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A flow meter for ultrasonically measuring the flow velocity of fluids.

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(54) Title: A FLOW METER FOR ULTRASONICALLY MEASURING THE FLOW VELOCITY OF FLUIDS

(57) **Abstract**: The invention regards a flow meter for ultrasonically measuring the flow velocity of fluids comprising a duct having a flow channel with an internal cross section comprising variation configured to generate at least one acoustic resonance within the flow channel for a specific ultrasonic frequency, and at least two transducers for generating and sensing ultrasonic pulses, configured to transmit ultrasonic pulses at least at said specific ultrasonic frequency into the flow channel such that the ultrasonic pulses propagate through a fluid flowing in the flow channel, wherein the flow meter is configured to determine the flow velocity of the fluid flowing in the flow channel based on a change in transit time, phase and/or pulse such as amplitude and/or form, of the ultrasonic pulses.

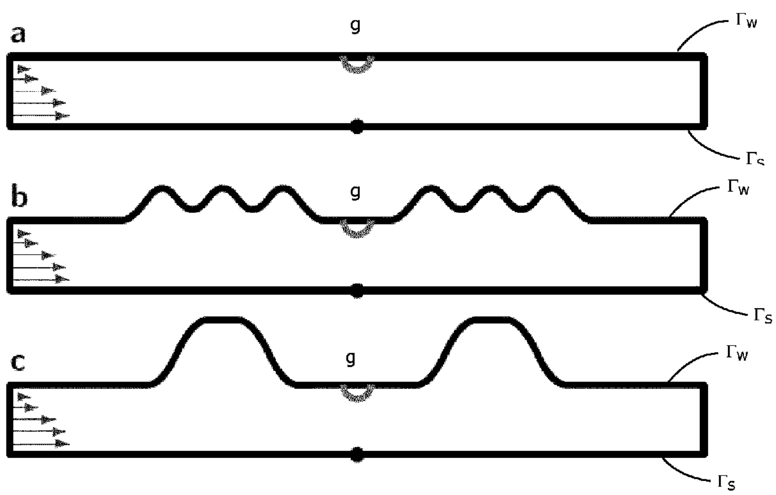

Fig. 1

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A flow meter for ultrasonically measuring the flow velocity of fluids

Field of invention

The invention relates to a flow meter and a method for ultrasonically measuring the flow velocity of fluids.

Background of the Invention

Ultrasonic flow meters for measuring a fluid velocity in a duct are known and widely used. They normally comprise two transducers which are used to generate and sense ultrasonic pulses. The transducers then measure the transit time or difference in phase of the ultrasonic pulses propagating in and against the direction of flow. By use of the transit times or phase change the average fluid velocity and the speed of sound in the fluid can be calculated. Normally the ultrasonic pulse is emitted from a first transducer in a direction angled in relation to the direction of the flow and then reflected, either by use of a specific reflector or the internal surface of the duct, to be received by a second transducer situated upstream or downstream from the first transducer.

In prior art there has been attempts to increase the accuracy of ultrasonic flow meters. It is known that the sensitivity is increased when the flow velocity is increased. Therefore a venturi tube is sometimes used to increase the flow velocity in a short section of the flow meter such that the velocity can be measured with higher accuracy. With knowledge of the geometry of the venture tube it is possible to determine the flow velocity in the system. A disadvantage of using a venture tube is that it creates a pressure drop, and the pressure drop increases as the sensitivity increases.

In prior art there has also been attempts on increasing the sensitivity by using ultrasonic signals that consist of standing waves.

DE 43 35 394 discloses an ultrasonic flow meter for measuring small flows accurately by use of standing waves. A standing wave (at a harmonic resonance frequency) is generated between two transducers placed opposite to each other with an unobstructed line-of-sight between them, and the flow is determined from the change in the standing wave frequency, or the resonance frequency, at different flows. To maintain the standing wave at different flows, it is required to change the frequency. Thus, the flow measurement is based on the use of at least two acoustic standing waves, or resonance frequencies, and broadband transducers are a requirement in order to adjust the frequency of the transducers when the flow velocity changes.

EP 0 801 311 discloses an ultrasonic flow meter, where the sensitivity to environmental changes, such as temperature, is reduced. The flow is measured based on a travelling wave and a harmonic standing wave between the transducers, which is maintained by changing the frequency. Thus, the flow is also in this invention determined by use of multiple frequency measurements.

Summary of the invention

Accurate measurements of fluid flow velocities play a pivotal role in a wide range of engineering applications. It is therefore a purpose of the present invention to provide a flow meter for ultrasonically measuring the flow velocity of fluids with a higher sensitivity than prior art flow meters, preferably without generating a pressure drop. Furthermore, it is a purpose of the present invention to provide a flow meter that is simple to construct and operate, and cheap to manufacture.

A first embodiment therefore relates to a flow meter for ultrasonically measuring the flow velocity of fluids comprising:

- a duct having a flow channel with an internal cross section comprising variation configured to generate at least one acoustic resonance within the flow channel for a specific ultrasonic frequency, and
- at least two transducers for generating and sensing ultrasonic pulses, configured to transmit ultrasonic pulses at least at said specific ultrasonic frequency into the flow channel such that the ultrasonic pulses propagate through a fluid flowing in the flow channel,

wherein the flow meter is configured to determine the flow velocity of the fluid flowing in the flow channel based on a change in transit time, phase and/or pulse such as amplitude and/or form, of the ultrasonic pulses.

A further aspect relates to a method for determining the flow velocity of fluid flowing in a flow channel having an internal cross section, the method comprising the steps of:

- generating an acoustic resonance in the flow channel, for a specific ultrasonic frequency, by use of variations in the internal cross section,

- transmitting ultrasonic pulses with said specific ultrasonic frequency into the flow channel by use of at least one transducer, such that the ultrasonic pulses propagate through the fluid,
- sensing the transmitted ultrasonic pulses by use of at least one transducer, and
- determining the flow velocity of the fluid based on the transit time or phase of the ultrasonic pulses or change of the ultrasonic pulse.

A further aspect relates to a method for determining the acoustic resonance frequency of a flow channel comprising variations in the internal cross section, the method comprising the steps of:
a. generating a fluid flow within the flow channel,
b. transmitting ultrasonic pulses at a selected starting frequency into the flow channel by use of at least one transducer, such that the ultrasonic pulses propagate through the fluid,
c. sensing the transmitted ultrasonic pulses by use of at least one transducer,
d. measuring the signal strength of the received ultrasonic pulses, the signal being a difference in transit time, a difference in phase and/or a change of the pulses,
e. repeating step a-d for a plurality of transmitted frequencies, optionally performed as a frequency sweep within a predefined interval of frequencies, and
f. selecting the frequency at which the highest signal strength is measured,
thereby determining the acoustic resonance frequency of said duct comprising said internal cross section variations.

A further aspect relates to a method for determining the positions of transducers within a flow channel comprising variations in the internal cross section, such that a maximal perturbation of the ultrasonic pulses is detected, the method comprising the steps of:
a. selecting a flow channel geometry, fluid flow velocity, and measurement frequency,
b. mapping the acoustic field for the selected flow channel geometry, fluid flow and measurement frequency, preferably by means of flow-acoustic models, and
c. determining positions wherein the acoustic field is maximal asymmetric,
thereby determining the positions of transducers, wherein a maximal perturbation of the ultrasonic pulses is detected.

A further embodiment relates to a flow meter for ultrasonically measuring the flow velocity of fluids comprising a duct having a flow channel, with an internal cross section, where through the fluid flows, and at least two transducers for generating and sensing ultrasonic pulses, wherein the ultrasonic pulses are transmitted into the flow channel such that it propagates through the fluid, whereby the flow velocity is determined based on, the transit time or phase of the ultrasonic pulses or change of the ultrasonic pulse, wherein the internal cross section comprises variations which generate an acoustic resonance within the flow channel for a specific ultrasonic frequency and that the ultrasonic pulse has the specific ultrasonic frequency.

The flow meters and methods listed above can be combined with any of the features as disclosed herein and below.

The combination of a duct geometry with a cross section variation, and measurements at the specific ultrasonic frequency at which the duct geometry generates an acoustic resonance, makes it possible to enhance the sensitivity of flow meters in some duct geometries by at least an order of magnitude and hereby provide a flow meter with a significantly improved accuracy.

Furthermore, it is possible to obtain the enhanced sensitivity of the flow meter by a simple measurement. Instead of measuring at multiple frequencies, the flow meter can be operated at a single, selected specific ultrasonic frequency, thereby making it more simple to construct and operate and cheaper to manufacture.

Acoustic resonance is to be interpreted as a spatial localized resonance which at certain frequencies is particularly sensitive to a background flow in the flow channel. The known type of acoustic resonance disclosed in the prior art is the resonance associated with standing waves and the harmonics or overtones of the fundamental standing wave generated between two transducers. The present invention relates to an acoustic resonance generated by variations in the internal cross section of a duct having a flow channel and utilizing this acoustic resonance for ultrasonic measurements to obtain an increased sensitivity of the presently disclosed flow meter.

The flow meter according to the invention can be in the form of a flow cell to be inserted in the flow path. A flow cell is an apparatus with an inlet and an outlet that can form part of the flow path for the fluid and includes the transducers mounted to generate and sense the ultrasonic pulses in the appropriate configuration. In another embodiment the flow meter is an apparatus that is mounted on or situated temporarily on a part of the flow path such as a pipe.

Change of the ultrasonic pulse is to be understood as change in the shape and/or size of the ultrasonic pulse, such as change in amplitude and/or form of the pulse.

The internal cross section is defined by the internal borders of the duct in a plane transverse to the direction of the flow. The variations of the internal cross section can be changes in the shape of the duct where the area of the internal cross section is kept constant. It can also be changes in the area of the internal cross section and/or a combination of any of the above.

The specific ultrasonic frequency can be a predefined frequency for a given flow meter. The predefined ultrasonic frequency can be selected such that it corresponds to an acoustic resonance frequency generated by the variations in the internal cross section. The variations in the internal cross section can generate an acoustic resonance frequency, i.e. a frequency at which the acoustic response is strongly affected by the background flow in the flow channel. I.e. this resonance frequency is different from the resonance frequency associated with the harmonics of a standing wave generated between two transducers positioned at a distance of an integer multiple of half wavelengths.

The predefined ultrasonic frequency may be selected based on a chosen flow channel with variations, wherein the transducers are situated such that an ultrasonic pulse generated by the first transducer can be sensed by the second transducer. The signal strength is then determined (either by measurements and/or by modelling) at a representative flow velocity for a plurality of frequencies, preferably in the form of a frequency sweep within a selected range. The predefined ultrasonic frequency is then selected as the frequency where acoustic resonance is observed.

Alternatively, the predefined ultrasonic frequency is chosen, and the signal strength is determined (either by measurements and/or by modelling) for different variations of the flow channel. The flow channel geometry disclosing an acoustic resonance at the predefined ultrasonic frequency is then selected for the measurements.

In an embodiment, the internal cross section has a constant area. In this embodiment the internal cross section can change form for example from a circular to an oval cross section. Further, the duct can have turns and/or be twisted or in any other way altered, as long as the area of the internal cross section is kept constant. This is one way of generating an acoustic resonance in the fluid flow for a specific frequency.

In one embodiment the variations in the internal cross section comprise area variations of the internal cross section. The cross sectional area is then changed in order to generate an acoustic resonance in the fluid flow for a specific frequency.

The area variations may comprise an enlarged part of the flow channel. I.e. the enlarged part may comprise an enlargement of the area of the internal cross section. By using one or more enlarged parts to generate the acoustic resonance no significant pressure drop is generated, as opposed to the use of a venturi duct. An enlarged part can also be denoted as a bulge in the duct, and can for example be an inverted venturi. It has been found that by use of an enlarged part, the acoustic resonance for a specific frequency can be substantially enhanced. This effect is further enhanced if the ultrasonic pulses propagate through the fluid in an enlarged part. This can for example be done by positioning at least one of the transducers such that the ultrasonic pulse enters and/or is emitted within the enlarged part.

In another embodiment the flow channel comprises at least two enlarged parts. It has been found that by use of two enlarged parts the acoustic resonance for a specific frequency can be substantially enhanced. This effect is further enhanced if the ultrasonic pulses propagate through the fluid in an enlarged part. This can for example be done by positioning at least one of the transducers such that the ultrasonic pulse enters or is emitted within the enlarged part.

In a further embodiment the flow velocity is determined based on the transit time or phase of ultrasonic pulses propagating in and against the direction of the fluid flow. A difference in the transit time and phase is closely related and is a measure for the same. The difference in phase can therefore be interpreted as a measure for the difference in transit time.

In a further embodiment the flow velocity is determined based on a change in the amplitude of the ultrasonic pulse. This is a way of determining the flow velocity that can be used instead or in combination with determination by use of the transit time or phase of ultrasonic pulses propagating in and against the direction of the fluid flow as mentioned above.

In yet a further embodiment the specific ultrasonic frequency is determined by measuring and/or modelling the signal strength of the received ultrasonic pulse for a plurality of transmitted frequencies. When designing a flow meter according to the invention a frequency sweep can be performed in order to find a frequency which generated the highest signal strength. This can be done by choosing a specific duct wherein the internal cross section comprises variations and subsequently generate a fluid flow in the duct. A frequency sweep can then be performed in a predefined interval, and it can be observed at which frequencies increased signal strength is sensed by the transducers. The interval for the frequency sweep can be within a testing interval, such as 25 to 35 kHz. Signal strength can be interpreted to be the difference in transit time, difference in phase or the peak amplitude of the ultrasonic pulses.

At the specific ultrasonic frequency, i.e. the acoustic resonance frequency generated by the variations in the internal cross section, the acoustic field within the flow meter generated by emitting identical ultrasonic pulses transducers upstream and downstream will not be mirror images of each other with respect to their geometric centre. This asymmetry in the field pattern will depend on the geometry of the variations in the internal cross section and the flow speed.

The measured transit time or phase change of an ultrasonic pulse will depend on the position of the transducers.

In a further embodiment the positions of the at least two transducers are selected to be where the perturbation of the ultrasonic pulse is largest. The positions of the at least two transducers may be selected to be where the transit time or phase change of the ultrasonic pulse is largest. An example of such a position is in the embodiment comprising two enlarged parts, where the pulses propagate through the fluid in the enlarged parts, and the transducers are positioned such that the ultrasonic pulse enters and/or is emitted within the enlarged parts, as illustrated in Fig. 4c.

Further, the positions of the at least two transducers may be selected to be where the perturbation of the ultrasonic pulse is largest, irrespective of an unobstructed line-of-sight between them. For example they may be positioned such that they are not placed facing opposite to each other.

The invention also relates to a method for determining the flow velocity of fluid flowing in a flow channel having an internal cross section, the method comprising the steps of;

- generating an acoustic resonance in the flow channel, for a specific ultrasonic frequency, by use of variations in the internal cross section,
- transmitting ultrasonic pulses with said specific ultrasonic frequency into the flow channel by use of at least one transducer, such that the ultrasonic pulses propagate through the fluid,
- sensing the transmitted ultrasonic pulses by use of at least one transducer, and
- determining the flow velocity of the fluid based on the transit time or phase of the ultrasonic pulses or change of the ultrasonic pulse.

A further embodiment relates to a method for determining the flow velocity of fluids in a flow channel, with an internal cross section, comprising the steps of; generating an acoustic resonance in the flow channel, for a specific ultrasonic frequency, by use of variations in the internal cross section, transmitting into the flow channel, such that it propagates through the fluid, ultrasonic pulses with the specific frequency, by use of a transducer, sensing the transmitted ultrasonic pulses by use of a transducer, determining the flow velocity based on the transit time or phase of the ultrasonic pulses or change of the ultrasonic pulse.

Thus, it is possible to improve the accuracy of the determination of the flow velocity of a fluid in a flow channel. Furthermore, it is possible to obtain the improved accuracy by a simple measurement, comprising measuring at a single and selected, specific ultrasonic frequency.

Advantageously, variations in the internal cross section comprise area variations of the internal cross section. Area variations can lead to an acoustic resonance for a specific frequency. The acoustic resonance for a specific frequency can be perturbed by the flow through the flow channel. Accordingly, this is a method for controlling an acoustic field in the fluid flow. In an embodiment, the area variations comprise at least one enlarged part of the flow channel, the enlarged part comprising an enlargement of the area of the internal cross section. The perturbation of the acoustic resonance is especially large, if the ultrasonic pulse propagates through an enlarged part of the flow channel. Hence, in an embodiment, the method comprises a flow channel comprising an enlarged part. In a further embodiment, the method comprises ultrasonic pulse propagation through the enlarged part of the flow channel.

In another embodiment, the use of two enlarged parts is especially suitable for generating a large perturbation of the acoustic resonance for specific frequencies. The perturbation of the acoustic resonance is especially large, if the ultrasonic pulse propagates through an enlarged part of the flow channel. Hence, in an embodiment, the method comprises a flow channel with at least two enlarged parts. In a further embodiment, the method comprises ultrasonic pulse propagation through an/the enlarged part(s) of the flow channel.

In an embodiment, the specific ultrasonic frequency is determined by measuring the signal strength of the received ultrasonic pulse for a plurality of transmitted frequencies. This is a method for determining the specific frequency to be used.

In an embodiment, the flow velocity is determined based on change of the ultrasonic pulse such that the change at least partly includes the change in amplitude of the ultrasonic pulse. Thus, the velocity can be determined by emitting one ultrasonic pulse which propagates through the fluid flow and then sensing it, the change in amplitude can then give the fluid velocity. If the emitted ultrasonic pulse shape is known, only the signal from the sensor is necessary for determining the flow velocity.

In an embodiment, the flow velocity is determined based on the difference in transit time or phase between ultrasonic pulses propagating in and against the direction of the fluid flow.

Description of the drawings

The invention will in the following be described in greater detail with reference to the accompanying drawings:

Fig. 1 a schematic view of three duct geometries

Fig. 2 a graph of the acoustic response for three duct geometries

Fig. 3 an example of the acoustic pressure field for three duct geometries

Fig. 4 a cross sectional view of different duct geometries and transducer positions

Fig. 5 graph of signal strengths for flow meters

Detailed description of the invention

Flow meters are used in a variety of applications such as house hold plumbing (e.g. measuring the usage of gas and/or water), offshore (e.g. measuring gas and/or oil flow) and in industrial productions where a large variety of fluids are used. If the flow velocity is known, for a specific fluid, it is possible to determine the mass flow.

It is desirable to be able to measure the flow velocity as precisely as possible. However, this can be a challenge, among other things due to the conventional low signal to noise ratio and it is especially difficult for low flow velocities. The present invention regards a flow meter that has a higher sensitivity, a higher to signal to noise ratio than prior art flow meters and can therefore determine the flow velocity more precisely, also at low flow velocities. Furthermore, the present invention regards a flow meter where the measurement can be based on a simple measurement at a single and selected, specific ultrasonic frequency.

The state of a fluid flow in a duct is characterised by the velocity $u = (u, v)$, the pressure p, and the density ρ. These variables are governed by the Navier-Stokes and the mass continuity equation. By introducing an acoustic source g and making the necessary approximations, the following equation for the acoustic pressure $\not{p}$ in a two dimensional flow channel (duct) can be derived:

$$\nabla^2 \not{p} + k^2 \not{p} + \frac{2i}{\omega}\left(k^2 u_0 \cdot \nabla \not{p} - \frac{\partial u_0}{\partial x} \cdot \nabla \frac{\partial \not{p}}{\partial x} - \frac{\partial u_0}{\partial y} \cdot \nabla \frac{\partial \not{p}}{\partial y}\right) = g$$

where the $k \equiv \omega / c$ is the wavenumber, c is the speed of sound in the medium, ω denotes the acoustic angular frequency, u_0 is the background flow field of the fluid, and i is the imaginary unit.

In fig. 1 a, b and c three different duct geometries are shown. The ducts are shown as symmetric ducts; such that the boundary; Γ_w is a hard wall boundary and Γ_s is a symmetric boundary. The boundary conditions on both Γ_w and Γ_s are; $\nabla p \cdot n = 0$, where n is the outward unit normal.

The duct in fig. 1a is a straight duct having no variations of the internal cross section. The ducts shown in fig. 1b and c have area variations of the internal cross section. The variations for both duct geometries comprise an enlargement of the internal cross section. In the following the duct geometry of the duct shown in fig. 1b will be denoted a corrugated duct and the duct of fig. 1c will be denoted a bulged duct.

The arrows indicate the fluid flow, and are taken to be a purely horizontal, parabolic velocity profile. Further, an acoustic source g is situated at the centre of the duct. In the following the ducts duct geometries shown in fig. 1 are evaluated further. The ducts are considered to have a height of 0.02 m and a length of 0.2 m, for duct a) and b) the height is defined as the height outside the enlarged parts. Further, the fluid flowing in the ducts is considered to be air.

In fig 2 is shown graphs of how the acoustic response depends on the frequency for the three duct geometries a, b and c of fig. 1. The mean flow speed has been set to 1 m/s. Fig. 2a shows the relative symmetry deviation of the acoustic pressure $\langle \delta p \rangle$ and fig. 2 b shows the mean acoustic pressure $\langle p \rangle$, both for frequencies in the range 27.5 to 32.5 kHz.

As can be seen on fig. 2a no significant changes for $\langle \delta p \rangle$ are observed for a straight duct (a), while the corrugated duct (b) shows some changes with frequency. For the bulged duct (c), however, several peaks are observed, and the strongest one occurs for f = 30 kHz, where the signal experiences an increase by a factor of ~10 compared to the two other ducts.

In Fig. 2b the dependence of $\langle p \rangle$ on frequency can be seen, $\langle p \rangle$ shows little change in the investigated frequency range for the straight duct (a), whereas several peaks are observed both for the corrugated duct (b) and the bulged duct (c). For f = 30 kHz, the bulged duct (c) displays a local maximum.

Accordingly, the duct geometry and sound frequency can be chosen such that the ultrasonic pulse exhibits a particularly high sensitivity to the background flow. A flow meter, measuring an air flow with the velocity in the order of 1 m/s, having the bulged duct (c) and an ultrasonic pulse with a frequency of 30 kHz enables the determination of the flow velocity with significantly higher precision than prior art flow meters.

To further illustrate the connection between an acoustic resonance and the frequency as shown in fig. 2, fig. 3 depicts the real part of the acoustic pressure field for the frequency f = 30 kHz in each of the three ducts (corresponding to a map of the acoustic field for the selected flow channel geometries, fluid flow and frequency, which may be obtained by flow-acoustic models such as described in the present description). Both the straight duct (a) and the corrugated duct (b) exhibit high degrees of symmetry in the acoustic pressure field. In the bulged duct (c), however, the acoustic field is clearly asymmetric.

Fig. 5 is a graph that shows the difference in phase (a measure for the difference in transit time) between ultrasonic pulses propagating in and against the direction of the fluid flow for different duct geometries and for different transducer positions. The ultrasonic pulses have a frequency of 30 kHz. It is desired to have a large phase difference as it will make the signal less prone to noise and improves the accuracy of the determined flow velocity.

Two duct geometries are considered: The straight duct of fig. 4a, (identical to the geometry of fig. 1 a) and a bulged duct of fig. 4c (identical to the geometry of fig. 1 c). The ducts are shown in fig. 4 in a cross sectional view.

Two different transducer positions for each of the duct geometries are shown. The transducers are positioned in pairs such that each transducer both generates and senses ultrasonic pulses from the other transducer. The transducers are angled such that the ultrasonic pulse propagates from a transducer reflected on the opposite duct wall and then sensed by the other transducer. The transducers are connected to a control unit (not shown) which is adapted to process the signals from the transducers and thereby determine the flow velocity of the fluid flowing in the duct.

For the straight duct fig. 4a two transducer positions, a first position 1 and a second position 2 are evaluated. The phase difference as a function of flow velocity for the straight duct is shown in fig. 5 for each of the transducer positions. "▼" (a triangle with the tip pointing downwards) denotes the phase difference for the first transducer position 1, whereas for the second transducer position 2 it is shown as "▲" (a triangle with the tip pointing upwards). From the graph of fig. 5 it can be seen that the second transducer position 2 has a slightly larger phase difference than the first transducer position 1, however, the phase difference is almost the same for the two transducer positions. This difference can be ascribed to the larger axially difference between the transducers in the second position 2 compared to the first position.

Turning to the bulged duct of fig 4c there are considered two transducer positions; a third position 3 and a fourth position 4. In both the transducer positions 3, 4 the transducers are positioned in the enlarged part such that the ultrasonic pulse propagates through the fluid in the enlarged part. The transducers at the third position 3 in fig. 4c and the transducer at the first position 1 in fig. 4a are situated, in the respective duct, at the same axially distance from each other. In the same way the two transducers at the second position 2 and the fourth position 4, in fig. 4a and 4c respectively, are positioned at the same axially distance from each other. On fig. 5 the phase difference for ultrasonic pulses propagating in and against the direction of the fluid flow is for the third transducer position 3 denoted "O" (a circle) and for the fourth transducer position 4 denoted "□" (a square).

It can be seen on fig. 5 that the phase difference (and accordingly the transit time) of the ultrasonic pulses are significantly larger for the transducers in the bulged duct compared to the transducers in the straight duct. Further, it can be seen that for the bulged duct geometry, the fourth transducer position 4 has a stronger signal (phase difference) compared to the third transducer position 3 when the flow speed is below 0.68 m/s. However, the third transducer position 3 has the largest signal (phase difference) when the flow speed is above 0.68 m/s. This large increase in the phase cannot be ascribed to the slightly larger distance that the ultrasonic pulse needs to travel in the bulged duct (c) compared to the straight duct (a). The increase in the phase difference is generated because the bulged duct (c) has variations in the cross section and because the specific frequency is chosen to be 30 kHz.

When an embodiment of the invention is to be constructed it can be done in the following way: A flow channel with variations is chosen. Subsequently, transducers are situated such that ultrasonic pulses can be generated by a transducer and after propagating through the fluid sensed by the other transducer. Then the signal strength is measured for a plurality of frequencies, preferably in the form of a sweep of an interval of frequencies, for a representative flow velocity in the velocity interval. If no acoustic resonance is observed then the duct geometry has to be changed and a new frequency sweep performed. If a perturbation of the acoustic resonance is identified the frequency that generates the perturbation is chosen for the flow meter.

It is also possible to construct an embodiment of the invention by choosing a specific ultrasonic frequency and then measure the signal strength for different variations of the geometry of the flow channel in order to identify an acoustic resonance.

Claims

1. A flow meter for ultrasonically measuring the flow velocity of fluids comprising:
   - a duct having a flow channel with an internal cross section comprising variation configured to generate at least one acoustic resonance within the flow channel for a specific ultrasonic frequency, and
   - at least two transducers for generating and sensing ultrasonic pulses, configured to transmit ultrasonic pulses at least at said specific ultrasonic frequency into the flow channel such that the ultrasonic pulses propagate through a fluid flowing in the flow channel,

   wherein the flow meter is configured to determine the flow velocity of the fluid flowing in the flow channel based on a change in transit time, phase and/or pulse, such as amplitude and/or form of the ultrasonic pulses.

2. The flow meter according to claim 1, wherein the internal cross section has a constant area.

3. The flow meter according to claim 1, wherein the variations in the internal cross section comprise area variations of the internal cross section.

4. The flow meter according to claim 3 wherein the area variations comprise an enlarged part of the flow channel, the enlarged part comprises an enlargement of the area of the internal cross section.

5. The flow meter according to claim 4 wherein the flow channel comprises at least two enlarged parts.

6. The flow meter according to any of the claims 4 to 5, wherein the ultrasonic pulses propagate through the fluid in an enlarged part.

7. The flow meter according to any of the preceding claims, wherein the flow velocity is determined based on the transit time or phase of ultrasonic pulses propagating in and against the direction of the fluid flow.

8. The flow meter according to any of the preceding claims, wherein the flow velocity is determined based on a change in the amplitude of the ultrasonic pulse.

9. The flow meter according to any of the preceding claims, wherein the specific ultrasonic frequency is determined by measuring and/or modelling the signal strength of the received ultrasonic pulse for a plurality of transmitted frequencies.

10. The flow meter according to any of the preceding claims, wherein the positions of the at least two transducers are selected to be where the perturbation of the ultrasonic pulses are largest.

11. The flow meter according to any of the preceding claims, wherein the positions of the at least two transducers are selected to be where the transit time or phase change of the ultrasonic pulses are largest.

12. The flow meter according to any of the preceding claims, wherein the positions of the at least two transducers are selected to be where the perturbation of the ultrasonic pulses are largest, irrespective of an unobstructed line-of-sight between them; for example they may be positioned such that they are not placed facing opposite to each other.

13. Method for determining the flow velocity of fluid flowing in a flow channel having an internal cross section, the method comprising the steps of;
    - generating an acoustic resonance in the flow channel, for a specific ultrasonic frequency, by use of variations in the internal cross section,
    - transmitting ultrasonic pulses with said specific ultrasonic frequency into the flow channel by use of at least one transducer, such that the ultrasonic pulses propagate through the fluid,
    - sensing the transmitted ultrasonic pulses by use of at least one transducer, and
    - determining the flow velocity of the fluid based on the transit time or phase of the ultrasonic pulses or change of the ultrasonic pulse.

14. Method according to claim 13, wherein variations in the internal cross section comprise area variations of the internal cross section.

15. Method according to claim 14, wherein the area variations comprise at least one enlarged part of the flow channel, the enlarged part comprising an enlargement of the area of the internal cross section.

16. Method according to claim 15, wherein the ultrasonic pulse propagates through an enlarged part of the flow channel.

17. Method according to any of the claims 13 to 16, wherein the specific ultrasonic frequency is determined by measuring the signal strength of the received ultrasonic pulse for a plurality of transmitted frequencies.

18. Method according to any of the claims 13 to 17, wherein the flow velocity is determined based on a change of the ultrasonic pulse such that the change at least partly includes the change in amplitude of the ultrasonic pulse.

19. Method according to any of the claims 13 to 18, wherein the flow velocity is determined based on the difference in transit time or phase between ultrasonic pulses propagating in and against the direction of the fluid flow.

20. A method for determining the acoustic resonance frequency of a flow channel comprising variations in the internal cross section, the method comprising the steps of:
a. generating a fluid flow within the flow channel,
b. transmitting ultrasonic pulses at a selected starting frequency into the flow channel by use of at least one transducer, such that the ultrasonic pulses propagate through the fluid,
c. sensing the transmitted ultrasonic pulses by use of at least one transducer,
d. measuring and/or modelling the signal strength of the received ultrasonic pulses, the signal being a difference in transit time, a difference in phase and/or a change of the pulses,
e. repeating step a-d for a plurality of transmitted frequencies, optionally performed as a frequency sweep within a predefined interval of frequencies, and
f. selecting the frequency at which the highest signal strength is measured, thereby determining the acoustic resonance frequency of said duct comprising said internal cross section variations.

21. A method for determining the positions of transducers within a flow channel comprising variations in the internal cross section, such that a maximal perturbation of the ultrasonic pulses is detected, the method comprising the

steps of:

a. selecting a flow channel geometry, fluid flow velocity, and measurement frequency,

b. mapping the acoustic field for the selected flow channel geometry, fluid flow and measurement frequency, preferably by means of flow-acoustic models, and

c. determining positions wherein the acoustic field is maximal asymmetric, thereby determining the positions of transducers, wherein a maximal perturbation of the ultrasonic pulses is detected.

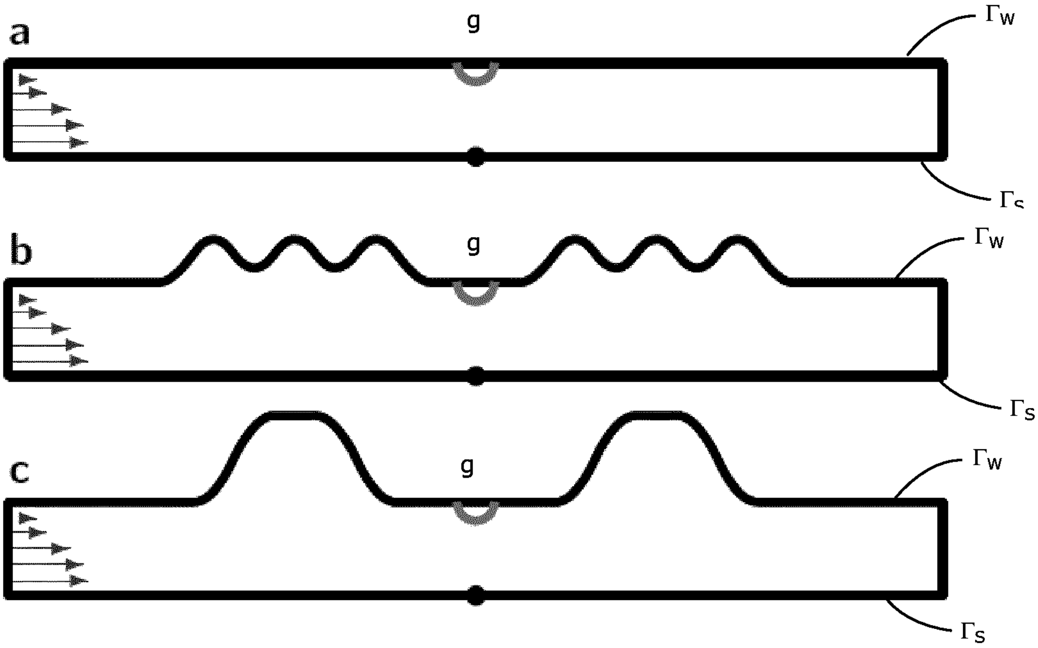

Fig. 1

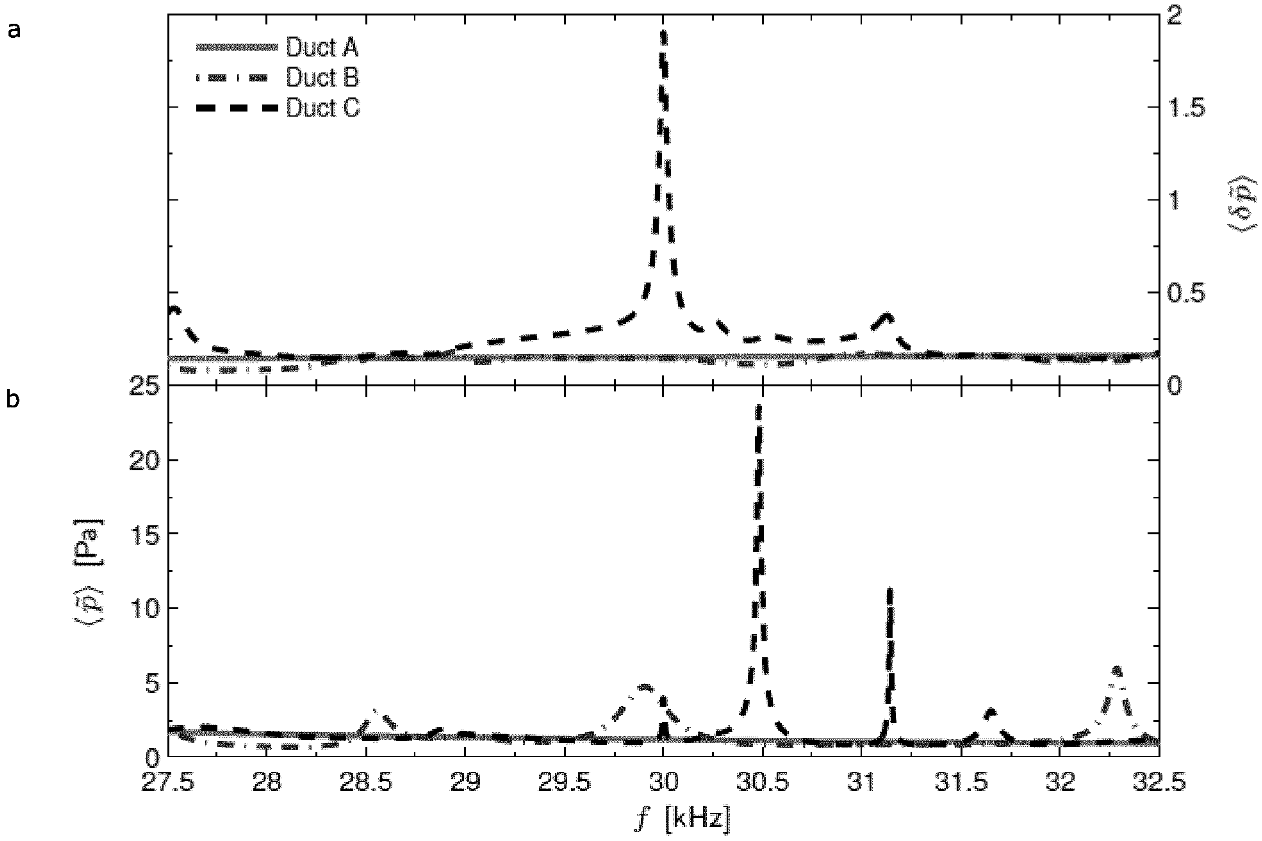
a
b
Duct A
Duct B
Duct C
2
1.5
1
0.5
0
$\langle \delta\bar{p} \rangle$
25
20
15
10
5
0
$\langle \bar{p} \rangle$ [Pa]
27.5
28
28.5
29
29.5
30
30.5
31
31.5
32
32.5
f [kHz]

Fig. 2

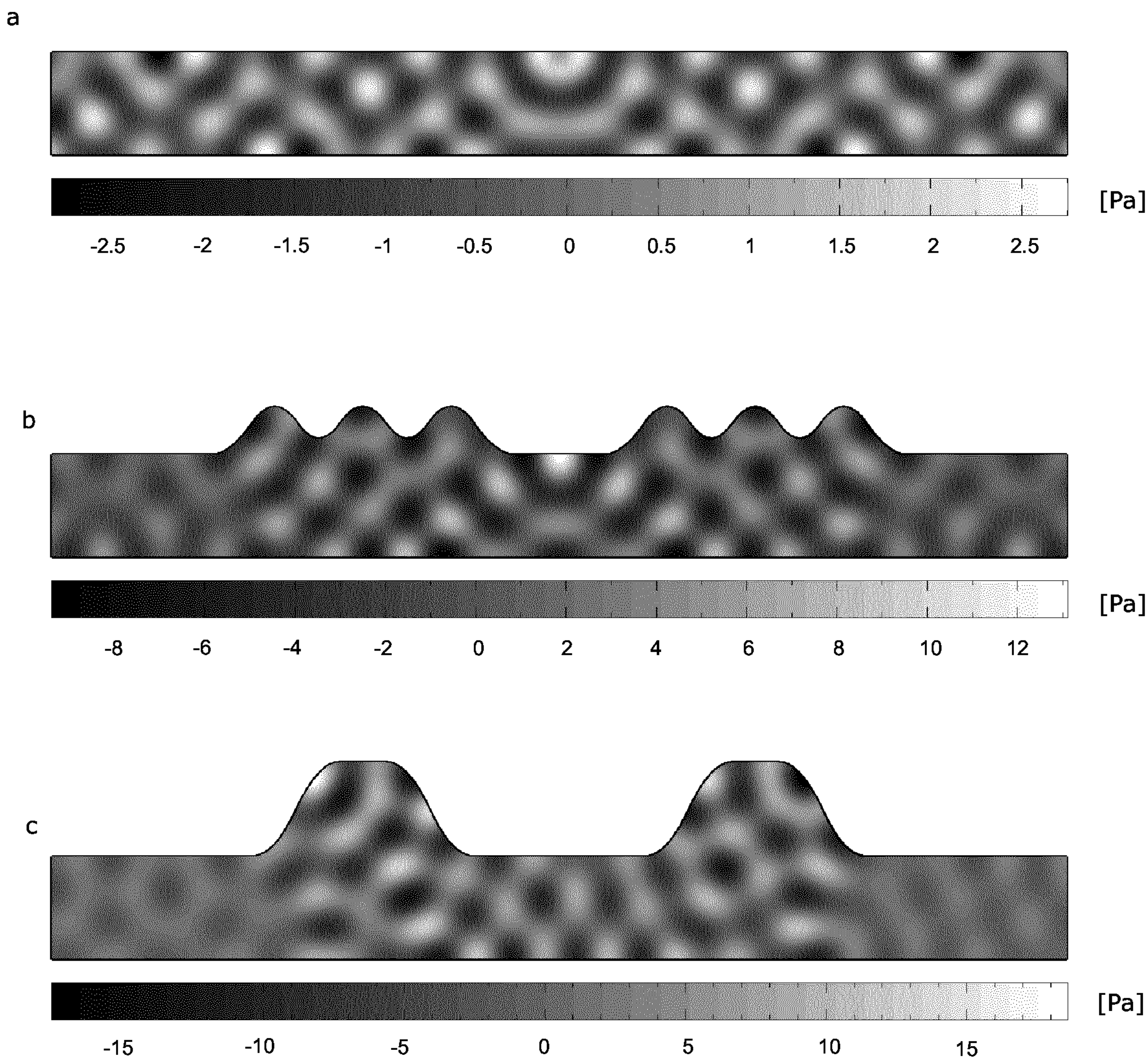
a
[Pa]
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
b
[Pa]
-8
-6
-4
-2
0
2
4
6
8
10
12
c
[Pa]
-15
-10
-5
0
5
10
15

Fig. 3

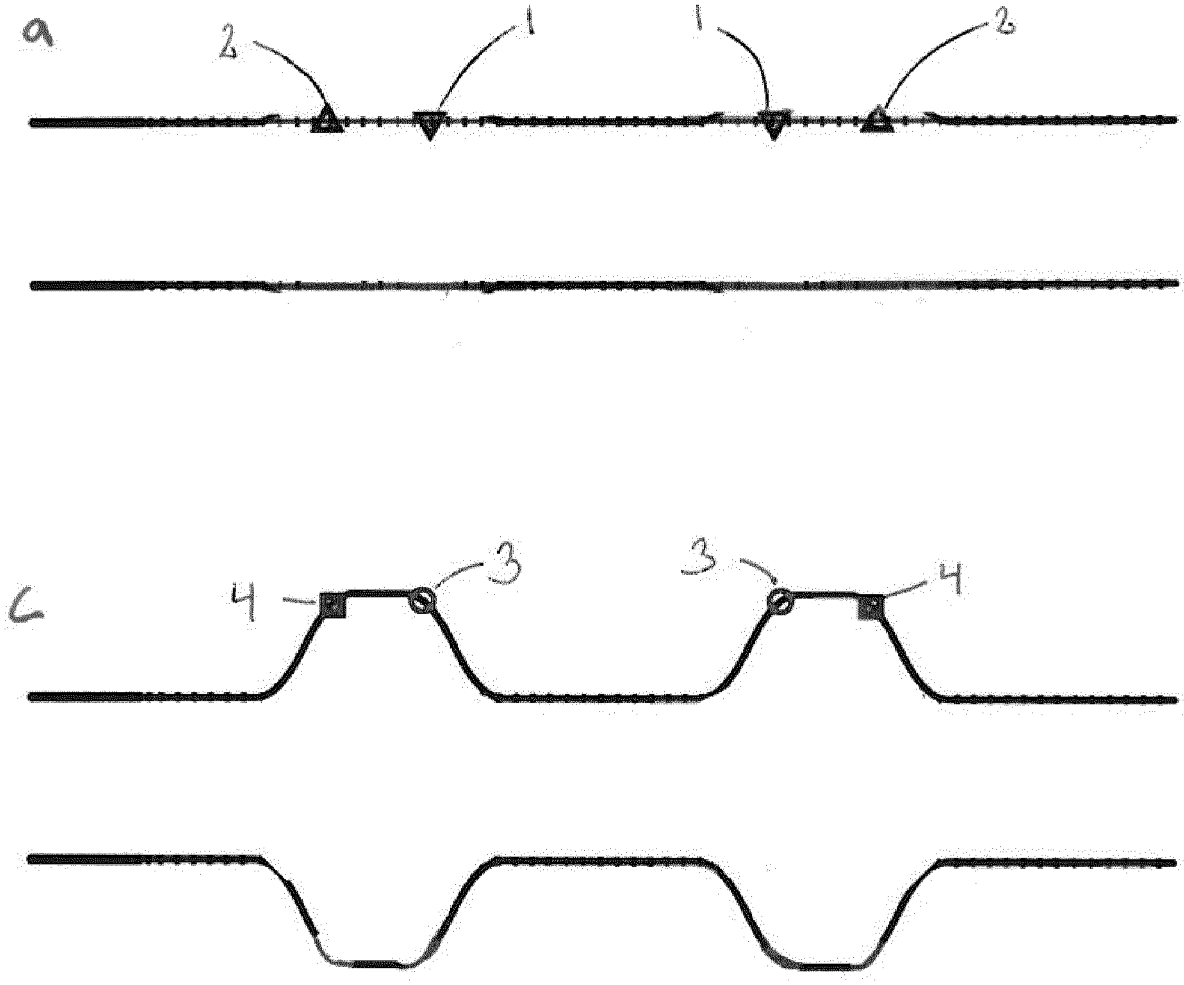

Fig. 4

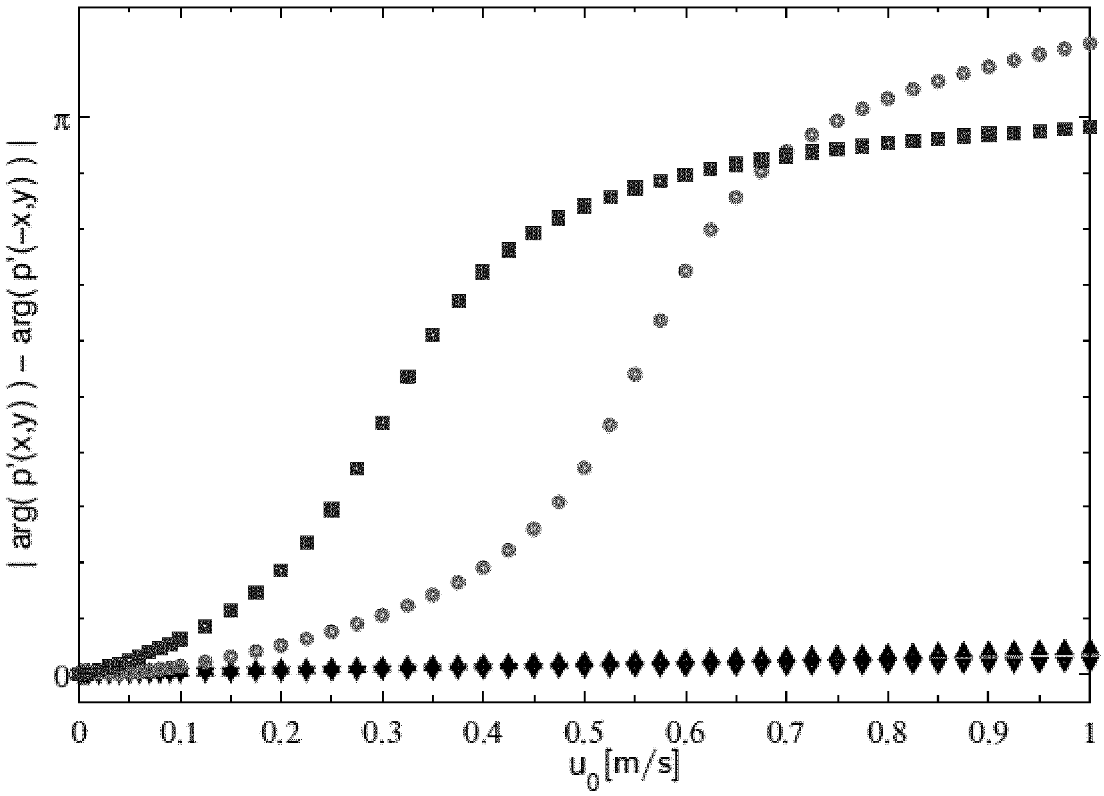

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/073113

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01F1/66
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 43 35 394 A1 (KERNFORSCHUNGSZ KARLSRUHE [DE] KARLSRUHE FORSCHZENT [DE]) 20 April 1995 (1995-04-20) cited in the application	1-9, 13-20
Y	abstract page 3, lines 3-16 page 3, lines 48-59 page 4, lines 3-38 figures 2, 3 -----	10-12,21

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 February 2015	26/02/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Baytekin, Hüseyin

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/073113

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	EP 0 801 311 B1 (F T TECH LTD [GB] F T TECHNOLOGIES LTD [GB]) 5 March 2003 (2003-03-05) cited in the application pages 2-3, paragraphs [0001], [0008], [0012], [0014], [0017], [0020] page 4, column 6, lines 10-56; claims 1-6 page 5, column 7, lines 16-36; claim 10 figures 1, 4 -----	1,13
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/073113

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