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(54) A METHOD OF SUPPLYING STEAM PISTON ENGINES WITH ULTRA-SUPERCRITICAL STEAM AND A STEAM INJECTOR FOR SUPPLYING STEAM PISTON ENGINES WITH ULTRA-SUPERCRITICAL STEAM

(57) The object of invention is a method of supplying steam piston engines with ultra-supercritical steam and a steam injector to effect the method. Steam is supplied via an electromagnetic steam injector with a high operating frequency and comprising the needle 3 tipped with a taper 12, where the position of the needle, dependent on the upward or downward motion, changes the annular cross-section of the gap between the seat of the inlet opening 15 of the head 14 and the taper 12 of the needle 3, where the needle 3 is operated with electromagnetic force by the solenoid 10, which in turn is operated by the driver 9 controlled by the control computer 8 according to the data output of the transducers 7, which relay the changes in the load of the steam piston engine related to the rotational speed of the crankshaft of the steam piston engine which is 25 Hz or higher, resulting in the adjustment, in real time, of the water (the steam of) dose according to the steam piston engine load.

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Description

[0001] A method of supplying steam piston engines with ultra-supercritical steam and a steam injector for supplying steam piston engines with ultra-supercritical steam

[0002] The object of invention is a method of supplying steam piston engines with ultra-supercritical steam and a steam injector to effect the method.

[0003] Supercritical steam is present at a pressure from 24.1 MPa and a temperature from 538°C. Ultra-supercritical steam is present at a pressure from 27.2 MPa and a temperature from 600°C. The steam in the ultra-supercritical state has no defined boundary between liquid water and its vapour. Water (the vapour of it) under a high pressure remains liquid at a high temperature and does not boil or evaporate. If the water heated to this high temperature range and maintained in this high pressure range is throttled to a lower pressure by passing its stream via an orifice, a part of the stream is immediately and explosively converted into steam downstream of the orifice. This phenomenon is applied as a means of propelling steam piston engines. The propulsion applications in steam piston engines are based on dedicated admission valves for supplying steam as the working medium to the engines; these inlet valves are known as steam injectors for steam piston engines, the prior art of which is shown in the patents: CN101892930, JP60184913, DE102007046316, US2008093477, and EP1277014.

[0004] However, the solutions being those inventions do not permit fast-acting, pulsed dosing of supercritical steam with an infinitely-variable, adjustment of the injected steam dose during the real-time operation of a steam piston engine.

[0005] A steam injector without the foregoing drawbacks is known as described in the patent no. PL220363; however, its mechanical design is complicated and does not provide a high durability or reliability of performance.

[0006] The purpose of the solution according to the invention is a novel method of supplying steam piston engines with ultra-supercritical steam by application of an injection pulse effect, and a novel steam injector intended to effect the method, characterized by a high operating frequency and an infinitely variable, precisely adjustable injected steam dose, and intended for a steam piston engine with a novel operating principle and a novel design, where the steam injector has a high durability and reliability by a radical simplification of the design.

[0007] In the solution according to the invention, a steam admission valve is replaced with a steam injector which directs highly-pressurized hot water directly into the chamber of a steam piston engine. The use of the steam injector which injects water instead of a steam admission valve results in a significantly lower amount of water injected into the steam piston engine during each stroke than the volume of steam passing through a steam admission valve in a steam piston engine with a steam turbine generator (where steam under atmospheric pressure occupies 1650 times more of volume than water). The comparably small amount of water is much easier to distribute with a steam injector than with a steam admission valve, which must pass much more steam in a turbine engine. This comparably small amount of water provides another advantage, which is speed. The comparably small amounts of water can be dosed with a speed corresponding to the rotational speed typical of Diesel engines. Steam, on the other hand, must pass through a steam admission valve and loses significant pressure when the engine starts working faster. This phenomenon is caused by flow throttling.

[0008] The essence of the method of supplying ultra-supercritical steam to a steam piston engine by application of an injection pulse effect is a precise dosing of supercritical and ultra-supercritical water (the vapour of it) to a cylinder of the steam piston engine, where the precise dosing is effected by an infinitely variable change of the cross-section of an annular gap between the inlet opening seat of the steam injector and the needle of the steam injector, where the steam injector is operating in pulses of a high frequency, whereas the location of the steam injector needle, which varies by moving up and down, is controlled with an electromagnetic field generated by a cylindrical coil (a solenoid), where the solenoid is controlled with a driver (a controller) and the steam piston engine control computer to ensure infinitely variable, real-time changes of the injected steam dose as an effect of the changes in the load of the steam piston engine and in relation to the rotational speed of the crankshaft of the steam piston engine at 25 Hz or higher, and, simultaneously, with the adjustment of the injected water (the vapour of) dose dependent on the load of the steam piston engine.

[0009] The essence of the design of the steam injector according to the invention is a design of the steam injector, comprising of a body made of three interconnected and separable components; in the vertical plane within the body is the vertically sliding needle, one end of which rests in the cylinder inlet seat, while the opposite end of which rests against a spring in the body; the spring presses the needle to the cylinder opening seat of the steam piston engine, whereas the vertical movement of the needle is effected by an electromagnetic field generated by the cylindrical coil (a solenoid), where the solenoid is controlled with a driver (a controller) and the steam piston engine control computer according to the outputs of the sensors which monitor the operation of the steam piston engine to ensure a precise and controlled linear positioning of the needle along the vertical axis. In a satisfactory solution, the end of the needle which rests in the cylinder inlet seat has a form of a taper with an apex angle α = 34°.

Satisfactory effects of the important characteristics of the invention

[0010] A technical advantage of the solution according to the invention is the feasibility of dosing a precise and variable dose of supercritical and ultra-supercritical water (the steam of) to a piston cylinder of a steam piston engine, and an infinitely variable adjustment of the same dose in the real time according to the changes in the load and the rotational speed of the steam piston engine. A technical advantage is also the feasibility of achieving high speeds by a steam piston engine, with a significant improvement in the efficiency of the steam piston engine.

[0011] The supply method and the design of the steam injector according to the object of the invention are shown in figures, where:

F i g. 1 shows a steam pulse injector of supercritical and ultra-supercritical water in the closed position;
F i g. 2 shows the geometric dependencies of the dosing needle taper within the cylinder inlet opening in the closed position of the pulse injector;
Fig.3 shows the geometric dependencies of the dosing needle taper within the cylinder inlet opening in the open position of the pulse injector.

[0012] The method according to the invention is shown in detail in an example of the design and operation of the steam injection valve.

[0013] Supercritical and ultra-supercritical water (the steam of) is dosed in portions to the cylinder 16 of a steam piston engine by an infinitely variable change of the annular cross-section of the gap located between the seat of the inlet opening 15, located in the steam injector head 14 and the taper 12 of the needle 3.

[0014] When the needle opens 3, a gap is formed between the taper 12 and the inlet opening 15 of the head 14; via this gap the steam is injected into the cylinder 16 and it is violently decompressed inside of the cylinder 16, by which the steam pressure is reduced and the steam volume increases to effect the work in the cylinder 16. The amount of the water being injected depends on the load of the steam piston engine and the amount (the dose) is infinitely variably in the real-time operation of the steam piston engine by changing the position of the needle 3; the change is effected by an axial movement of the needle 3 in a vertical plane which changes the surface area of the annular gap between the seat of the inlet opening 15 and the taper 12 of the needle 3.

[0015] The surface area of the annular gap is the result of a cross-sectional differential at diameter $\phi 1$ of the inlet opening 15 and diameter $\phi 2$ of the needle 3 in the plane 13. An increase in the annular gap surface area increases the steam dose admitted to the cylinder.

[0016] The axial movement of the needle 3 is a result of the total of: force F1, generated by the solenoid 10, and force F2 of the spring 1, where the force F1 is a result of the changes in the electromagnetic field generated by the solenoid as an effect of the current and the frequency generated by the solenoid driver 9, which is actuated according to the preset values from the control computer 8 according to the data 7 (rotational speed, pressure, temperature, etc.) relayed in real-time from the sensors installed on the steam piston engine.

[0017] The steam injector to realize the method comprises the body 17, which is formed by three separable components I to III, which are in turn interconnected with a threaded joint, and where the body houses axially aligned internal voids or seats: of the spring 1, the void below the needle 3, and the injection chamber 11 below. Whereas the needle 3 is a cylinder the bottom end of which is a taper with an apex angle $\alpha = 34°$ and the needle is aligned with the central axis along the vertical plane, and the needle moves in slide bearings 2 and 5; the needle top end is held by the spring 1, which presses the needle down into the seat of the inlet opening 15 of the cylinder 16, whereas the inlet opening edges are chamfered at an angle $\beta = 17°$ relative to the vertical axis of the steam injector. The body component I has the solenoid 10 between the slide bearings 2 and 5; the solenoid controls the positioning of the needle 3 with electromagnetic fields. The body components I and II feature the internal passageways 4 and 5 along the vertical plane and between the injection chamber 11 and the spring chamber 1; the internal passages equalize the pressure in the closed internal void of the body; below and within the body component I is the inlet opening 6 of the injection chamber 11 which admits steam. The upward and downward movement of the needle 3 respectively opens and closes the entry to the inlet opening 15 of the cylinder 16.

Claims

1. A method of supplying steam piston engines with ultra-supercritical steam **characterized by** that the steam is supplied via an electromagnetic steam injector with a high operating frequency and comprising the needle 3 tipped with a taper 12, where the position of the needle, dependent on the upward or downward motion, changes the annular cross-section of the gap between the seat of the inlet opening 15 of the head 14 and the taper 12 of the needle 3, where the needle 3 is operated with electromagnetic force by the solenoid 10, which in turn is operated by the driver 9 controlled by the control computer 8 according to the data output of the transducers 7, which relay the changes in the load of the steam piston engine related to the rotational speed of the crankshaft of the steam piston engine which is 25 Hz or higher, resulting in the adjustment, in real time, of the water (the steam of) dose according to the steam piston engine load.

2. A method according to claim 1 **characterized by** that the axial movement of the needle 3 which is a

result of the total of: force F1, generated by the solenoid 10, and force F2 of the spring 1, where the force F1 is a result of the changes in the electromagnetic field generated by the solenoid as an effect of the current and the frequency generated by the solenoid driver 9.

3. A method according to claim 1 **characterized by** that the surface area of the annular gap is the result of a cross-sectional differential at diameter $\phi 1$ of the inlet opening 15 and diameter $\phi 2$ of the needle 3 in the plane 13.

4. A steam injector for supplying ultra-supercritical steam to steam piston engines **characterized by** that the steam injector incorporates the body 17, which is formed by three separable and interconnected components I to III, where the body houses axially aligned internal voids or seats: of the spring 1, the void below the needle 3, and the injection chamber 11 below, whereas the needle 3 is a cylinder the bottom end of which is a taper and the needle is aligned with the central axis along the vertical plane, and the needle moves in slide bearings 2 and 5; the needle top end is held by the spring 1, which presses the needle down into the seat of the inlet opening 15 of the cylinder 16, whereas the body component I has the solenoid 10 between the slide bearings 2 and 5; the solenoid controls the positioning of the needle 3 with electromagnetic fields, and where the body components I and II feature the internal passageways 4 and 5 along the vertical plane and between the injection chamber 11 and the spring chamber 1, and below and within the body component I is the inlet opening 6 of the injection chamber 11.

5. A steam injector according to claim 2, **characterized by** that the needle 3 has the bottom end in the form of a taper with an apex angle α = 34°.

6. A steam injector according to claim 2, **characterized by** that the inlet opening 15 edges are chamfered at an angle β = 17° relative to the vertical axis of the steam injector.

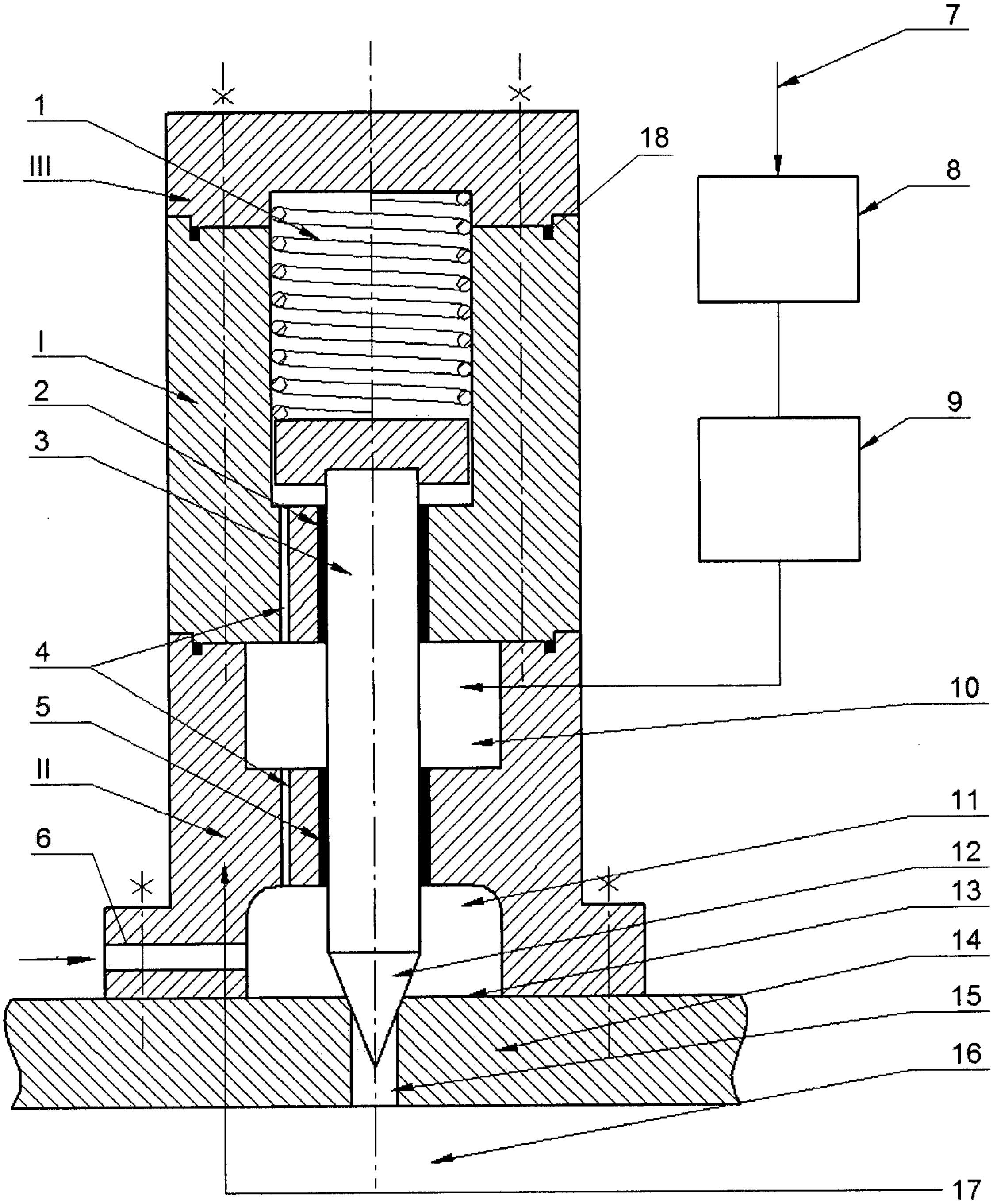

Fig.1

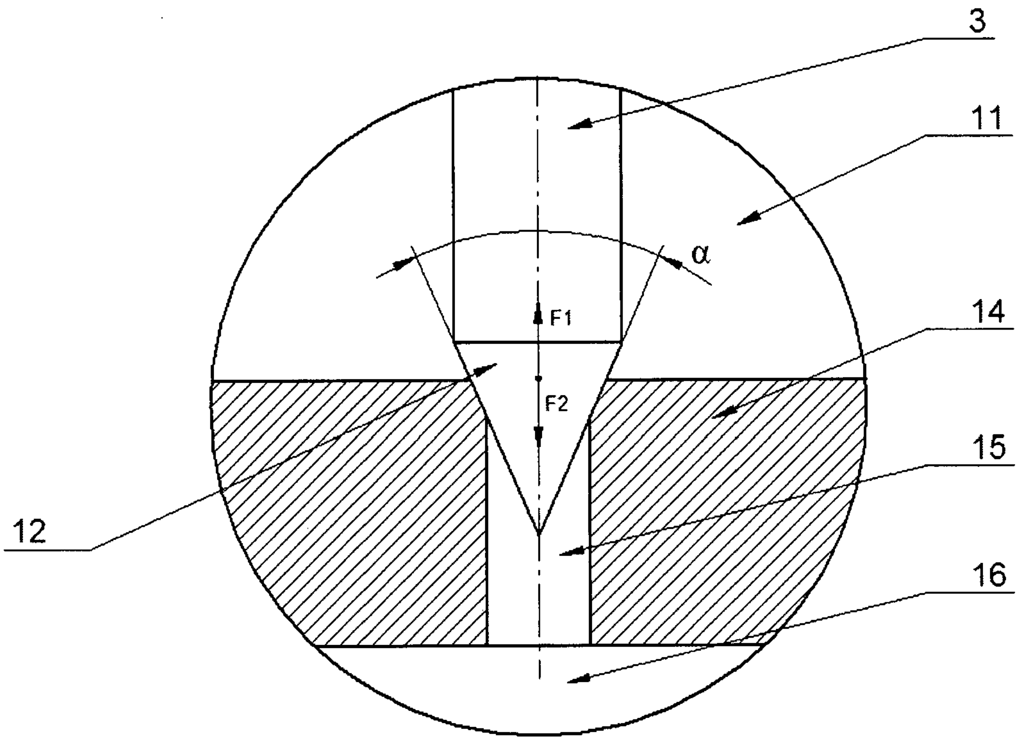

Fig.2

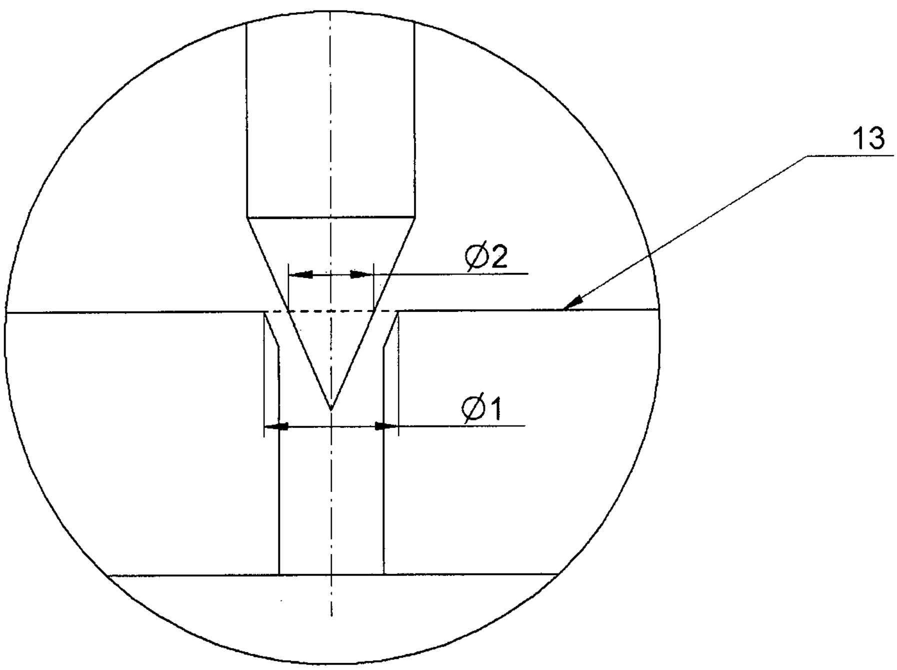

Fig.3

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EUROPEAN SEARCH REPORT

Application Number
EP 18 46 0047

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	20 March 2019	Zerf, Georges

CATEGORY OF CITED DOCUMENTS

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

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