Method and Device for Converting Thermal Energy into Kinetic Energy

The invention relates to a method for converting thermal energy into kinetic energy, whereby a medium undergoes the following changes of state in at least one chamber separated by a displacer:

- compression, preferable isothermal compression, with thermal dissipation in a compression chamber
- heat absorption, preferably isochoric heat absorption, in a regenerator during passage of the medium from a compression chamber to an expansion chamber
- expansion, preferably isothermal expansion, with heat supply in an expansion chamber and dissipation of effective work
- heat dissipation, preferably isochoric heat dissipation, in the regeneration on returning the medium to the compression chamber.

Furthermore, the invention relates to a device for implementation of the said method.

Energy cannot be "created" in the sense of new generation. Energy is present in nature in a wide variety of forms, but not every existing form of energy can be used equally for human needs. The energy contained in wood is very useful for heating purposes, for example, but is not very suitable for the generation of light or cold for the refrigerator, etc.

Although there are almost ideally available forms of energy for very specific applications, such as for example petroleum for cars, or natural gas for industrial heating, the universally applicable form of energy in the mind of humans is electric energy. However, it is virtually non-existent in nature in the form that we know.

That means that an available form of energy must first be converted into electric energy in several steps – and with varying degrees of effectiveness. If you take for example fossil sources of energy such as coal, natural gas and petroleum, which have stored the energy of the sun in chemical form for millions of years, to

generate electric energy, three conversion processes and the relevant industrial plant are necessary. First the stored chemical energy is converted into heat through combustion. The heat is used to generate high-tension steam, which is converts the heat into kinetic energy in the steam turbine. The steam turbine drives the generator in which the kinetic energy is finally converted into electric energy.

Each of these energy conversions has a specific degree of efficiency, i.e. energy is lost every time and the overall efficiency is accordingly low. For example, only some 40% of the energy stored in coal, natural gas and petroleum can be converted into electric energy. The remaining 60% are lost to use in the form of electricity as so-called waste heat.

In other conversion processes, such as e.g. the conversion of chemical energy in petroleum into kinetic energy to drive cars, ships, trains or even aircraft, the efficiency is no better either, although the conversion chain is shorter.

If you only look at the huge amounts of electricity consumed worldwide, for instance, you can see what enormous quantities of energy cannot be used and are lost. The loss of primary energy not usable for conversion into electric energy is already a major problem, especially because of the waste of limited resources, but the environmental pollution inseparably associated with the conversion of chemical energy into thermal energy through combustion is a much more serious problem for future generations, such as climate changes due to greenhouse gases, as shown by the CO_2 problem, for example.

Therefore it is not surprising that man has for decades been trying to improve and optimise the conversion processes, and also to make use of a part of the waste heat, such as e.g. in district heating. Use of a part of the waste heat from thermal power plants for heating purposes is already a significant contribution towards improving the efficiency of conversion. The efforts to convert other forms of energy, such as e.g. wind energy or solar energy, into electric energy are also producing first results.

Efforts to shorten the conversion chain by applying other conversion processes and thus to improve the overall degree of efficiency are also very promising. An interesting such conversion process has been realised in the Stirling motor. The Stirling motor can convert thermal energy directly into kinetic energy without the "detour" via steam.

After the steam engine, the Stirling motor is the second-oldest heat engine, i.e. a machine that can convert thermal energy into kinetic energy. And although the Stirling motor has a significantly higher efficiency that the steam engine and the carburettor or diesel engine on principle, it has still not become very widespread. Whereas the steam engine and the carburettor or diesel motor were constantly developed further, in order to achieve not only the satisfactory lifetime but above all the right performance with considerably improved efficiency, the Stirling motor has almost sunk into oblivion. Only recently it has started to receive more attention due to its lower environmental burden and independence of the heat source. However, a great deal of research and development is still necessary for it to achieve the same degree of "maturity" as the modern steam engine or carburettor motor in cars.

Considerable development work is still necessary, for example, to bring the efficiency of a built Stirling motor up to the efficiency of an ideal Stirling motor, which is identical to that of the Carnot process. For a possible mobile use, work will have to be invested primarily in increasing the performance and improving the dynamic behaviour during rapid load switches.

The most important advantages of the Stirling motor compared with conventional heat engines, although they still have not been realised satisfactorily due to this development deficit, are:

1. it works with any heat source, such as e.g. solar or process heat, combustion of biomass, landfill gas or other incinerable waste right down to waste, etc.;

2. continuous heat supply, i.e. combustion under optimal conditions is possible, so that the exhaust contains hardly any pollutants;
3. closed cycle – the medium does not have to be renewed constantly;
4. due to the thermodynamically favourable process, very high degrees of efficiency can generally be expected – even in the partial load range;
5. extremely smooth running and noiseless.

Currently, three different types of Stirling motor are distinguished in terms of embodiment: type α, type β and type γ. These types of Stirling motors differ primarily in terms of function principle and structural design.

The ideal Stirling process corresponds with a Carnot process and therefore has a very high degree of efficiency. In practice, however, exact implementation, i.e. an exact copy of the ideal, or rather the theoretical, process is not possible. In embodied machines a number of design-related deviations have to be accepted that have a negative effect on efficiency and performance.

In the Stirling motors designed or built to date, for instance, it has not been possible to realise either isochoric heat absorption or isochoric heat dissipation, nor isothermal compression or isothermal expansion. The main reasons for this lie primarily in the inevitable clearance volumes and the continuous instead of discontinuous volume change. Piston and displacer are moved by means of crank drives with flywheels, so that although there is a reversal of motion at the dead centres, there is no short standstill as required by the theoretical process.

The three types, the α, β, and γ motors, correspond with the three basic design solutions developed to date in order to imitate the ideal Stirling process as well as possible in the embodied machines.

In the α motor, two pistons in separate cylinders are used, whereby one piston is arranged in the hot expansion chamber and the other is in the cold compression chamber. Depending on the step or crankshaft angle, both pistons are either working pistons and then again displacers.

The big disadvantage of α motors is the piston packing in the hot expansion chamber, which greatly limits the lifetime of the motor and for which a satisfactory solution has not been found to date. Another disadvantage is the crank drive with the associated major deviation from the theoretical process and the low degree of efficiency.

So far, a number of different cylinder arrangements have been developed, such as parallel, aligned opposite, parallel opposite, V cylinders or the Finkelstein rotation cylinder, etc., which all function in the same way, have the same weaknesses and the same low degree of efficiency.

In the β machine, a piston and displacer are used, whereby both piston and displacer are arranged in the same cylinder. For the complicated motion of piston and displacer, which depending on cycle move towards each other, then again in the same direction, for example towards the crankshaft, or one is or should be at a standstill while the other is moving, complex gears such as e.g. rhombic gears are required.

The major disadvantage of β machines, similar to the α machines, is seals running dry. Furthermore the motion of piston and displacer, which acts like a crank drive despite complex gears, and therefore has dead centres with reversal of motion, but no real standstill. In the β type, the degree of efficiency actually achieved by embodied Stirling motors is far removed from the efficiency of the ideal Stirling process.

Another major disadvantage of the β machines is the complex sealing system of the displacer slide rod in the compression piston. Because piston and displacer are arranged in the same cylinder, the displacer slide rod runs through the compression piston.

A number of different embodiments of the β machines have been developed to date, such as e.g. Rankine-Napie or Philips, without being able to influence the disadvantages of the β machine.

In the γ machine, piston and displacer are arranged in separate cylinders. This avoids the complex sealing system for the displacer slide rod in the compression piston. In return, the dead volume detrimental to efficiency is increased.

The greatest disadvantages of γ machines, as already described for α and β machines, are the dry seals of the working piston. Moreover, the motion of piston and displacer caused by the crankshaft drive or crank-like drive, which makes a good approximation to the ideal Stirling process impossible in the embodied machines. Therefore, the γ machine also has a significantly poorer efficiency than the ideal Stirling process.

Another major disadvantage of γ machines is the greater dead volume, which has an additional negative impact on efficiency, and the relatively low compression ratio that can be achieved, so that only modest volume performance is possible.

In addition to the single-action machines described, double-action Stirling machines have also been developed and embodied, especially of the α type, for example the Franchot Stirling motor. In this motor, a Stirling process takes place in the space above the two pistons, but also below each piston, i.e. the two cylinders always perform two different cycles of two different Stirling processes at the same time with the top and bottom of the pistons. Thereby, the two pistons and their cylinders delimit four variable volumes, which can be regarded as pairs constituting two separate α machines. Like in single-action α machines, the expansion piston and the compression piston must have a phase displacement of about 90°.

The efficiency of double-action α machines such as the Franchot Stirling motor is not better than that of single-action α machines. The serious disadvantages and

problems are also the same. Merely the volume performance can be improved through compactness.

The Siemens Stirling motor is also known, which embodies the standard configuration of most stronger Stirling motors with any number of cylinders, such as e.g. the 4-95' of United Stirling with a mechanical capacity of approx. 52 kW. In this embodiment, a number of models have also been developed, such as e.g. arrangement of the cylinders in a row, in a "U" or "V" shape, in a rectangle or in a circle. Although the arrangement of heater, regenerator and cooler in the Siemens Stirling motor was chosen in such a way that the piston sealing in the casing is located in the cold section, the basic disadvantages of the α machines remain.

Attempts to embody the principle of the Stirling motor with free piston arrangements or as a circular piston motor, system Wankel, are also known. None of these embodiments has resulted in an improvement of efficiency; on the contrary, in addition to poorer efficiency compared with the α machines, the disadvantages and problems were only enhanced.

All these various embodiments of Stirling motors have the additional disadvantages due to the clearance volumes in heat exchangers, regenerators and return-flow pipes in common, which additionally lower the pressure ratio and thus the efficiency.

The aim of the invention is to create a method of the type set out above, that on the one hand avoids the above disadvantages and on the other hand makes it possible for the first time to embody a Stirling motor in such a way that its mode of action can be approximated to the ideal Stirling process much better than before. Said object is fulfilled by the invention.

The method according to the invention is characterised by the fact that the medium flows back and forth between at least two enclosed chambers, whereby to release effective work the medium is guided through a machine between the chambers, whereby heat absorption takes places before the machine and heat

dissipation takes place after the machine, and that the medium is compressed in the chamber after heat dissipation, and that by means of a displacer it subsequently flows from one side through the regenerator to the other side of the displacer, whereby the flow of the medium is controlled using control units, in particular valves, and every displacer is moved by a drive. With this invention it is for the first time possible to achieve a significantly higher efficiency than with any other embodiments of Stirling motors to date.

The higher efficiency is due primarily to the better approximation of the work process described to the theoretical cycle process, which is achieved with the method of the invention. Due to the temperature difference of the medium in the two coupled chambers and the resulting pressure differentials, it flows into the cold chamber and thereby performs work through a work machine. The resulting compensation state is due to the fact that the greater part of the medium is in the cold chamber. In the subsequent isochoric regenerator cycle, with heat supply, the pressure differential builds up inversely between the two chambers and is again converted into work through the work machine. This behaviour is in analogy to an oscillating circuit and with a constant Carnot efficiency it makes a higher power density with reference to the volume of medium possible than in the theoretical, ideal Stirling process.

In a special embodiment of the invention, the chamber is separated into a double-action chamber by the displacer. Thus, the process can be speeded up, since return-flow pipes are not required. Moreover, seals against any buffer space otherwise required are dispensed with.

In accordance with a special feature of the invention, each displacer is moved by a separate drive. In accordance with this feature of the invention, there are no crank drives or crank-like drives, which are mainly responsible for the poor approximation of the embodied processes to the ideal Stirling process. Instead of the crank drives, a linear drive is used that can be controlled independently from other movements, so that any number of standstill times of any length can be achieved in the displaces for example.

In accordance with another embodiment of the invention, the displacers in the coupled chambers are moved by a drive via a rigid connection. This allows for a simple design, whereby for example two hot and two cold chambers are coupled with each other. This allows complete immersion of the hot-hot chambers in the heat source, and immersion of the cold-cold chambers in the cold source, without suffering losses through heat conduction between warm and cold source medium. The two displacers are connected by a rigid slide rod that absorbs the forces acting between the displacers. To move the displacers, only the frictional drag and flow losses have to be overcome. The regenerators may also be located within or outside the slide rod. The slide rod itself does not have to be sealed off. The theoretical power density with reference to the volume of medium is higher than in the ideal Stirling process. This embodiment allows the use of low temperature for power generation and for the generation of cold.

In accordance with a special embodiment of the invention, the chamber is divided by the displacer into an expansion chamber and a compression chamber, whereby the medium used for effective work, after exiting the expansion chamber through the regenerator allocated to this chamber for dissipation of effective work through the work machine and after the work machine, possibly with output of cold, flows into the compression chamber of the coupled chamber and then through movement of the displacer flows from the compression side through the regenerator allocated to this chamber into the expansion chamber of the same chamber. This embodiment is the so-called "cold" motor. The work machine can be designed very simply, since it is not subjected to high temperature stress. Additionally, cold can be generated through expansion of the cold medium cooled by the generator, which can be utilised before flowing into the cold workspace through a heat exchanger. The efficiency and power density is higher than in a Stirling motor of type γ that has the piston flanged onto the cold side.

In accordance with another embodiment of the invention, the chamber is separated by the displacer into an expansion chamber and a compression chamber, whereby the medium used for effective work, after exiting the expansion

chamber for dissipation of effective work, possibly through a heater, flows through the work machine and subsequently through the regenerator and possibly through a compressor, possibly through an additional cooler, into the compression chamber of the coupled chamber, and subsequently through movement of the displacer flows from the compression side through the regenerator allocated to this chamber into the expansion chamber of the same chamber. This embodiment is the so-called "hot" motor. The theoretical efficiency of this type is close to that of the Carnot efficiency, the theoretical power density with reference to the volume of the medium is higher than in the ideal Stirling process.

In accordance with yet another embodiment of the invention, the chamber is divided by the displacer into two expansion chambers and compression chambers each, whereby the medium used for effective work, after exiting an expansion chamber through the regenerator allocated to this chamber for dissipation of effective work through the work machine and after the work machine flows into the compression chamber of the coupled chamber and then through movement of the displacer flows from the compression side through the regenerator allocated to this chamber into the other expansion chamber of the same chamber. As already mentioned, this "low temperature" motor allows low temperature to be utilised both for power generation and for the generation of cold.

In accordance with another special embodiment of the invention, heat absorption is isobaric, in particular immediately before the work machine. The major advantage must be seen in the fact that the temperature in the displacers is limited to the maximum regenerator temperature, whereby the regenerator temperature is lower than the heater temperature.

In accordance with an advantageous embodiment of the invention, compression is achieved by pressure equalisation and/or by a compressor. If compression is to be achieved solely by means of pressure equalisation, one rotating machine, i.e. the compressor, can be dispensed with. This certainly makes the process simpler. If a compressor is integrated, an even higher efficiency is achieved.

It is also an object of the invention, however, to provide a device for implementation of the said method.

The device for implementation of the method in accordance with the invention is characterised by the fact that at least two enclosed chambers are provided, whereby each chamber is divided into two sections by a displacer which can be moved by a drive, whereby one section contains a heater and the other section a cooler, and each chamber has a regenerator allocated to it, whereby both sections are connected to this regenerator, and that at least one section of each chamber is connected to a work machine, whereby the section used for subsequent dissipation of effective work is connected to the corresponding section of the other chamber, and that control units, in particular valves, are provided to control the medium. As already mentioned above, a higher power density is achieved with the device in accordance with the invention.

Another advantage of the device in accordance with the invention must be seen in the fact that the machine can be operated with a low clock speed. The chambers have no real piston seals and thus circumvent the sealing problem, which occurs particularly at greater piston volumes. By eliminating this problem, large-volume chambers can be used, which can be operated at low clock speeds and discontinuously. Thus, an approximation to the ideal Stirling process is achieved.

With the lower clock speed and thus longer heat transition time than in conventional Stirling motors, isothermal processes can be realised better. The large heat transition surfaces in the chambers accommodate the use of biomass fuels.

Another advantage is found in minimisation of the clearance volume. The clearance volume is the volume not involved in the thermodynamic process, which as a result has a detrimental effect on efficiency. It is produced virtually through sinus movement of the piston, and in real terms by the volume of the regenerator, the heater pipe, etc., through which the medium flows. The ratio of large-volume chambers and by comparison small-volume elements such as work machine,

regenerator, heater and cooler results in a favourable ratio between clearance volume and work volume, and is a significantly lower than that of the machines currently embodied.

The minimisation of drive forces is also advantageous. They are made up of the flow resistance of pressing the medium through between the chambers isochorically, activating the valves, and possibly compression of the medium by a compressor. One of the main components, friction of the dry-running piston sealing rings together with friction of the crank drive, is eliminated.

In summary it can therefore be said that through the elimination of moving seals that are under temperature stress and run dry, which were the main problem to date, it is possible to produce this motor in standard mechanical engineering. The separation of chamber and work machine allows the use of standard machine elements. Due to the rapidly rotating work machine, the generator has a smaller rated size. Elimination of the mechanical drive unit also simplifies the design. The displacer does not have to be synchronised with the work machine, the optimal work points can be set separately from each other.

In accordance with a special feature of the invention, at least one control unit, in particular a valve, is provided in the connections between the work machine and the individual sections. It serves to uncouple the work cycle and the regenerator cycle. Instead of control via valves, slit control could also be used.

In accordance with another special feature of the invention, four, six or more even-numbered chambers are provided, whereby the chambers are always coupled in pairs. With the increasing number of coupled chairs, the process-related waviness at the work machine is reduced and the regenerator cycle can be extended by comparison with the work cycle.

In accordance with a very special feature of the invention, the work machine is a turbine, in particular an axial, radial or Tesla turbine. The use of turbines allows the elimination of moving seals subject to temperature stress and running dry, which are the main problem in Stirling motors driven by pistons. With the disk or

Tesla turbine, in particular, better isothermal expansion or compression is possible.

In accordance with one embodiment of the invention, the work machine is a piston motor. This embodiment has the advantage that it is cheap and can be build using standard components.

In accordance with a further embodiment of the invention, the work machine is a screw motor. Like the turbines, the screw motor has the advantage of eliminating seals.

In accordance with a special embodiment of the invention, the drive for the displacer is a linear drive. The linear drive guarantees accurately controllable acceleration and braking of the displacer. This makes discontinuous movement in accordance with the ideal thermodynamic process possible with low losses. All passages and thus seals for rods or crank drive can thus be eliminated. A possible rapid power control is possible instantaneously by changing the displacer clock speed and does not have to be induced by changing the upper temperature. Thus, very good control is possible in the partial load range.

In accordance with another feature of the invention, a heater is included upstream and/or downstream from the regenerator. The heater supplies energy to the medium in addition to the heater head in the chamber, thus enlarging the total absorption surface in the hot area.

A special embodiment of the invention is characterised by the fact that the chamber is divided by the displacer into an expansion chamber and a compression chamber, that the expansion chamber is connected to the regenerator allocated to this chamber and the regenerator is connected to the work machine, that the outflow side of the work machine is connected to the compression chamber of the coupled other chamber, and this compression chamber is connected to the expansion chamber of the same chamber by the regenerator allocated to this chamber, whereby one control unit each, in particular

a valve, is provided between regenerator and inflow side of the work machine, and outflow side of the work machine and compression chamber. Here the same advantages apply accordingly, as already described above for the "cold" motor.

Another special embodiment of the invention is characterised by the fact that the chamber is divided by the displacer into an expansion chamber and a compression chamber, that the expansion chamber is connected to the inflow side of the work machine and the outflow side of the work machine is connected to the compression chamber of the coupled other chamber through the regenerator and possibly through a compressor, and this compression chamber is connected to the expansion chamber of the same chamber through the regenerator allocated to this chamber, whereby one control unit each, in particular a valve, is provided between expansion chamber and inflow side of the work machine, and outflow side of the regenerator and compression chamber. Here the same advantages apply accordingly, as already described above for the "hot" motor.

An alternative embodiment of the invention is characterised by the fact that the chamber is divided by the displacer into two expansion chambers and two compression chambers, that each expansion chamber is connected to the inflow side of the work machine through a regenerator and the outflow side of the work machine is connected to the compression chamber of the coupled other chamber, and this compression chamber is connected to the expansion chamber of the other chamber through a regenerator, whereby one control unit each, in particular a valve, is provided between the regenerator downstream from the expansion chamber and the inflow side of the work machine, and the outflow side of the work machine and the compression chamber. Here the same advantages apply accordingly, as already described above for the "low-temperature" motor.

Naturally, the hot gasses could also be expanded, in accordance with the work principle of the hot motor.

Another embodiment of the invention is characterised by the fact that a heater is provided in flow direction after the section connected to the work machine. This

allows the work machine to achieve higher temperatures, which result in a better power yield.

In accordance with an advantageous embodiment of the invention, the heater is locally separated from the section, for example in the combustion chamber of a heating boiler. Thus, only the elements used as heater are subject to highest temperature stress, so that only these parts have to be dimensioned accordingly.

The invention is explained in more detail based on the design examples illustrated in the figure.

The figures show:

Fig. 1 the device for transformation of thermal energy into kinetic energy as a hot motor,

Fig. 2 the device as a cold motor,

Fig. 3 the device as a low-temperature motor,

Fig. 4 an embodiment of the device with locally separated heaters, and

Fig. 5 schematics of the mode of action of a device.

By way of introduction, it is noted that in the described embodiment the same parts and the same states are allocated the same reference numbers and the same component names, whereby the disclosures contained throughout the description can be applied by analogy to the same parts and the same states with the same reference numbers or same component names.

As shown in Fig. 1, the device using a medium for conversion of thermal energy into kinetic energy has two enclosed chambers 1, 2, whereby each chamber 1, 2 is divided by a movable displacer 3, 4 into two sections, namely an expansion

chamber and a compression chamber. Each displacer 3, 4 can be moved by a drive, in particular by a linear drive 5. Each chamber 1, 2 has a regenerator 6, 7 allocated to it. Both sections of the chamber 1 resp. 2 are connected to this regenerator 6 resp. 7 by pipes 8, 9 resp. 10, 11.

One section – the expansion chamber in this case – of each chamber 1 resp. 2 is connected to a work machine 12. The expansion chamber of chamber 1 used for dissipation of effective work is connected to the corresponding section – i.e. the compression chamber – of chamber 2 after the work machine 12.

To control the medium control units, in particular valves 13, are provided, which are arranged between the work machine 12 and the individual sections of the chamber 1 resp. 2. Slit control could also be used instead of the valves 13.

As the work machine 12, a turbine, in particular an axial or radial turbine, can be used. Naturally, a piston or screw motor is also possible as work machine 12. The work machine 12 is connected to the generator 18 by a shaft 17.

In the ideal process, the medium undergoes the following changes of state:

- isothermal compression with thermal dissipation in a compression chamber
- isochoric heat absorption in a regenerator 6 resp. 7 during transition of the medium from the compression chamber to the expansion chamber
- isothermal expansion with heat supply in an expansion chamber and dissipation of effective work
- isochoric heat dissipation in the regenerator 6 resp. 7 during return flow into the compression chamber.

Generally, it can be shown that the medium flows back and forth between the two double-action enclosed chambers 1, 2. To release effective work, the medium is guided through a work machine 12 between the chambers 1, 2. Subsequently, the medium flows in the double-action chamber 1, 2 by means of the displacer 3 resp. 4 from one side through the regenerator 6 resp. 7 to the other side of the displacer

3 resp. 4, whereby the flow of medium is controlled via the valves 13 and each displacer 3, 4 is moved by a drive 5.

As already mentioned, Fig. 1 shows the device, also referred to as 4-quadrant turbine, as a "hot" motor, since the medium is guided through the work machine 12 in its highest temperature state. The expansion chamber is connected to the inflow side of the work machine 12 and the outflow side of the work machine 12 is connected to the regenerator 6 resp. 7 and through a compressor 19 to the compression chamber of the coupled other chamber 2. This compression chamber is connected to through the regenerator 7 allocated to this chamber 2 with the expansion chamber of the same chamber 2, whereby one valve 13 each is provided between the expansion chamber and the inflow side of the work machine 12, and the outflow side of the regenerator 7 and the compression chamber.

The regenerator 6 resp. 7 consists of a heater 14, a coupled regenerator 15, and a cooler 16, whereby the expansion chamber is connected to the heater 14 and the compression chamber is connected to the cooler 16. Moreover, the regenerator 6 resp. 7 is divided vertically into individual sectors. These sectors are sealed off against each other. In the inner sectors the medium flows from the work machine 12 to the compressor 19, and the outer sectors serve for the regenerator cycle of the medium.

The expansion chamber is connected to the heater 14 of the regenerator 6 allocated to this chamber 1, and the regenerator 6 is connected to the work machine 12. The outflow side of the work machine 12 is connected through the cooler 16 with the compression chamber of the coupled other chamber 2, and this compression chamber is connected through the regenerator 7 allocated to this chamber 2 with the expansion chamber of the same chamber 2. A valve 13 each is provided between the regenerator 6 resp. 7 and the inflow side of the work machine 12, and the outflow side of the work machine 12 resp. compressor 19 and the compression chamber.

Fig. 2 shows the 4-quadrant turbine as a "cold" motor. The chamber 1, 2 is again divided by the displacer 3, 4 into an expansion chamber and a compression chamber.

In this case, the medium used for efficient work, after exiting the expansion chamber, flows through the regenerator 6 allocated to this chamber 1 to release effective work through the work machine 12, and after the work machine 12 into the compression chamber of the coupled chamber 2. Subsequently, the medium, through movement of the displacer 4, flows from the compression side through the regenerator 7 allocated to this chamber 2 into the expansion chamber of the same chamber 2.

Fig. 3 shows the device as a low-temperature motor. Thereby, the displacer 3, 4 is moved in a rigid connection 20 by a drive 5. The chamber 1, 2 is divided by the displacer 3, 4 into two expansion chambers and two compression chambers each. Each expansion chamber in chamber 1 is connected through a regenerator 6, 7 with the inflow side of the work machine 12, and the outflow side of the work machine 12 with the compression chamber of the coupled other chamber 2. This compression chamber is connected through the regenerators 6 resp. 7 with the expansion chamber of the other chamber 1, whereby one valve 13 each is provided between the regenerator 6 resp. 7 downstream from the expansion chamber and the inflow side of the work machine 12, and the outflow side of the work machine 12 and the compression chamber.

The medium used for efficient work, after exiting an expansion chamber, flows through the regenerator 6 resp. 7 allocated to this chamber 1 to release effective work through the work machine 12, and after the work machine 12 into the compression chamber of the coupled chamber 2. Subsequently, the medium, through movement of the displacer 3 resp. 4, flows from the compression side through the regenerator 6 resp. 7 allocated to this chamber 2 into the expansion chamber of chamber 1.

To cool chamber 2, it can be arranged under the earth for example.

Moreover the displacers 3 resp. 4 can also be designed as coupled membranes.

In Fig. 4, each chamber 1, 2 is divided by the displacer 3, 4 into one expansion chamber and one compression chamber. Each displacer 3, 4 can be moved by a drive, in particular by a linear drive 5. Moreover, each displacer 3, 4 is arranged in a guide 22. Each chamber 1, 2 has a regenerator 6, 7 allocated to it. Both sections of the chamber 1 resp. 2 are connected to this regenerator 6 resp. 7 by pipes.

Moreover the expansion chamber is equipped with an intermediate heater 21. This intermediate heater 21 can be designed as a layered intermediate heater 21 or in the form of lamella packages. The compression chamber is equipped with a cooler 16.

The expansion chamber can possibly be connected through the intermediate heater 21 to a locally separated heater 14. The heater 14 could be arranged in a heating boiler. Isobar heating takes place in this heater 14. The medium flows from heater 14 through the work machine 12. The work machine 12, preferably a Tesla turbine, is coupled to generator 18 by a direct shaft 17.

The process is illustrated once more in summary. The compressed medium flows from the compression chamber of chamber 1 through the allocated regenerator 6 and intermediate heater 21 into the expansion chamber of the same chamber 1 and is thereby heated isochorically. The passage is actuated by movement of the displacer 3. After exiting the expansion chamber of chamber 1, the medium flows through the external heater 14, in which isobaric heat absorption takes place, to the work machine 12.

From the work machine 12, the medium flows through the regenerator 7 and the cooler 16 into the compression chamber of chamber 2 and is compressed isothermally by subsequent flow or by a compressor. The compression heat is dissipated in cooler 16 of chamber 2. Through movement of the displacer 4 in

chamber 2, the compressed medium is passed through the regenerator 7 and the intermediate heater 21 into the expansion chamber of chamber 2.

After exiting the expansion chamber of chamber 2, the medium flows through the external heater 14, in which isobaric heat absorption takes place, to work machine 12. From work machine 12, the medium flows back to the compression chamber of chamber 1.

In principle, the medium flows in a figure of eight, whereby the work machine 12 is provided as the centre. The individual process steps are controlled by the relevant valves – not shown.

Fig. 5 describes the mode of action of the device with valve control based on a real example. In chamber 1 with displacer 3, the medium has a temperature To of 530°C and a pressure Po of 30 bar. In chamber 2 with displacer 4, the temperature Pu is 30°C and the pressure Pu is 10 bar. Due to the pressure differential created in the displacer cycle between chamber 1 and chamber 2, valve 23 and valve 24 opens in flow direction. The hot medium with a temperature of 530°C flows out of chamber 1 through valve 23 into the heater, where it is overheated to 630°C and then returned to 530°C through polytropic relief in the work machine 12. Subsequently, the medium flows through valve 24, the regenerator 7, where it is cooled to 60°C, the cooler 16, where it is cooled to 30°C, to chamber 2. The valves 25 and 26 block the pressure differential and are not opened until after the subsequent regenerator cycle, i.e. in the next work cycle.

The regenerator cycle starts after the work cycle has produced pressure equalisation between the chambers 1,2; i.e. the pressure is the same throughout the system (mean pressure). The displacers 3, 4 now move into the opposite dead centre positions and thereby displace the medium through the regenerator-cooler unit to the other side of each displacer 3, 4. The isochoric heating resp. cooling of the medium that takes place thereby effects a change of pressure in the relevant chamber 1, 2; i.e. when cold is passed into hot, a pressure increase is effected, when hot is passed into cold a pressure reduction is effected. The regenerator

cycle is thus ended and the pressure differential used for the subsequent work cycle.

In conclusion, it must be pointed out that for better legibility the individual components and assemblies in the drawing are not shown proportionally or to scale.

PATENT CLAIMS

1. Method for converting thermal energy into kinetic energy, whereby a medium undergoes the following changes of state in at least one chamber separated by a displacer:
   - compression, preferable isothermal compression, with thermal dissipation in a compression chamber
   - heat absorption, preferably isochoric heat absorption, in a regenerator during passage of the medium from a compression chamber to an expansion chamber
   - expansion, preferably isothermal expansion, with heat supply in an expansion chamber and dissipation of effective work
   - heat dissipation, preferably isochoric heat dissipation, in the regeneration on returning the medium to the compression chamber.

   characterised by the fact that the medium flows back and forth between at least two enclosed chambers (1, 2), whereby to release effective work the medium is guided through a machine (12) between the chambers (1, 2), whereby heat absorption takes places before the machine (12) and heat dissipation takes place after the machine (12), and that the medium is compressed in the chamber (1, 2) after heat dissipation, and that by means of a displacer (3, 4) it subsequently flows from one side through the regenerator (6, 7) to the other side of the displacer (3, 4), whereby the flow of the medium is controlled using control units, in particular valves (13, 23, 24, 25, 26), and every displacer (3, 4) is moved by a drive (5).

2. Method in accordance with Claim 1, characterised by the fact that the chamber (1, 2) is divided by the displacer (3, 4) into a double-action chamber (1, 2).

3. Method in accordance with Claim 1 or 2, characterised by the fact that each displacer (3, 4) is moved by a separate drive (5).

4. Method in accordance with Claim 1 or 2, characterised by the fact that the displacer (3, 4) of the coupled chambers (1, 2) are moved via a rigid connection (20) by a drive.

5. Method in accordance with one or more of Claims 1 to 4, characterised by the fact that the chamber (1 resp. 2) is divided by the displacer (3 resp. 4) into one expansion chamber and one compression chamber, whereby the medium used for effective work, after exiting the expansion chamber, flows through the regenerator (6 resp. 7) allocated to this chamber (1 resp. 2) to release effective work through the work machine (12), and after the work machine (12), possibly with output of cold, flows into the compression chamber of the coupled chamber (1 resp. 2) and then through movement of the displacer (3 resp. 4) flows from the compression side through the regenerator (6 resp. 7) allocated to this chamber (1 resp. 2) into the expansion chamber of the same chamber (1 resp. 2).

6. Method in accordance with one or more of Claims 1 to 4, characterised by the fact that the chamber (1 resp. 2) is divided by the displacer (3 resp. 4) into one expansion chamber and one compression chamber, whereby the medium used for effective work, after exiting the expansion chamber for dissipation of effective work, possibly through a heater (14), flows through the work machine (12) and subsequently through the regenerator (6 resp. 7) and possibly through a compressor (19), possibly through an additional cooler (16), into the compression chamber of the coupled chamber (1 resp. 2), and subsequently through movement of the displacer (3 resp. 4) flows from the compression side through the regenerator (6 resp. 7) allocated to this chamber (1 resp. 2) into the expansion chamber of the same chamber (1 resp. 2).

7. Method in accordance with one or more of Claims 1 to 4, characterised by the fact that the chamber (1 resp. 2) is divided by the displacer (3 resp. 4) into two expansion chambers and compression chambers each, whereby the medium used for effective work, after exiting an expansion chamber through

the regenerator (6 resp. 7) allocated to this chamber (1 resp. 2) for dissipation of effective work through the work machine (12) and after the work machine (12) flows into the compression chamber of the coupled chamber (1 resp. 2) and then through movement of the displacer (3 resp. 4) flows from the compression side through the regenerator (6 resp. 7) allocated to this chamber (1 resp. 2) into the other expansion chamber of the same chamber (1 resp. 2).

8. Method in accordance with on or more of Claims 1 to 4 or x, y, characterised by the fact that there is isobaric heat absorption, in particular immediately before the work machine (12).

9. Method in accordance with on or more of Claims 1 to 4 or x, y, characterised by the fact that there is compression by means of pressure equalisation and/or a compressor.

10. Device for implementation of the method in accordance with one or more of Claims 1 to 9, characterised by the fact that at least two enclosed chambers (1, 2) are provided, whereby each chamber (1, 2) is divided into two sections by a displacer (3, 4) which can be moved by a drive (5), whereby one section contains a heater (14) and the other section a cooler (16), and each chamber (1, 2) has a regenerator (6, 7) allocated to it, whereby both sections are connected to this regenerator (6, 7), and that at least one section of each chamber (1, 2) is connected to a work machine (12), whereby the section used for subsequent dissipation of effective work is connected to the corresponding section of the other chamber (1, 2), and that control units, in particular valves (13, 23, 24, 25, 26), are provided to control the medium.

11. Device in accordance with Claim 10, characterised by the fact that at least one control unit, in particular a valve (13, 23, 24, 25, 26) is provided in the connections between the work machine (12) and the individual sections.

12. Device in accordance with Claim 10 or 11, characterised by the fact that four, six or more even-numbered chambers (1, 2) are provided, whereby the chambers (1, 2) are always coupled in pairs.

13. Device in accordance with one or more of Claims 10 to 12, characterised by the fact that the work machine (12) is a turbine, in particular an axial, radial or Tesla turbine.

14. Device in accordance with one or more of Claims 10 to 12, characterised by the fact that the work machine (12) is a piston motor.

15. Device in accordance with one or more of Claims 10 to 12, characterised by the fact that the work machine (12) is a screw motor.

16. Device in accordance with one or more of Claims 10 to 15, characterised by the fact that the drive (5) for the displacer is a linear drive.

17. Device in accordance with one or more of Claims 10 to 16, characterised by the fact that there is a heater (14) upstream and/or a cooler (16) downstream from the regenerator (6, 7).

18. Device in accordance with one or more of Claims 10 to 17, characterised by the fact that the chamber (1, 2) is divided by the displacer (3, 4) into an expansion chamber and a compression chamber, that the expansion chamber is connected to the regenerator (6, 7) allocated to this chamber (1, 2), and the regenerator (6, 7) is connected to the work machine (12), that the outflow side of the work machine (12) is connected to the compression chamber of the coupled other chamber (1, 2) and this compression chamber is connected through the regenerator (6, 7) allocated to this chamber (1, 2) to expansion chamber of the same chamber (1, 2), whereby a control unit each, preferably a valve (13, 23, 24, 25, 26) is provided between the regenerator (6, 7) and the inflow side of the work machine (12), and the outflow side of the work machine (12) and the compression chamber.

19. Device in accordance with one or more of Claims 10 to 17, characterised by the fact that the chamber (1, 2) is divided by the displacer (3, 4) into an expansion chamber and a compression chamber, that the expansion chamber is connected to the inflow side of the work machine (12) and the outflow side of the work machine (12) is connected through the regenerator (6, 7) and possible through a compressor (19) to the compression chamber of the coupled other chamber (1, 2) and this compression chamber is connected through the regenerator (6, 7) allocated to this chamber (1, 2) to expansion chamber of the same chamber (1, 2), whereby a control unit each, preferably a valve (13, 23, 24, 25, 26) is provided between the expansion chamber and the inflow side of the work machine (12), and the outflow side of the regenerator (6, 7) and the compression chamber.

20. Device in accordance with one or more of Claims 10 to 17, characterised by the fact that the chamber (1 resp. 2) is divided by the displacer (3 resp. 4) into two expansion chambers and two compression chambers, that each expansion chamber is connected to the inflow side of the work machine (12) through a regenerator (6 resp. 7) and the outflow side of the work machine (12) is connected to the compression chamber of the coupled other chamber (1 resp. 2), and this compression chamber is connected to the expansion chamber of the other chamber (1 resp. 2) through a regenerator (6 resp. 7), whereby one control unit each, in particular a valve (13, 23, 24, 25, 26), is provided between the regenerator (6 resp. 7) downstream from the expansion chamber and the inflow side of the work machine (12), and the outflow side of the work machine (12) and the compression chamber.

21. Device in accordance with one or more of Claims 10 to 17, characterised by the fact that a heater (14) is arranged in flow direction after the section connected to the work machine (12).

22. Device in accordance with Claim 21, characterised by the fact that the heater (14) is arranged locally separate from the section, for example in the combustion chamber of a heating boiler.

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