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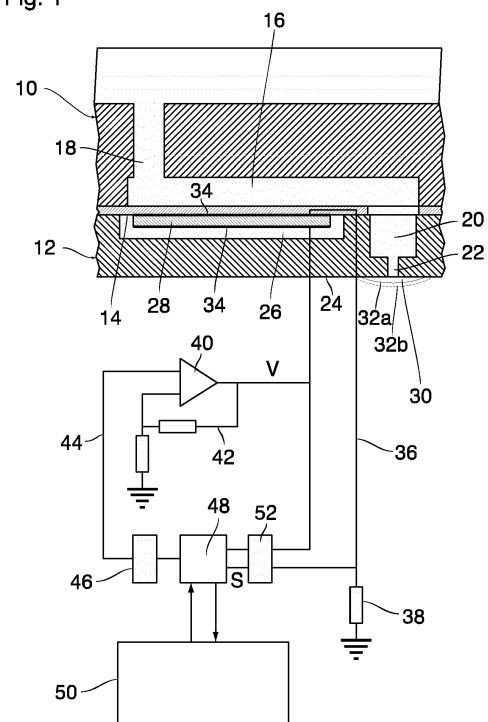
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(54) **A CIRCUIT AND METHOD DETECTING EJECTION ABNORMALITIES IN AN INKJET PRINT HEAD**

(57) The invention relates to a method of detecting failing nozzles in an ejection unit during the printing of an object of a print job comprising one or more objects, wherein the ejection unit is arranged to eject droplets of a liquid and comprises one or more of nozzles, one or more liquid ducts each connected to one of the one or more nozzles, and one or more electro-mechanical transducers each arranged to create an acoustic pressure wave in the liquid in one of the one or more liquid ducts, and further arranged to sense a residual pressure wave in the liquid in each of the one or more liquid ducts. The method comprises actuating the electro-mechanical transducer to generate a pressure wave in the liquid in one of the one or more liquid ducts. The method comprises sensing a residual pressure wave in the liquid in the one of the one or more liquid ducts. Further, the method comprises comparing the residual pressure wave sensed in the previous sensing step in the one of the one or more liquid ducts with the residual pressure wave of the one or more liquid ducts sensed in one or more previous executions of the method by determining the difference of one or more parameters of the residual pressure wave sensed in the sensing step and one or more parameters of the residual pressure wave sensed in one or more previous executions of the method. Also, the method comprises determining whether the one of the one or more of nozzles is in an operative state or in a malfunctioning state, wherein the one of the one or more of nozzles is determined to be in a malfunctioning state when the difference of one or more parameters of the residual pressure wave sensed in the liquid in each of the one of the one or more liquid ducts in the sensing

step and one or more parameters of the residual pressure wave sensed in the one of the one or more liquid ducts in one or more previous executions of the method exceeds a predetermined threshold..

Fig. 1



Description

BACKGROUND OF THE INVENTION

[0001] The present invention generally pertains to detecting ejection abnormalities in an inkjet print head, in particular a piezo-actuated inkjet print head.

[0002] During the execution of print processes several faults can disturb the jetting of a nozzle, leading to ejection abnormalities. For example, blocking of an ink nozzle due to the presence of a dirt particle is one of the most common causes of malfunction in ink jetting. In order to identify whether a nozzle jetting abnormally, it is customary actuating the one or more electro-mechanical transducers in the print head to generate a pressure wave in the liquid in the plurality of ducts, in order to subsequently sense a residual pressure wave in the liquid in the plurality of ducts.

[0003] After the above mentioned process, the sensed residual pressure wave is compared with the residual pressure wave of a correctly functioning nozzle after manufacturing. From said comparison, a plurality of abnormalities along with their root cause can be detected, such as the presence of dirt particles, air bubbles, or dry ink.

[0004] However, the comparison with the residual pressure wave of a correctly functioning nozzle after manufacturing does not allow detecting the malfunctioning of nozzles that arises due to prolonged use of a print head. Said prolonged use may cause a drift in the behavior of one or more nozzles, which may cause ejection abnormalities such as side-shooting nozzles. These abnormalities are difficult to detect by means of a comparison of a residual pressure wave resulting from an actuation of an electro-mechanical transducer and the residual pressure wave of a correctly functioning ejection unit at the time of manufacturing. However, they may still lead to visible artifacts in the printed image.

[0005] As a consequence, it is desired to have a method for detecting ejection abnormalities in an inkjet print head that is capable of detecting the ejection abnormalities caused by prolonged use.

SUMMARY OF THE INVENTION

[0006] In an aspect of the present invention, a method of detecting failing nozzles in an ejection unit during the printing of an object of a print job comprising one or more objects to claim 1 is provided. In another aspect of the present invention, a droplet ejection device is provided comprising a plurality of ejection units. Said ejection unit is arranged to eject droplets of a liquid and comprises one or more of nozzles, one or more liquid ducts each connected to one of the one or more nozzles, and one or more electro-mechanical transducers each arranged to create an acoustic pressure wave in the liquid in one or more ducts, and further arranged to sense a residual pressure wave in the liquid in each of the one or more

ducts.

[0007] The method of the present invention comprises actuating the electro-mechanical transducer to generate a pressure wave in the liquid in one or more ducts. Said actuation typically causes the ejection of a liquid through the one or more nozzles in the ejection unit. Subsequently, the method of the present invention comprises sensing a residual pressure wave in the liquid in each of the one or more ducts. The sensed residual pressure wave allows performing different analyses in order to ascertain the jetting quality of an ejection unit.

[0008] In another step, the method of the present invention comprises comparing the residual pressure wave previously sensed in the one of the one or more ducts with the residual pressure wave of the one of the one or more ducts sensed in one or more previous executions of the method by determining the difference of one or more parameters of the residual pressure wave previously sensed and one or more parameters of the residual pressure wave sensed in one or more previous executions of the method.

[0009] In another step, the method of the present invention comprises determining whether the one of the one or more of nozzles is in an operative state or in a malfunctioning state, wherein the one of the one or more of nozzles is determined to be in a malfunctioning state when the difference of one or more parameters of the residual pressure wave previously sensed in the liquid of the one of one or more ducts and one or more parameters of the residual pressure wave sensed in the one of the one or more ducts in one or more previous executions of the method exceeds a predetermined threshold.

[0010] In an embodiment, all of the steps of the present invention previously described are performed for more than one of the one or more liquid ducts such that a determination is made about whether each of the more than one of the one or more of nozzles is in an operative state or in a malfunctioning state by performing the comparing step for the more than one of the one or more liquid ducts with their residual pressure wave sensed in one or more previous executions of the method exceeds a predetermined threshold.

[0011] In an embodiment, the method of the present invention comprises actuating the electro-mechanical transducer (28) to generate a pressure wave in the liquid in the one or more liquid ducts (16) comprises actuating the electro-mechanical transducer (28) with a waveform that causes the ejection of a droplet.

[0012] In an embodiment, the method of the present invention comprises that actuating the electro-mechanical transducer to generate a pressure wave in the liquid in the one or more liquid ducts (16) comprises actuating the electro-mechanical transducer (28) with a plurality of waveforms.

[0013] In an embodiment, the method of the present invention comprises that actuating the electro-mechanical transducer with a plurality of waveforms comprises actuating the electro-mechanical transducer with a plu-

rality of waveforms with a waveform period between 0,1 milliseconds and 40 milliseconds.

[0014] In an embodiment, the method of the present invention comprises that actuating the electro-mechanical transducer with a plurality of waveforms comprises actuating the electro-mechanical transducer with a plurality of identical waveforms.

[0015] In an embodiment, the method of the present invention comprises that actuating the electro-mechanical transducer with a plurality of waveforms comprises actuating the electro-mechanical transducer with a plurality of different waveforms.

[0016] In an embodiment, the method of the present invention comprises that wherein the electro-mechanical transducer is actuated with one or more waveforms suitable for causing the ejection of liquid.

[0017] In an embodiment, the method of the present invention comprises that the one or more parameters of the residual pressure wave sensed in the liquid in each of the one or more liquid ducts comprise at least one or more of frequency, phase, amplitude, and damping factor of the residual pressure wave.

[0018] In an embodiment, the method of the present invention comprises that actuating the electro-mechanical transducer to generate a pressure wave in the liquid in the one or more liquid ducts comprises actuating the electro-mechanical transducer with a different waveform or plurality of waveforms in different executions of the method.

[0019] In an embodiment, the method of the present invention comprises that when it is determined in the step of determining whether the one of the one or more of nozzles is in an operative state or in a malfunctioning state that one or more of nozzles are in a malfunctioning state the method further comprises determining the root cause of the malfunctioning state based upon the difference of one or more parameters of the residual pressure wave sensed in the liquid in each of the one or more liquid ducts in the step of sensing a residual pressure wave in the liquid in the one of the one or more liquid ducts and one or more parameters of the residual pressure wave sensed in each of the one or more liquid ducts in one or more previous executions of the method exceeds a predetermined amount.

[0020] In an embodiment, the method of the present invention comprises that the root cause of the malfunctioning state is one of a side-shooting nozzle, the presence of dried ink in a nozzle, the presence of excess water in the ink, the presence of water in the nozzle face, or the presence of dirt in the nozzle.

[0021] Further, the present invention comprises a droplet ejection device comprising a number of ejection units arranged to eject droplets of a liquid and each comprising a nozzle, a liquid duct connected to the nozzle, and an electro-mechanical transducer arranged to create an acoustic pressure wave in the liquid in the duct, wherein each of the ejection units is associated with a processor configured to perform the method according to any of the

methods of the present invention.

[0022] Further, the present invention relates to a printing system comprising the droplet ejection device of the present invention as an ink jet print head and a control unit comprising a processor suitable for executing the method according to any of the methods of the present invention.

[0023] Also, the present invention relates to a software product comprising program code on a machine-readable non transitory medium, the program code, when loaded into a control unit of the printing system of the present invention, causes the control unit to execute any of the methods of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The present invention will become more fully understood from the detailed description given below, and the accompanying drawings which are given by way of illustration only, and are thus not limitative of the present invention, and wherein:

Fig. 1 is a cross-sectional view of mechanical parts of a droplet ejection device according to the invention, together with an electronic circuit for controlling and monitoring the device.

Fig. 2 is a graph showing the ratio between the amplitude measured in the residual pressure wave of a nozzle and the amplitude of a correctly jetting nozzle for a plurality of burst lengths

Fig. 3 is a graph showing the ratio between the phase measured in the residual pressure wave of a nozzle and the phase of a correctly jetting nozzle for a plurality of burst lengths

Fig. 4 is a graph showing the ratio between the frequency measured in the residual pressure wave of a nozzle and the frequency of a correctly jetting nozzle for a plurality of burst lengths

DETAILED DESCRIPTION OF EMBODIMENTS

[0025] The present invention will now be described with reference to the accompanying drawings, wherein the same or similar elements are identified with the same reference numeral.

[0026] A single ejection unit of an ink jet print head is shown in Fig. 1. The print head constitutes an example of a droplet ejection device according to the invention. The device comprises a wafer 10 and a support member 12 that are bonded to opposite sides of a thin flexible membrane 14.

[0027] A recess that forms an ink duct 16 is formed in the face of the wafer 10 that engages the membrane 14, e.g. the bottom face in Fig. 1. The ink duct 16 has an

essentially rectangular shape. An end portion on the left side in Fig. 1 is connected to an ink supply line 18 that passes through the wafer 10 in thickness direction of the wafer and serves for supplying liquid ink to the ink duct 16.

[0028] An opposite end of the ink duct 16, on the right side in Fig. 1, is connected, through an opening in the membrane 14, to a chamber 20 that is formed in the support member 12 and opens out into a nozzle 22 that is formed in a nozzle face 24 constituting the bottom face of the support member.

[0029] Adjacent to the membrane 14 and separated from the chamber 20, the support member 12 forms another cavity 26 accommodating a piezoelectric actuator 28 that is bonded to the membrane 14.

[0030] An ink supply system which has not been shown here keeps the pressure of the liquid ink in the ink duct 16 slightly below the atmospheric pressure, so as to prevent the ink from leaking out through the nozzle 22.

[0031] The nozzle face 24 is made of or coated with a material which is wetted by the ink, so that adhesion forces cause a pool 30 of ink to be formed on the nozzle face 24 around the nozzle 22. The pool 30 is delimited on the outward (bottom) side by a meniscus 32a.

[0032] The piezoelectric transducer 28 has electrodes 34 that are connected to an electronic circuit that has been shown in the lower part of Fig. 1. In the example shown, one electrode of the transducer is grounded via a line 36 and a resistor 38. Another electrode of the transducer is connected to an output of an amplifier 40 that is feedback-controlled via a feedback network 42, so that a voltage V applied to the transducer will be proportional to a signal on an input line 44 of the amplifier. The signal on the input line 44 is generated by a D/A-converter 46 that receives a digital input from a local digital controller 48. The controller 48 is connected to a processor 50.

[0033] When an ink droplet is to be expelled from the nozzle 22, the processor 50 sends a command to the controller 48 which outputs a digital signal that causes the D/A-converter 46 and the amplifier 40 to apply an actuation pulse to the transducer 28. This voltage pulse causes the transducer to deform in a bending mode. More specifically, the transducer 28 is caused to flex downward, so that the membrane 14 which is bonded to the transducer 28 will also flex downward, thereby to increase the volume of the ink duct 16. As a consequence, additional ink will be sucked-in via the supply line 18. Then, when the voltage pulse falls off again, the membrane 14 will flex back into the original state, so that a positive acoustic pressure wave is generated in the liquid ink in the duct 16. This pressure wave propagates to the nozzle 22 and causes an ink droplet to be expelled. The pressure wave will then be reflected at the meniscus 32a and will oscillate in the cavity formed between the meniscus and the left end of the duct 16 in Fig. 1. The oscillation will be damped due to the viscosity of the ink. Further, the transducer 28 is energized with a quench pulse which has a polarity opposite to that of the actuation pulse and is timed such that the decaying oscillation will

be suppressed further by destructive interference.

[0034] The electrodes 34 of the transducer 28 are also connected to an A/D converter 52 which measures a voltage drop across the transducer and also a voltage drop across the resistor 38 and thereby implicitly the current flowing through the transducer. Corresponding digital signals S are forwarded to the controller 48 which can derive the impedance of the transducer 28 from these signals. The measured electric response (current, voltage, impedance, etc.) is signaled to the processor 50 where the electric response is processed further.

[0035] A graph showing the ratio between the amplitude measured in the residual pressure wave of a nozzle and the amplitude of a correctly jetting nozzle for a plurality of burst lengths is shown in Fig. 2. The result obtained for measurements of the amplitude of nozzles for different burst lengths can be observed in Fig. 2. Further, the nozzles may be classified in different categories (e.g. side shooter, acceptable functioning behavior, correct functioning behavior, and non-jetting nozzle) depending upon their jetting behavior based upon the observed result while performing a printing operation. As explained below in relation with Figs. 3 and 4 it is possible to perform the same operation using different parameters amongst those observable in a residual pressure wave: phase, amplitude, etc. A person of skill in the art would readily understand that any other parameter, e.g. damping factor, etc., may be also used. This procedure is used to determine the proper functioning of the nozzles for different burst lengths, such that those leading to a more reliable jetting are decided. Once the most reliable bursts of pulses have been determined, the method of the present invention can compare the residual pressure wave sensed in a step of the method in the one of the one or more liquid ducts with the residual pressure wave of the one or more liquid ducts sensed in one or more previous executions of the method. This process may be performed by determining the difference of one or more parameters of the residual pressure wave sensed and one or more parameters of the residual pressure wave sensed in one or more previous executions of the method. This process allows the method of the present invention to detect subtle variations in the behavior of the print heads, commonly known as drift.

[0036] Further, a person skilled in the art would readily also understand that a step of comparing the residual pressure wave sensed in a step of the method in the one of the one or more liquid ducts with the residual pressure wave of the one or more liquid ducts sensed in one or more previous executions of the method can be performed for the different parameters shown in Figs. 2 to 4 or other additional factors such as damping factor. As a consequence, the step of determining whether the one of the one or more of nozzles is in an operative state or in a malfunctioning state can be performed using information about one or more of the mentioned parameters of the residual pressure wave.

[0037] A graph showing the ratio between the phase

measured in the residual pressure wave of a nozzle and the phase of a correctly jetting nozzle for a plurality of burst lengths is shown in Fig. 3. Further, the nozzles have been classified in four different categories (side shooter, acceptable functioning behavior, correct functioning behavior, and non-jetting nozzle) depending upon their jetting behavior based upon the observed result while performing a printing operation.

[0038] Further, a person skilled in the art would readily also understand that the method of the present invention can be applied to each and all of the plurality of nozzles of a print head. Also, person skilled in the art would readily also understand that the method of the present invention may comprises actuating the electro-mechanical transducer to generate a pressure wave in the liquid in the one or more liquid ducts comprises actuating the electro-mechanical transducer with a plurality of waveforms, known in the art as bursts.

[0039] A graph showing the ratio between the frequency measured in the residual pressure wave of a nozzle and the frequency of a correctly jetting nozzle for a plurality of burst lengths is shown in Fig. 4. Further, the nozzles have been classified in four different categories (side shooter, acceptable functioning behavior, correct functioning behavior, and non-jetting nozzle) depending upon their jetting behavior based upon the observed result while performing a printing operation.

[0040] Based on the determinations above, the method of the present invention is able to determine whether each of the one or more of nozzles is determined to be in a malfunctioning state when the difference of one or more parameters of the residual pressure wave sensed in the liquid in each of the one or more ducts in a previous step and one or more parameters of the residual pressure wave sensed in each of the one or more ducts in one or more previous executions of the method exceeds a predetermined threshold. In one embodiment, the method of the present invention determines that one nozzle is in a malfunctioning state if the difference of one or more parameters of the residual pressure wave sensed in the liquid in each of the one or more ducts in a previous step and one or more parameters of the residual pressure wave sensed in each of the one or more ducts in one or more previous executions of the method exceed a first predetermined threshold. Further, in an embodiment the method of the present invention determines that one nozzle is in a malfunctioning state if two more parameters of the residual pressure wave sensed in each of the one or more ducts in one or more previous executions of the method exceed a second predetermined threshold, wherein said second predetermined threshold is smaller than the first predetermined threshold. Further, a person skilled in the art would readily also understand that the method of the present invention can make determination about the jetting state based on whether a combination of parameters differ from those measured in previous executions of the method for the same nozzle more than a threshold, based on the information gathered in simu-

lations.

[0041] The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

10 Claims

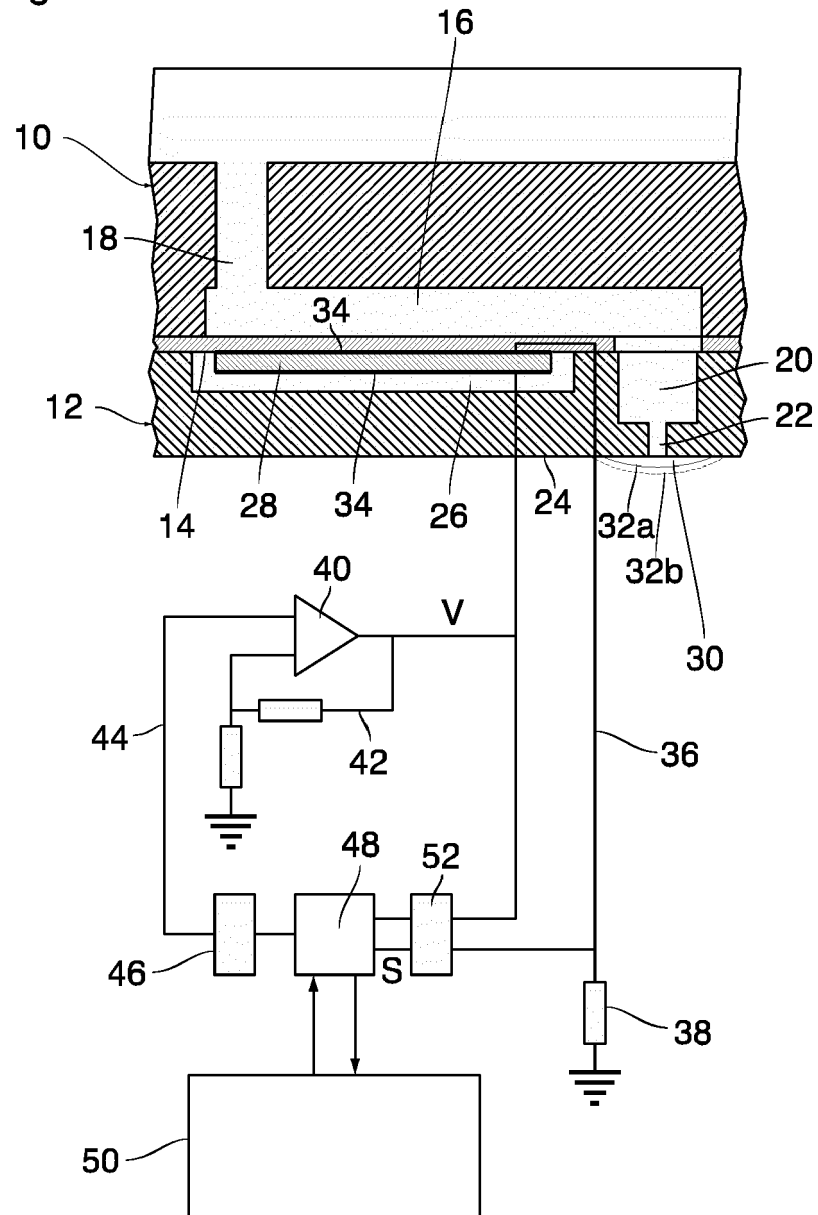
1. A method of detecting failing nozzles in an ejection unit during the printing of an object of a print job comprising one or more objects, wherein the ejection unit is arranged to eject droplets of a liquid and comprises one or more of nozzles (22), one or more liquid ducts (16) each connected to one of the one or more nozzles (22), and one or more electro-mechanical transducers (28) each arranged to create an acoustic pressure wave in the liquid in one of the one or more liquid ducts (16), and further arranged to sense a residual pressure wave in the liquid in each of the one or more liquid ducts (16), the method comprising:

- a) actuating the electro-mechanical transducer (28) to generate a pressure wave in the liquid in one of the one or more liquid ducts (16); and
- b) sensing a residual pressure wave in the liquid in the one of the one or more liquid ducts (16); and
- c) comparing the residual pressure wave sensed in step b) in the one of the one or more liquid ducts (16) with the residual pressure wave of the one or more liquid ducts (16) sensed in one or more previous executions of the method by determining the difference of one or more parameters of the residual pressure wave sensed in step b) and one or more parameters of the residual pressure wave sensed in one or more previous executions of the method; and
- d) determining whether the one of the one or more of nozzles (22) is in an operative state or in a malfunctioning state, wherein the one of the one or more of nozzles (22) is determined to be in a malfunctioning state when the difference of one or more parameters of the residual pressure wave sensed in the liquid in each of the one of the one or more liquid ducts (16) in step b) and one or more parameters of the residual pressure wave sensed in the one of the one or more liquid ducts (16) in one or more previous executions of the method exceeds a predetermined threshold.

2. The method of claim 1, wherein steps a), b), c) and d) are performed for more than one of the one or more liquid ducts (16) such that a determination is

- made about whether each of the more than one of the one or more of nozzles (22) is in an operative state or in a malfunctioning state by performing the comparing step for the more than one of the one or more liquid ducts (16) with their residual pressure wave sensed in one or more previous executions of the method exceeds a predetermined threshold.
3. The method of any preceding claim, wherein actuating the electro-mechanical transducer (28) to generate a pressure wave in the liquid in the one or more liquid ducts (16) comprises actuating the electro-mechanical transducer (28) with a waveform that causes the ejection of a droplet.
 4. The method of any preceding claim, wherein actuating the electro-mechanical transducer (28) to generate a pressure wave in the liquid in the one or more liquid ducts (16) comprises actuating the electro-mechanical transducer (28) with a plurality of waveforms.
 5. The method of claim 4, wherein actuating the electro-mechanical transducer (28) with a plurality of waveforms comprises actuating the electro-mechanical transducer (28) with a plurality of waveforms with a waveform period between 0,1 milliseconds and 40 milliseconds;
 6. The method of claims 4 or 5, wherein actuating the electro-mechanical transducer (28) with a plurality of waveforms comprises actuating the electro-mechanical transducer (28) with a plurality of identical waveforms.
 7. The method of claims 4 or 5, wherein actuating the electro-mechanical transducer (28) with a plurality of waveforms comprises actuating the electro-mechanical transducer (28) with a plurality of different waveforms.
 8. The method of any preceding claim, wherein the electro-mechanical transducer (28) is actuated with one or more waveforms suitable for causing the ejection of liquid.
 9. The method of any preceding claim, wherein the one or more parameters of the residual pressure wave sensed in the liquid in each of the one or more liquid ducts (16) comprise at least one or more of frequency, phase, amplitude, and damping factor of the residual pressure wave.
 10. The method of any preceding claim, wherein actuating the electro-mechanical transducer (28) to generate a pressure wave in the liquid in the one or more liquid ducts (16) comprises actuating the electro-mechanical transducer (28) with a different waveform or plurality of waveforms in different executions of the method.
 11. The method of any preceding claim, wherein when it is determined in step d) that one or more of nozzles (22) are in a malfunctioning state the method further comprises determining the root cause of the malfunctioning state based upon the difference of one or more parameters of the residual pressure wave sensed in the liquid in each of the one or more liquid ducts (16) in step b) and one or more parameters of the residual pressure wave sensed in each of the one or more liquid ducts (16) in one or more previous executions of the method exceeds a predetermined amount.
 12. The method of claim 10, wherein the root cause of the malfunctioning state is one of a side-shooting nozzle, the presence of dried ink in a nozzle, the presence of excess water in the ink, the presence of water in the nozzle face, or the presence of dirt in the nozzle.
 13. A droplet ejection device comprising a number of ejection units arranged to eject droplets of a liquid and each comprising a nozzle (22), a liquid duct (16) connected to the nozzle (22), and an electro-mechanical transducer (28) arranged to create an acoustic pressure wave in the liquid in the duct (16), wherein each of the ejection units is associated with a processor (50) configured to perform the method according to any of the claims 1 to 12.
 14. A printing system comprising the droplet ejection device according to claim 13 as an ink jet print head and a control unit comprising a processor (50) suitable for executing the method according to any of the claims 1 to 12.
 15. A software product comprising program code on a machine-readable non transitory medium, the program code, when loaded into a control unit of a printing system according to claim 14, causes the control unit to execute any of the methods of claims 1 to 12.

Fig. 1



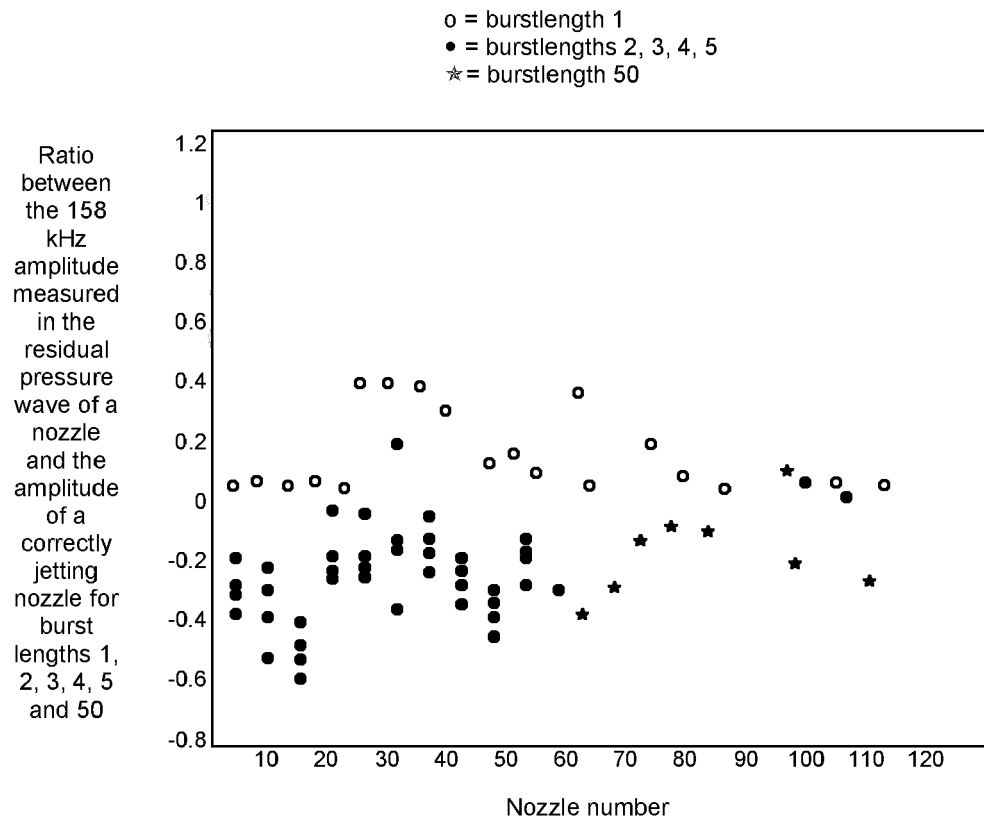


Figure 2

- = burstlength 1
- = burstlengths 2, 3, 4, 5
- ☆ = burstlength 50

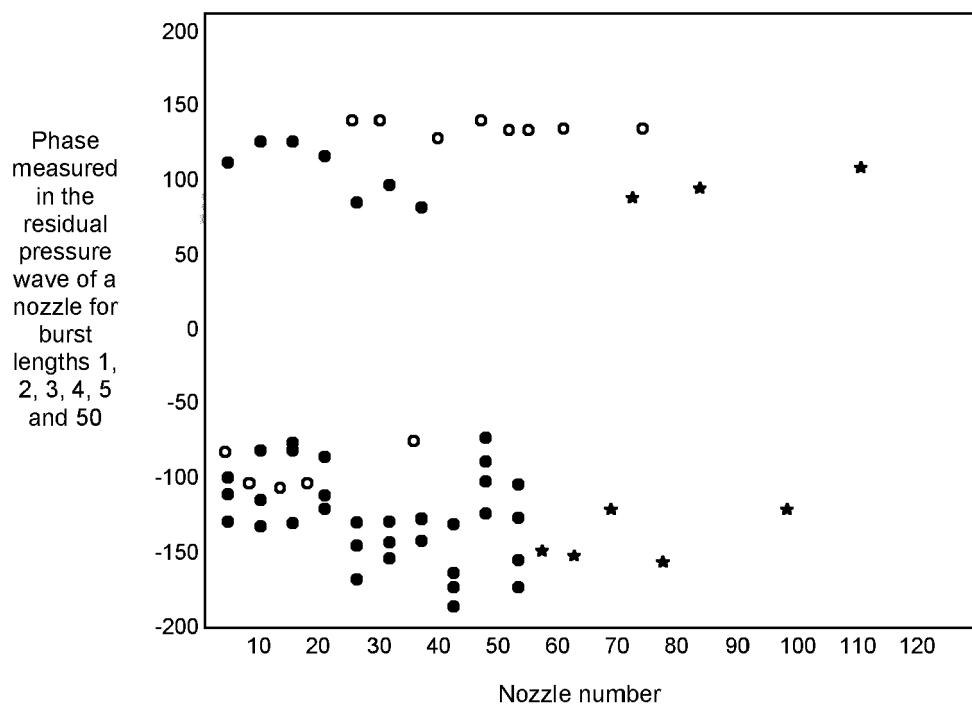


Figure 3

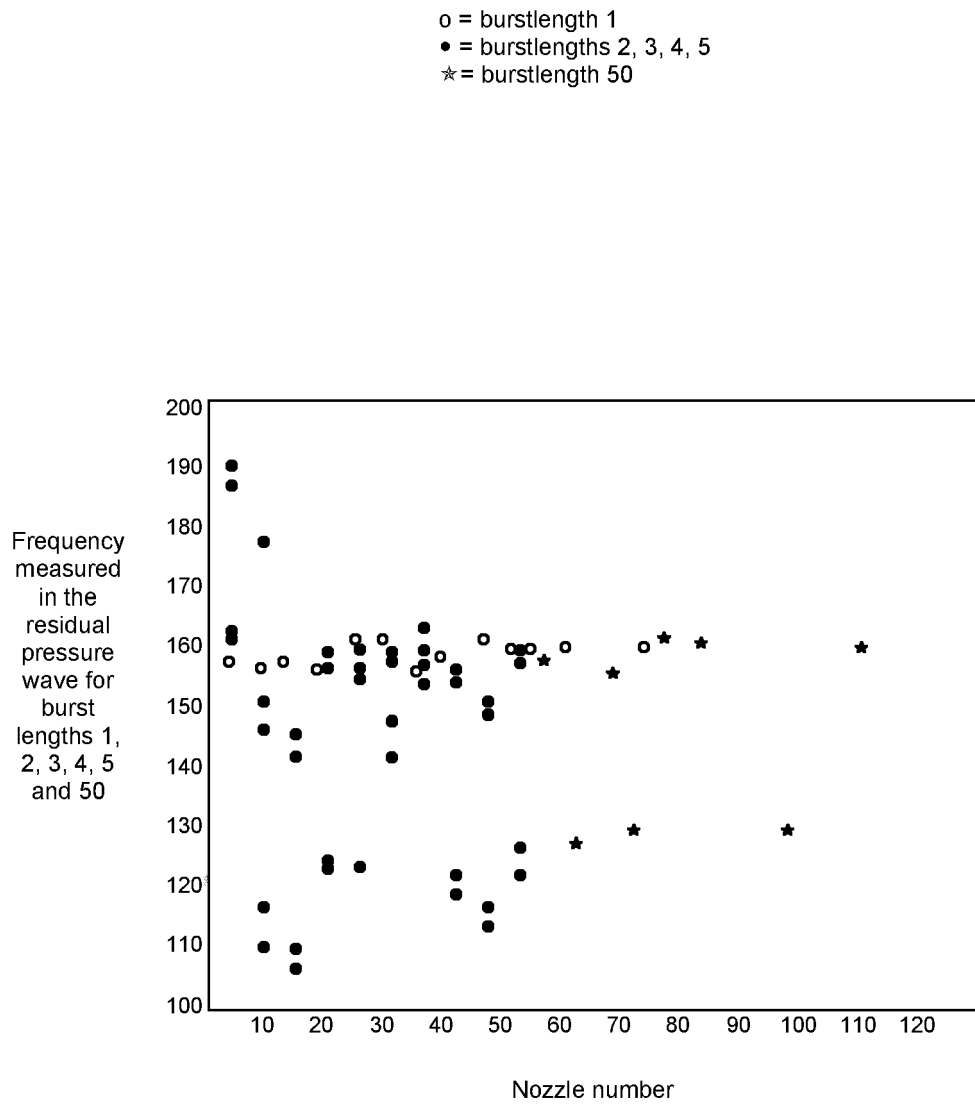


Figure 4



EUROPEAN SEARCH REPORT

Application Number
EP 20 21 0408

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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	EP 3 670 188 A1 (CANON PRODUCTION PRINTING HOLDING BV [NL]) 24 June 2020 (2020-06-24) * paragraphs [0027], [0037], [0041]; claims 1, 5; figures 1-3 *	1-15	INV. B41J2/21 B41J2/045
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X	US 2013/141484 A1 (KASAI TSUNEO [JP] ET AL) 6 June 2013 (2013-06-06) * paragraphs [0234] - [0235], [0330] - [0332], [0382], [0383], [0386]; figures 4, 31, 42, 43 *	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			B41J
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 3 May 2021	Examiner Cavia Del Olmo, D
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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 20 21 0408

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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03-05-2021

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