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(54) **METHOD OF GENERATION OF LIQUID JET PULSATIONS AND APPARATUS FOR IMPLEMENTATION OF THIS METHOD**

VERFAHREN ZUR ERZEUGUNG VON FLUSSIGKEITSSTRAHLPULSATIONEN UND VORRICHTUNG ZUR DURCHFÜHRUNG DIESES VERFAHRENS

PROCEDE POUR GENERER DES PULSATIONS DE PRESSION, ET APPAREIL SERVANT A LA MISE EN OEUVRE DE CE PROCEDE

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Description

Technical field

[0001] The present invention relates to a method of generation of pressure pulsations for generating pulsating liquid jets and an apparatus for implementation of the method.

Background art

[0002] Continuous liquid jets are commonly used for cutting and disintegration of various materials, for cleaning and removal of surface layers and coatings. Generating of sufficiently high pressure pulsations in pressure liquid upstream from the nozzle exit (so called modulation) enables to generate a pulsating liquid jet that emerges from the nozzle as a continuous liquid jet and it not forms into pulses until certain standoff distance from the nozzle exit. The advantage of such a pulsating jet compared to the continuous one consists in fact that the initial impact of pulses of pulsating jet on the target surface generates impact pressure that is several times higher than stagnation pressure generated by the impact of continuous jet under the same conditions. In addition, the impact of pulsating jet induces also fatigue stress in target material due to cyclic loading of the target surface. This further improves an efficiency of the pulsating liquid jet compared to the continuous one.

[0003] At present, several types of devices intended for generation of pulsating liquid jets are available as, for example, from document US-A-4393991. Internal mechanical flow modulators are mechanical devices integrated in the nozzle. They are formed essentially by channeled rotor placed upstream the nozzle exit. The rotor cyclically changes resistance of flow by its rotation and thus modulates velocity of the jet emerging from the nozzle (E. B. Nebeker: Percussive Jets - State-of-the-Art, Proceedings of the 4th U.S. Water Jet Symposium, WJTA, St. Louis, 1987). The main shortcoming of the above mentioned principle is very low lifetime of moving components in the nozzle.

[0004] Modulation of continuous liquid jets by Helmholtz oscillator is based on the fact that changes in flow cross-section and/or flow discontinuities provoke periodical pressure fluctuations in flowing liquid (Z. Shen & Z. M. Wang: Theoretical analysis of a jet-driven Helmholtz resonator and effect of its configuration on the water jet cutting property, Proceedings of the 9th International Symposium on Jet Cutting Technology, BHRA, Cranfield, 1988). The same physical principle is used in so-called self-resonating nozzles. Certain type of shock pressure is developed when liquid flows over exit of resonating tube. The shock pressure is carried back to the tube inlet where it creates standing wave by addition with pressure pulsations. If frequency of the shock pressure corresponds to natural frequency of the flow, pressure resonance occurs and the jet starts to create discrete annular vortexes that result in generation of cavitations and/or pulses. (G. L. Chahine et al.: Cleaning and cutting with self-resonating pulsed water jets, Proceedings of the 2nd U.S. Water Jet Symposium, WJTA, St. Louis, 1983). The primary disadvantage of the above mentioned devices is low depth of modulation of liquid jet.

[0005] An ultrasonic nozzle for modulation of high-speed water jet is based on a vibrating transformer placed upstream in the vicinity of the nozzle exit in such a way that pressurized fluid flows through annulus between the transformer and nozzle wall. The vibrating transformer is connected to magnetostrictive and/or piezoelectric transducer. The transformer generates highly intensive ultrasound field upstream of the nozzle exit that modulates high-speed water jet escaping from the nozzle (M. M. Vijay: Ultrasonically generated cavitating or interrupted jet, U. S. Patent No. 5,154,347, 1992). High wear of the tip of vibrating transformer due to intense cavitational erosion, increased dimensions and weight of cutting tool rank among the most important drawbacks of the above mentioned device. The level of modulation is strongly dependent on the position of the tip of the vibrating transformer with respect to the nozzle exit. In addition to that, the ultrasonic nozzle device does not allow utilizing of existing cutting tools for continuous water jets, which significantly increases costs of its implementation in industrial practice.

Disclosure of the invention

[0006] The present invention is directed to a method of acoustic generation of pulsations of liquid jet and an apparatus for implementation of the method.

[0007] The method according to the present invention consists in that pressure pulsations are generated by acoustic actuator in acoustic chamber filled with pressure liquid; the pressure pulsations are amplified by mechanical amplifier of pulsations and transferred by liquid waveguide fitted with pressure liquid feed to the nozzle and/or nozzle system. Liquid compressibility and tuning of the acoustic system, consisting of acoustic actuator, acoustic chamber, mechanical amplifier of pulsations and liquid waveguide, are utilized for effective transfer of pulsating energy from the generator to the nozzle and/or nozzle system. The acoustic system can be complemented with tuneable resonant chamber allowing resonant tuning of the acoustic system.

[0008] Unlike the ultrasonic nozzle device (M. M. Vijay: Ultrasonically generated cavitating or interrupted jet, U. S. Patent No. 5,154,347, 1992), the acoustic generator of pulsations according to the present invention is not sensitive to the accurate setting of the position of the acoustic actuator in the acoustic chamber and the acoustic actuator is not subjected to the immense wear due to an intensive cavitation erosion.

[0009] The method and the apparatus for acoustic generation of pulsations of liquid jet according to the present invention allow transmitting of pressure pulsations in the liquid over longer distances as well. Therefore, the generator of pulsations can be connected into the pressure system between a pressure source and working (jetting) tool equipped with nozzle(s) at the distance up to several meters from the working tool. Thanks to that, during generation of pulsations of liquid jet according to present invention it is possible not only to better protect the generator of pulsations against adverse impacts of the working environment in close proximity of the working tool but also to utilize standard working tools that are commonly used in work with continuous jets. This can significantly reduce costs of implementation of the technology of pulsating liquid jets in the industrial practice.

Description of the drawings

[0010] The present invention will be even more clearly understandable with reference to the drawings appended hereto, in which: Figure 1 is a schematic cross-sectional view of an apparatus for implementation of a method of generation of pressure pulsations for generating pulsating liquid jets according to the present invention utilizing direct action of an acoustic actuator on the pressure liquid in the acoustic chamber; Figure 2 is a schematic cross-sectional view of an apparatus for implementation of a method of generation of pressure pulsations for generating pulsating liquid jets according to the present invention utilizing indirect action of an acoustic actuator on the pressure liquid in the acoustic chamber via the wall of the acoustic chamber; and Figure 3 is a schematic cross-sectional view of an apparatus for implementation of a method of generation of pressure pulsations for generating pulsating liquid jets according to the present invention utilizing direct action of an acoustic actuator on the pressure liquid in the acoustic chamber and equipped with a tuneable resonant chamber.

Examples

Example 1

[0011] Fig Figure 1 is a schematic cross-sectional view of an apparatus for implementation of a method of generation of pressure pulsations for generating pulsating liquid jets according to the present invention utilizing direct action of an acoustic actuator on the pressure liquid in the acoustic chamber. Acoustic actuator 1, consisting of piezoelectric transducer 10 and cylindrical waveguide 11, transforms supplied electric power into mechanical vibration. Cylindrical waveguide 11 with diameter of 38 mm inserted into the cylindrical acoustic chamber 2 with diameter of 40 mm and filled with pressure liquid 3 transmits mechanical vibration into the liquid. As a result, pressure pulsations are generated in the pressure liquid 3. Pressure pulsations of the liquid are amplified in mechanical amplifier of pulsations 4 in the shape of cone frustum and transposed into the flowing pressure liquid at the point of connection to the pressure distribution 5 of the apparatus for application of liquid jet. Pressure pulsations are transferred by a liquid waveguide 6 from the mechanical amplifier of pulsations 4 to the nozzle and/or nozzle system 7 (i.e. to the working tool). The liquid waveguide 6 consists of metal tube 12 and hose 13. Pressure pulsations of liquid are used for generation of pulsating liquid jet 8 in the nozzle and/or nozzle system 7.

Example 2

[0012] Figure 2 is a schematic cross-sectional view of an apparatus for implementation of a method of generation of pressure pulsations for generating pulsating liquid jets according to the present invention utilizing indirect action of an acoustic actuator on the pressure liquid in the acoustic chamber via the wall of the acoustic chamber. Acoustic actuator 1, consisting of piezoelectric transducer 10 and cylindrical waveguide 11, transforms supplied electric power into mechanical vibration. Cylindrical waveguide 11 with diameter of 38 mm is fixed to the wall of the cylindrical acoustic chamber 2 with diameter of 40 mm and filled with pressure liquid 3. Mechanical vibration of cylindrical waveguide 11 oscillates the wall of the cylindrical acoustic chamber 2 that transmits the oscillations into the pressure liquid 3. As a result, pressure pulsations are generated in the pressure liquid 3. Pressure pulsations of the liquid are amplified in mechanical amplifier of pulsations 4 in the shape of cone frustum and transposed into the flowing pressure liquid at the point of connection to the pressure distribution 5 of the apparatus for application of liquid jet. Pressure pulsations are transferred by a liquid waveguide 6 from the mechanical amplifier of pulsations 4 to the nozzle and/or nozzle system 7 (i.e. to the working tool). The liquid waveguide 6 consists of metal tube 12 and hose 13. Pressure pulsations of liquid are used for generation of pulsating liquid jet 8 in the nozzle and/or nozzle system 7.

Example 3

[0013] Figure 3 is a schematic cross-sectional view of an apparatus for implementation of a method of generation of pressure pulsations for generating pulsating liquid jets according to the present invention utilizing direct action of an acoustic actuator on the pressure liquid in the acoustic chamber equipped with a tuneable resonant chamber. Acoustic actuator 1, consisting of piezoelectric transducer 10 and cylindrical waveguide 11, transforms supplied electric power into mechanical vibration. Cylindrical waveguide 11 with diameter of 38 mm inserted into the cylindrical acoustic chamber 2 with diameter of 40 mm and filled with pressure liquid 3 transmits mechanical vibration into the liquid. As a result, pressure pulsations are generated in the pressure liquid 3. Acoustic chamber 2 is connected with a tuneable resonant chamber 9 that serves for matching of natural frequency of the acoustic system to the driving frequency of pressure pulsations. Pressure pulsations of the liquid are amplified in mechanical amplifier of pulsations 4 in the shape of cone frustum and transposed into the flowing pressure liquid at the point of connection to the pressure distribution 5 of the apparatus for application of liquid jet. Pressure pulsations are transferred by a liquid waveguide 6 from the mechanical amplifier of pulsations 4 to the nozzle and/or nozzle system 7 (i.e. to the working tool). The liquid waveguide 6 consists of metal tube 12 and hose 13. Pressure pulsations of liquid are used for generation of pulsating liquid jet 8 in the nozzle and/or nozzle system 7.

Industrial applicability

[0014] Solution according to the present invention can be utilized in many industrial branches, such as mining (rock cutting, quarrying and processing of ornamental and dimension stones), civil engineering (repair of concrete structures, surface cleaning), and engineering (surface layer removal, cleaning, and cutting).

Claims

1. A method of generating of liquid jet pulsations **characterized in that** acoustic pulsations generated by an acoustic actuator (1) acting directly or indirectly on stationary volume of pressure liquid (3); said acoustic pulsations being amplified by mechanical amplifier of pulsations (4) and transferred by a liquid waveguide (6) provided with supply of pressure liquid to a nozzle and/or nozzle system (7).

2. The method according to claim 1, wherein a resonant natural frequency of an acoustic system is matched to the frequency of acoustic pulsations by means of a tuneable resonant chamber (9).

3. An apparatus for implementation of the method according to claim 1, **characterized in that** it is composed of an acoustic system consisting of an acoustic actuator (1), an acoustic chamber (2) which internal volume being filled with stationary pressure liquid (3), a mechanical amplifier of pulsations (4), said mechanical amplifier of pulsations having advantageously conical, cylindrical, cathenoidal, Bessel's, exponential or stepped shape or their combination, and liquid waveguide (6) that is usually metal tubing or hose or combination of both; said acoustic chamber (2) is fitted with said mechanical amplifier of pulsations (4) that is connected with a nozzle and/or nozzle system (7) by means of said liquid waveguide (6) that is fitted with pressure liquid feed (5); said acoustic system is parallelly connected to the said pressure liquid feed (5) at arbitrary distance from the nozzle and/or nozzle system (7).

4. The apparatus according to claim 3, wherein the acoustic actuator (1) is partially immersed in the pressure liquid (3).

5. The apparatus according to claim 3, wherein the acoustic actuator (1) is fixed to the wall of the acoustic chamber (2).

6. The apparatus according to claims 3 to 5, wherein the length-cross dimension (diameter) ratio of the acoustic chamber (2) is greater than 1.

7. The apparatus according to claims 3 to 6, wherein the cross-section of the acoustic chamber (2) exceeds emissive area of the acoustic actuator (1) maximally by 20%.

8. The apparatus according to claims 3 to 7, wherein the acoustic actuator is electromechanical transducer (10); said electromechanical transducer (10) being advantageously piezoelectric or magnetostrictive.

9. The apparatus according to claims 3 to 8, further **characterized in that** its part is a tuneable resonant chamber (9) for tuning up of resonant natural frequency of the acoustic system to the driving frequency of pressure pulsations.

Patentansprüche

1. Verfahren zur Erzeugung von Flüssigkeitsstrahlpulsationen, **dadurch gekennzeichnet, dass** von einem akkustischen Aktuator (1) erzeugte akustische Pulsationen direkt oder indirekt auf ein stationäres Volumen einer Druckflüssigkeit (3) einwirken, wobei die akustischen Pulsationen durch einen mechanischen Pulsationsverstärker (4) verstärkt und durch einen flüssigen Wellenleiter (6), der mit einer Druckflüssigkeitsquelle versehen ist, zu einer Düse und/ oder einem Düsensystem (7) übertragen werden.

2. Verfahren nach Anspruch 1, wobei eine Eigenresonanzfrequenz eines akkustischen Systems der Frequenz der akkustischen Pulsationen durch eine durchstimmbare Resonanzkammer (9) angepasst wird.

3. Vorrichtung zur Durchführung nach Anspruch 1, **dadurch gekennzeichnet, dass** die Vorrichtung aufweist:

ein akustisches System mit einem akustischen Aktuator (1) eine akustische Kammer (2) deren Innenvolumen mit einer stationären Druckflüssigkeit (3) gefüllt ist, einen mechanischen Pulsationsverstärker (4), wobei der mechanische Pulsationsverstärker vorzugsweise eine konische, zylindrische, cathenuidale Form, eine

Form nach einer Bessel's-Funktion, einer Exponentialfunktion oder eine stufenförmige Form oder Kombinationen davon aufweist und einen Flüssigkeitswellenleiter (6), üblicherweise ein Metallrohr oder ein Schlauch oder Kombinationen von beiden, wobei die Akustikkammer (2) mit dem mechanischen Pulsationsverstärker (4) verbunden ist, der mit einer Düse und/oder einem Düsensystem (7) über den Flüssigkeitswellenreiter (6) verbunden ist, der wiederum mit der Druckflüssigkeitsquelle (5) verbunden ist, wobei das akustische System parallel zu der Druckflüssigkeitsquelle (5) in beliebigen Abstand von der Düse und/oder dem Düsensystem (7) verbunden ist.

4. Vorrichtung nach Anspruch 3, wobei der akustische Aktuator teilweise in die Druckflüssigkeit (3) eingetaucht ist.

5. Vorrichtung nach Anspruch 3, wobei der akustische Aktuator (1) an der Wand der Akustikkammer (2) befestigt ist.

6. Vorrichtung nach einem der Ansprüche 3 bis 5, wobei das längs zu quer Abmessungs(durchmesser) verhältnis der Akustikkammer (2) größer als 1 ist.

7. Vorrichtung nach einem der Ansprüche 3 bis 6, wobei der Querschnitt der Akustikkammer (2) den Emissionsbereich des akustischen Aktuators (1) maximal um 20 % überschreitet.

8. Vorrichtung nach einem der Ansprüche 3 bis 7, wobei der Akkustikaktuator ein elektromechanischer Transducer (10) ist, der vorzugsweise ein piezoelektrischer oder magnetostriktiver Transducer ist.

9. Vorrichtung nach einem der Ansprüche (8), **dadurch gekennzeichnet, dass** er eine durchstimmbare Resonanzkammer (9) aufweist, um die Eigenresonanzfrequenz des akustischen Systems auf die Steuerfrequenz der Druckpulsationen einzustellen.

Revendications

1. Procédé pour générer des pulsations de jets de liquide **caractérisé en ce que** les pulsations acoustiques générées par un actionneur acoustique (1) agissent directement ou indirectement sur un volume immobile de liquide sous pression (3) ; lesdites pulsations acoustiques étant amplifiées par un amplificateur mécanique de pulsations (4) et transférées par un guide d'ondes à liquide (6) alimenté en liquide sous pression vers une buse et/ou un système de buse (7).

2. Le procédé selon la revendication 1, dans lequel une fréquence naturelle de résonance d'un système acoustique est mise en adéquation avec la fréquence des pulsations acoustiques au moyen d'une chambre de résonance réglable (9).

3. Dispositif pour la mise en oeuvre du procédé selon la revendication 1, **caractérisé en ce qu'**il est composé d'un système acoustique constitué d'un actionneur acoustique (1), d'une chambre acoustique (2) dont le volume interne est rempli d'un liquide sous pression immobile (3), d'un amplificateur mécanique de pulsations (4), ledit amplificateur mécanique de pulsations présentant avantageusement une forme conique, une forme cylindrique, une forme caténoïdale, une forme de Bessel, une forme exponentielle ou une forme étagée ou une combinaison de ces formes, et d'un guide d'ondes à liquide (6) qui est généralement un tube ou un tuyau métallique ou une combinaison des deux ; ladite chambre acoustique (2) est fixée audit amplificateur mécanique de pulsations (4) qui est relié à une buse et/ ou à un système de buse (7) au moyen dudit guide d'ondes à liquide (6) qui est muni d'une alimentation en liquide sous pression (5) ; ledit système acoustique est parallèlement relié à ladite alimentation en liquide sous pression (5) à une distance arbitraire de la buse et/ou du système de buse (7).

4. Le dispositif selon la revendication 3, dans lequel l'actionneur acoustique (1) est partiellement plongé dans le liquide sous pression (3).

5. Le dispositif selon la revendication 3, dans lequel l'actionneur acoustique (1) est fixé à la paroi de la chambre acoustique (2).

6. Le dispositif selon les revendications 3 à 5, dans lequel le rapport de dimension dans le sens de la longueur (diamètre) de la chambre acoustique (2) est supérieur à 1.

7. Dispositif selon les revendications 3 à 6, dans lequel la section transversale de la chambre acoustique (2) dépasse la zone émissive de l'actionneur acoustique (1) de 20 % au maximum.

8. Le dispositif selon les revendications 3 à 7, dans lequel l'actionneur acoustique est un transducteur électromécanique (10) ; ledit transducteur électromécanique (10) étant avantageusement piézoélectrique ou magnétostrictif.

9. Le dispositif selon les revendications 3 à 8, **caractérisé en ce que** sa pièce est une chambre de résonance réglable (9) pour le réglage de la fréquence naturelle de résonance du système acoustique sur la fréquence d'activation des pulsations de pression.

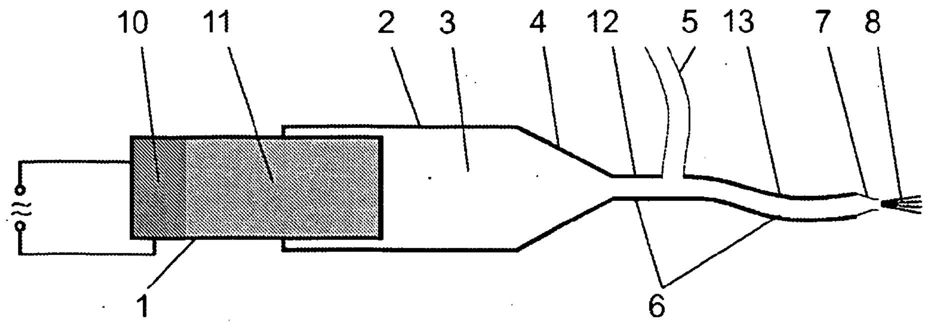

Fig. 1

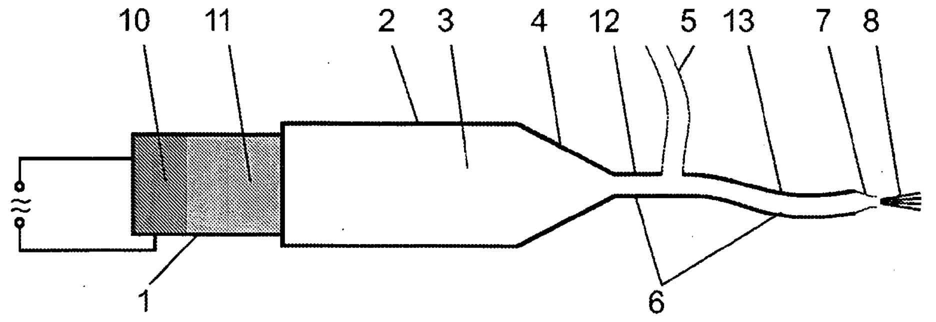

Fig.2

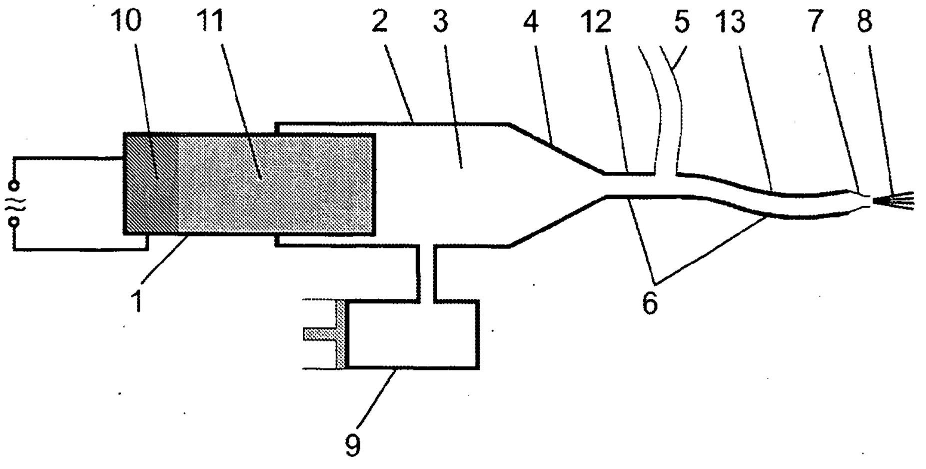

Fig.3

REFERENCES CITED IN THE DESCRIPTION

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