the electrical cancel signal is of a polarity that is the same as the polarity of the last electrical signal for ejecting the last droplet of the maximum number of successive droplets.

3. The method according to claim 1, wherein the electrical cancel signal is of a polarity that is opposite to the polarity of the last electrical signal for ejecting the last droplet of the maximum number of successive droplets.

4. The method according to claim 1, wherein the underpressure pulse (51_c) of the electrical cancel signal is applied in antiresonance, with a tolerance of $\pm 1/8^{th}$ of the acoustic resonance period of the ink channel (4), with the pressure pulse (52_2) of the last electrical drive signal and the pressure pulse (52_c) of the electrical cancel signal is applied in antiresonance, with a tolerance of $\pm 1/8^{th}$ of the acoustic resonance period of the ink channel (4), with the underpressure pulse (51_2) of the last electrical drive signal.

5. The method according to claim 1, wherein the underpressure pulse (51_c) of the electrical cancel signal is applied in antiresonance, with a tolerance of $\pm 1/8^{th}$ of the acoustic resonance period of the ink channel (4), with the underpressure pulse (51_2) of the last electrical drive signal and the pressure pulse (52_c) of the electrical cancel signal is applied in antiresonance, with a tolerance of $\pm 1/8^{th}$ of the acoustic resonance period of the ink channel (4), with the pressure pulse (52_2) of the last electrical drive signal.

6. The method according to any one of the previous claims, wherein the number of successive droplets of the ink jet ink ejected from the ink channel (4) to form a printed dot of appropriate tone on a receiving medium is fixed so that the printed dot is of a fixed tone.

7. The method according to any one of the previous claims, wherein the maximum number of successive droplets forming a printed dot on the receiving medium is 2.

8. A multi-pulse ink jet print head comprising:

- an ink channel (4) and electrically actuable means (5) associated with the ink channel (4) and actuable in accordance with print tone data, thereby to eject a number of successive droplets of an ink jet ink from the ink channel (4) to form a printed dot of appropriate tone on a receiving medium, the ink channel (4) being **characterised by** an acoustic resonance frequency and corresponding acoustic resonance period;
- means for storing at least one electrical drive signal for controlling the electrically actuable means (5) so as to eject a droplet of the number of successive droplets, the electrical drive signal **characterized by** having a polarity;
- means for applying a number of electrical drive signals, each electrical drive signal inducing a jet pulse (52_1) in the ink channel (4) for ejecting a corresponding droplet (d1) of the number of successive droplets, each electrical drive signal having the same polarity;

characterized in that the multi-pulse ink jet print head further comprises

- means for storing an electrical cancel signal, the electrical cancel signal for reducing residual acoustic pressure waves in the ink channel (4), the electrical cancel signal **characterized by** having a polarity which is the same as or opposite to the polarity of the number of electrical drive signals, and inducing an underpressure pulse (51_c) and a pressure pulse (52_c) in the ink channel (4);
- means for applying the electrical cancel signal after applying a last electrical drive signal for ejecting a last droplet of a maximum number of successive droplets,

wherein at least one of the underpressure pulse (51_c) or the pressure pulse (52_c) of the electrical cancel signal is applied in antiresonance, with a tolerance of $\pm 1/8^{th}$ of the acoustic resonance period of the ink channel (4), with the jet pulse (52_2) for ejecting the last droplet (d2) of the maximum number of droplets.

9. An ink jet printing system comprising a multi-pulse ink jet print head according to claim 8 for operating the ink jet printing system according to the method of any one of the claim 1 to 7.

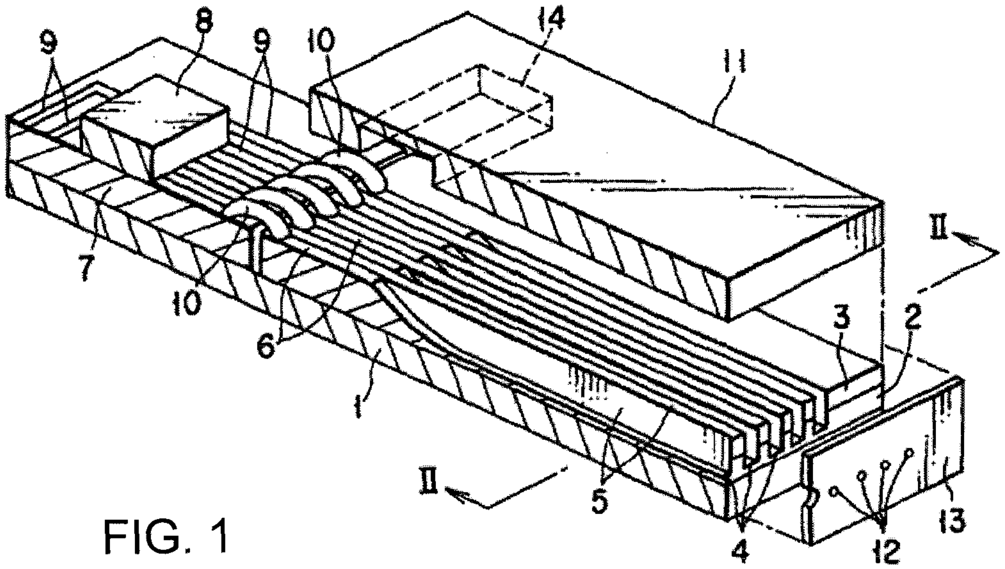

FIG. 1

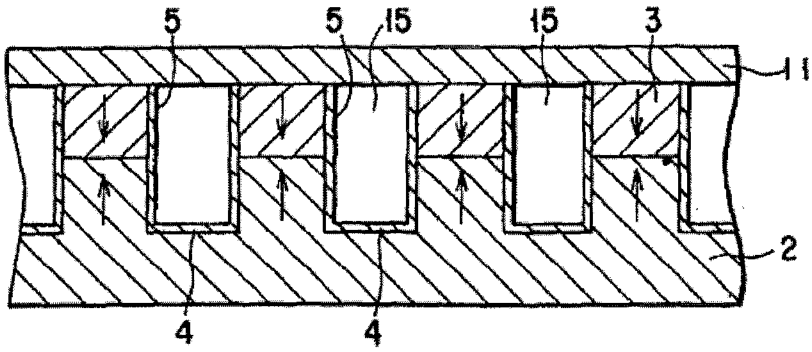

FIG. 2

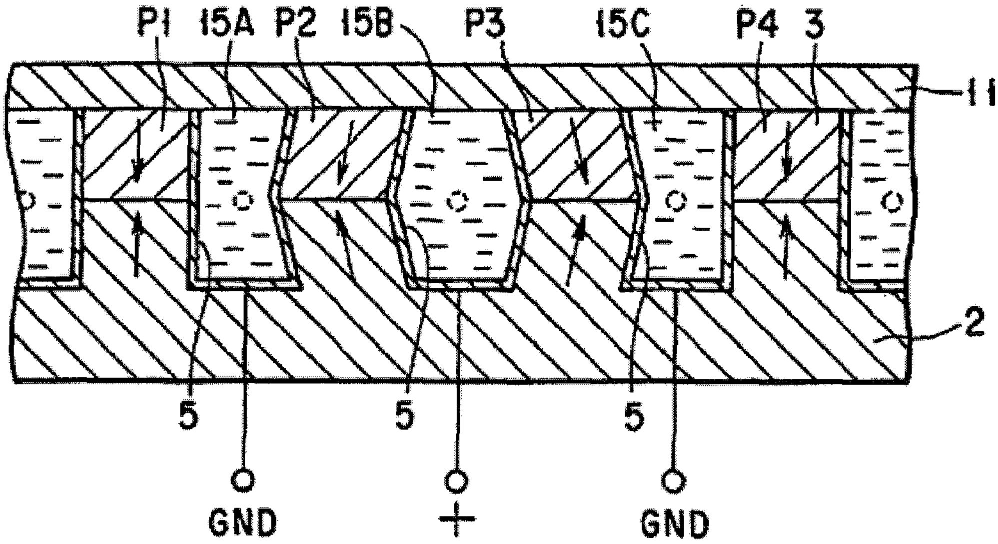
P1
15A
P2
15B
P3
15C
P4
3
11
2
5
5
5
GND
+
GND

FIG. 3A

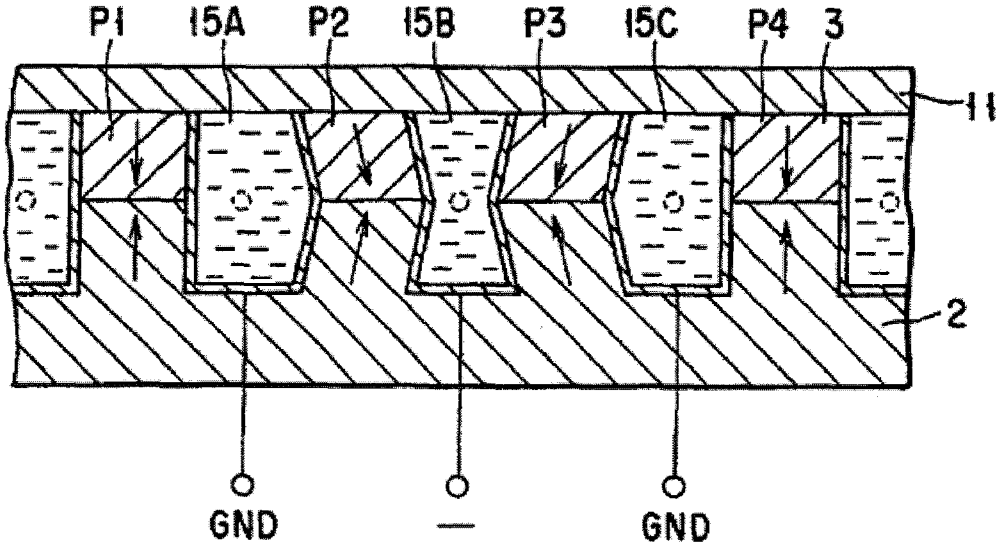
P1
15A
P2
15B
P3
15C
P4
3
11
2
GND
—
GND

FIG. 3B

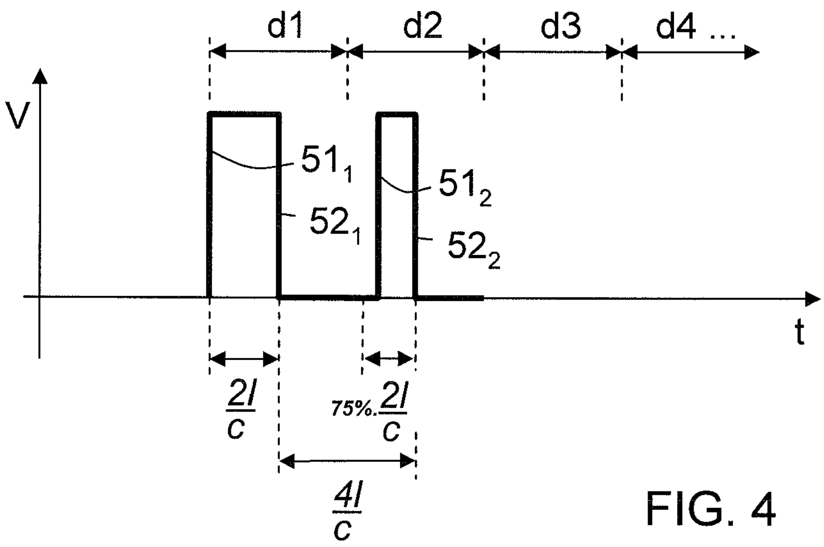

FIG. 4
Prior Art

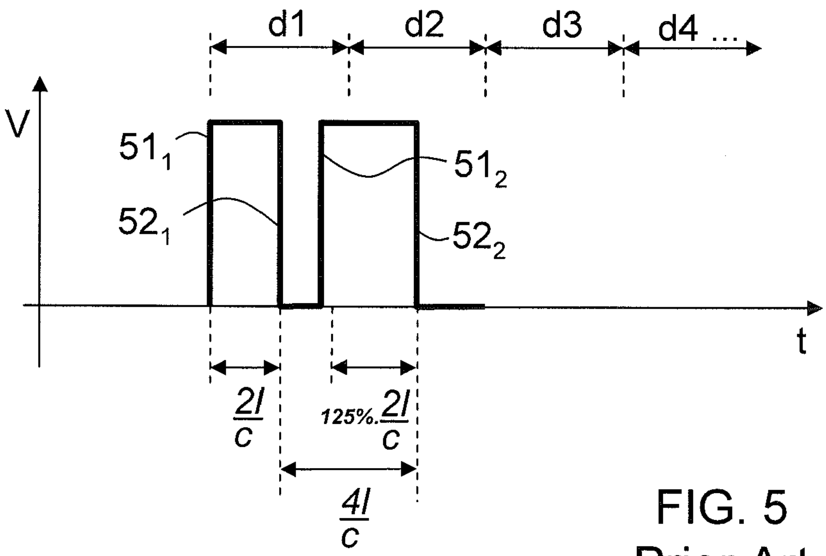

FIG. 5
Prior Art

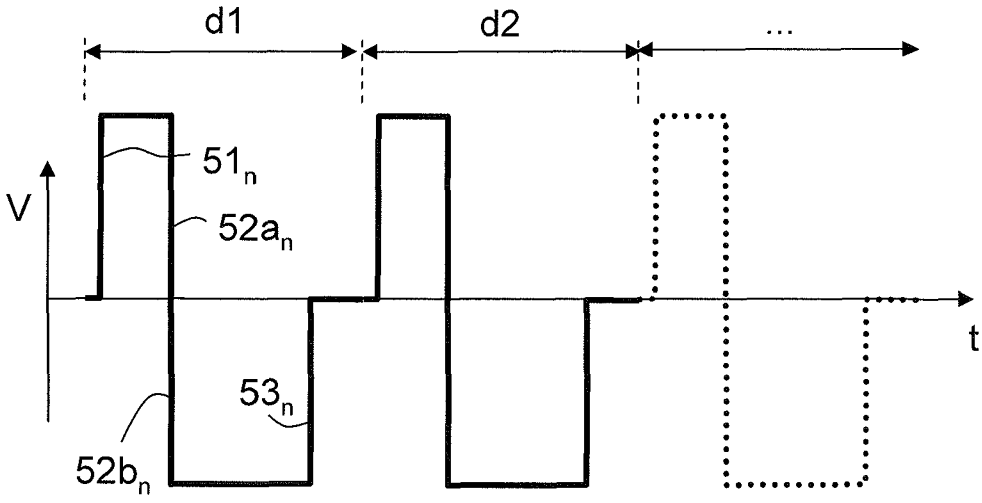

FIG. 6
Prior Art

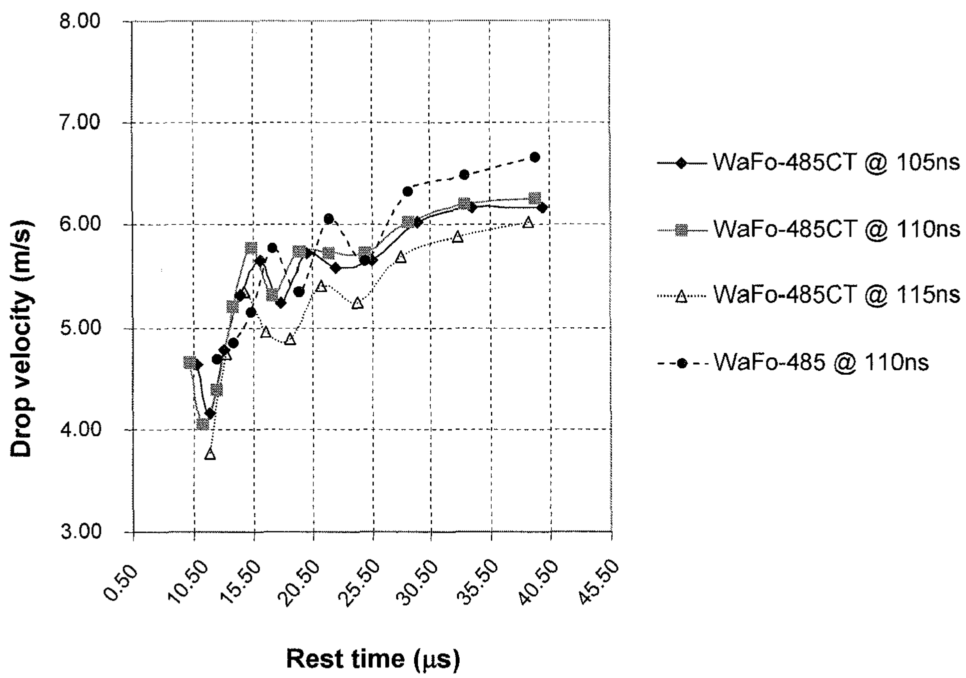

FIG. 11

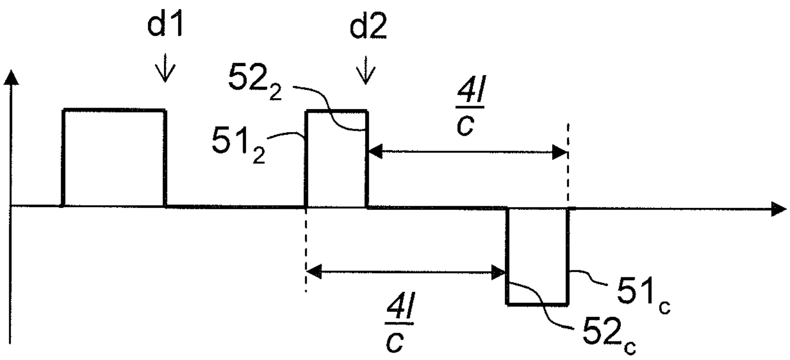

FIG. 7

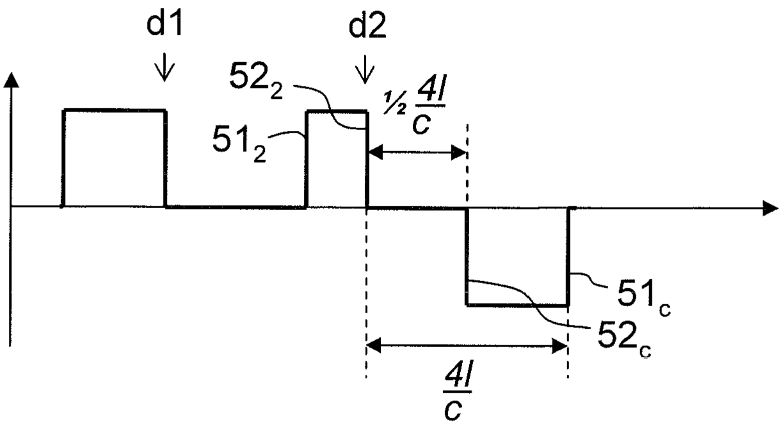

FIG. 8

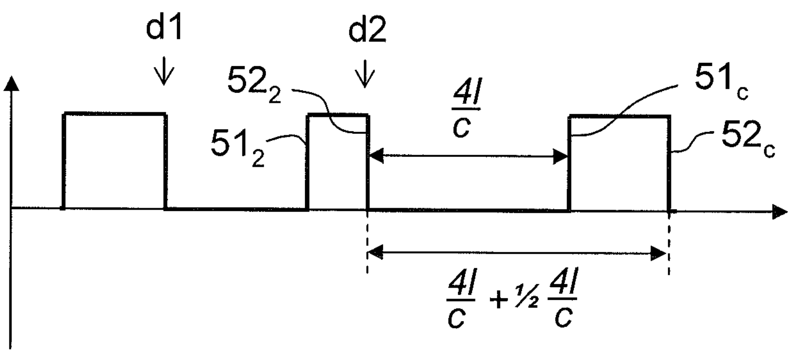

FIG. 9

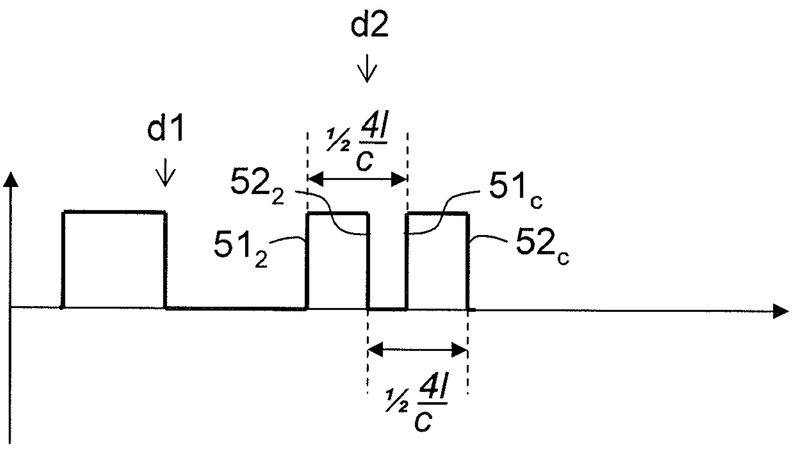

FIG. 10

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 12 3944

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	US 6 141 113 A (TAKAHASHI YOSHIKAZU [JP]) 31 October 2000 (2000-10-31) * column 1, line 56 - column 2, line 24 * * column 4, line 42 - column 7, line 5 * * column 8, lines 28-31 * * figures 1,5 * -----	1,2,7-9 3	INV. B41J2/045
Y	US 4 972 211 A (AOKI MAKOTO [JP]) 20 November 1990 (1990-11-20) * column 3, lines 22-51 * * column 4, lines 9-13 * * figure 5b * -----	3	
X	EP 1 652 669 A (BROTHER IND LTD [JP]; KYOCERA CORP [JP]) 3 May 2006 (2006-05-03) * paragraphs [0030], [0040], [0041], [0048] * * figure 12 * -----	1,2,8,9	
			TECHNICAL FIELDS SEARCHED (IPC)
			B41J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	23 May 2008	Bonnin, David

CATEGORY OF CITED DOCUMENTS

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& : member of the same patent family, corresponding document

2

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 07 12 3944

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23-05-2008

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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