

Dec. 29, 1936.

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2,066,151

RECIPROCATING STEAM ENGINE

Filed July 16, 1934

3 Sheets-Sheet 1

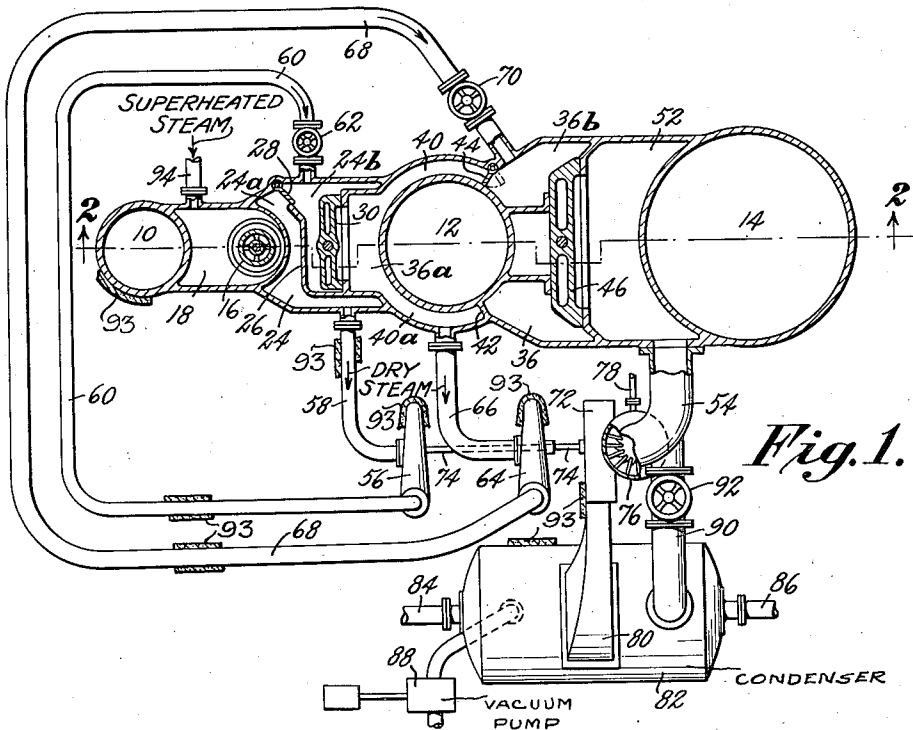
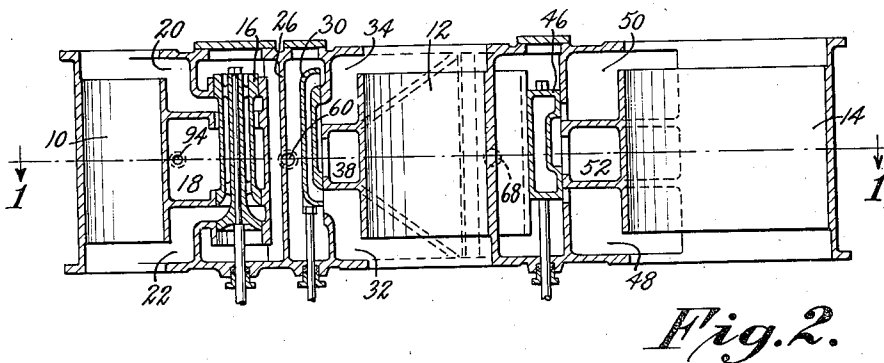
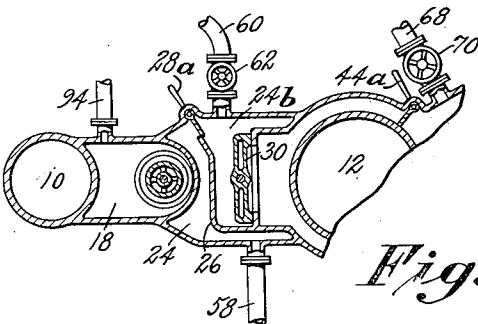


Fig. 3.

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3 Sheets-Sheet 2

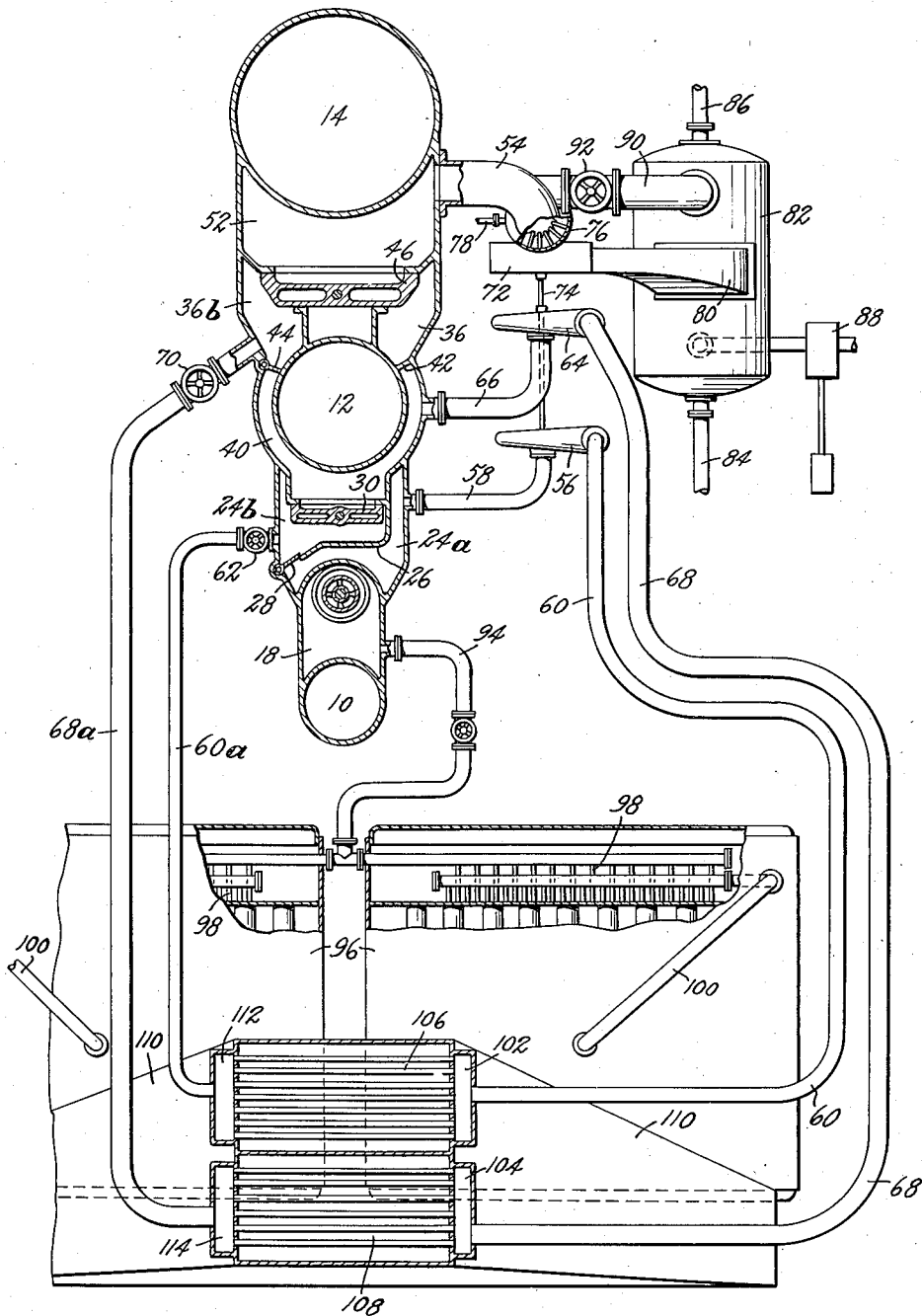


Fig. 4.

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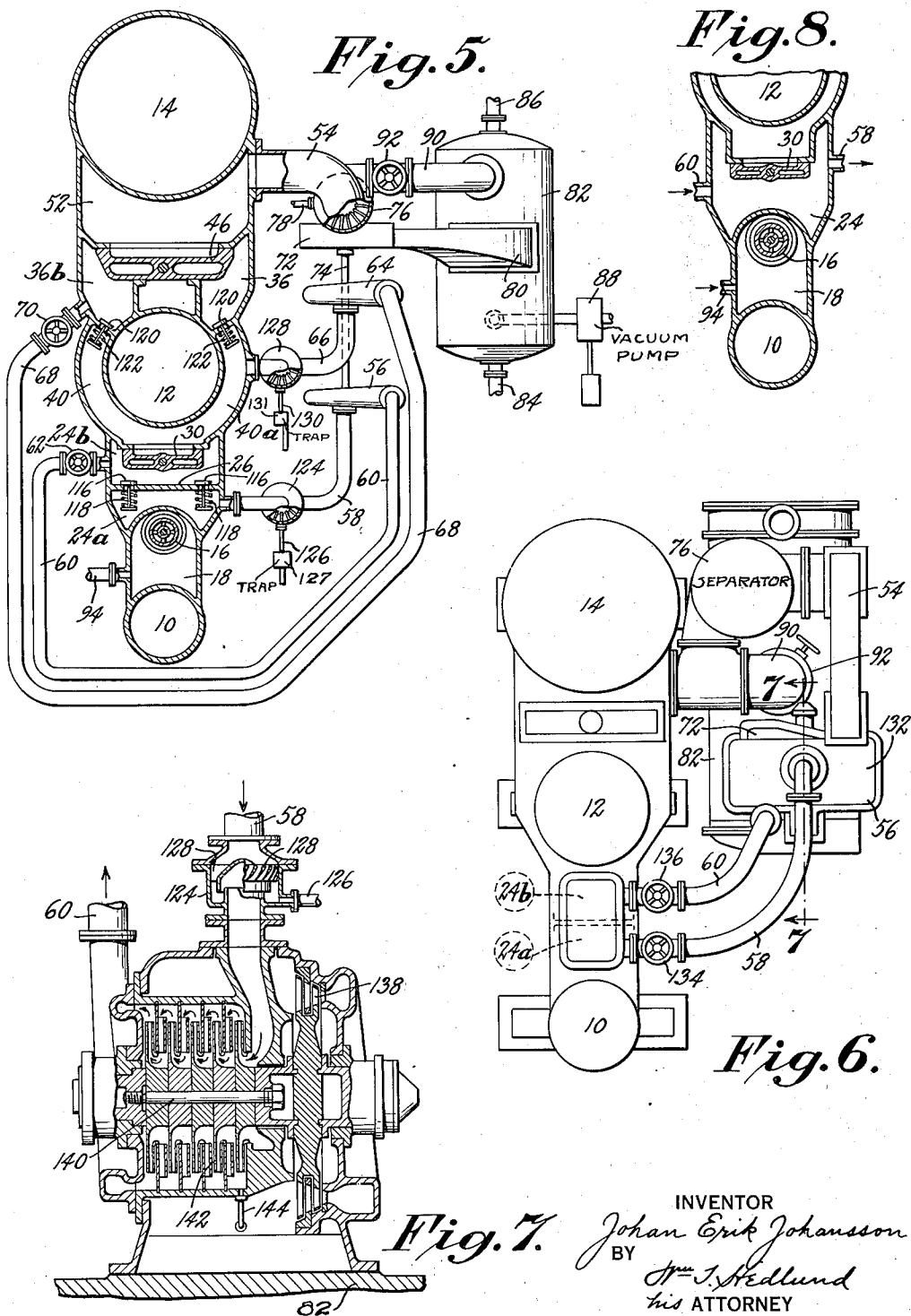
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3 Sheets-Sheet 3



UNITED STATES PATENT OFFICE

2,066,151

RECIPROCATING STEAM ENGINE

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Application July 16, 1934, Serial No. 735,313
In Sweden January 16, 1930

22 Claims. (Cl. 60—21)

This application is a continuing application embodying the subject matter of and replacing my copending applications Serial No. 516,319 filed February 17, 1931 and Serial No. 640,770 filed November 2, 1932, and is to be considered as relating back to said copending applications for all dates and rights incident to the filing thereof, and the filing of foreign applications corresponding thereto.

The present invention relates to reciprocating steam engines and has particular reference to reciprocating steam engines of the multiple expansion type. Still more particularly, the invention relates to marine steam engines of the above type.

It is a well known fact, established by both theoretical considerations and practical operating results, that the thermal efficiency of a given steam engine is greater if superheated steam is expanded from a given initial pressure to a given exhaust pressure than if saturated steam is expanded through the same pressure range. In addition to this, however, the increase in the operating economy of the engine actually obtained by the use of superheated steam is substantially larger than that which can be accounted for due to the increased theoretical thermal efficiency. This additional increase in economy is obtained because the engine, when working with superheated steam, utilizes the available heat drop of the steam more efficiently than when working with saturated steam.

From the foregoing it follows that it is desirable to employ superheated steam to as great an extent as possible and it is common practice to supply superheated steam to the high pressure inlet of engines of the kind to which the present invention relates. Practical considerations, however, limit the amount of superheat that can be added to the steam before initial expansion, and as a result, the temperature of the superheated steam as ordinarily supplied to multiple expansion engines drops to saturation temperature long before expansion of the steam in the engine is completed. Thus, substantially all multiple expansion superheated steam engines operate, with respect to one or more low pressure and/or intermediate pressure cylinders, on wet saturated steam, and with respect to such cylinders the advantages to be derived from the use of superheated steam are not secured.

In order to increase the economy of such engines by increasing the expansion range through which the steam in the engine remains superheated it has heretofore been proposed to reheat

the steam between expansion stages and also in some instances to compress it, but all of the methods heretofore proposed involve one or more serious disadvantages that either introduce losses which reduce the net gain to a degree making them impractical or involve so large a capital expenditure for apparatus that in many cases they are not economically justified.

Considered in its broader aspects, the present invention has for a general object the improvement in the economy of multiple expansion reciprocating steam engines by the employment of a novel method of treatment of the steam whereby steam which has been partially expanded in an engine is withdrawn therefrom and reheated by a mechanical agency which may also impart additional pressure, after which the steam is returned to the engine for further expansion through a lower pressure range than that through which it was expanded prior to its withdrawal from the engine.

A further object is the improvement of the economy of an engine of the kind described by expanding the steam to a lower pressure than is practically possible in a reciprocating engine and utilizing the additional energy thus obtained, which would otherwise be lost, to effect reheating of the steam by mechanical agency as mentioned above.

A still further object of the invention is the provision of relatively simple and inexpensive apparatus for carrying the foregoing and other objects into effect which is of a nature such that it may be applied readily to existing engines without either complicating the controls thereof or necessitating the provision of automatic interlocks, releases or the like in order to permit reversing of the engine.

In order to carry my invention into effect, I provide a pump, which is advantageously in the form of a rotary compressor, to the inlet of which partially expanded steam withdrawn from an engine receiver at intermediate pressure is delivered. If the steam as delivered to the pump is wet, the moisture is preferably removed by a separator or the like before the steam is compressed in the pump, so that the heat incident to the compression will appear in the form of superheat, and a higher economy of the process will be obtained. The energy represented by the power input to the pump is transferred to the steam in the form of superheat and additional pressure and the steam having the additional energy is returned to the engine by the pump for further expansion in a cylinder working in a

lower pressure range than the cylinder or cylinders in which the steam was expanded before withdrawal to the pump. A highly efficient compressor or pump is not essential, since if radiation losses are disregarded, which losses are kept at a minimum by suitably insulating the pump and steam conduits, substantially all of the energy input to the pump is converted into additional heat and pressure in the steam as delivered from the pump. In some instances it may be desirable to impart to the steam a relatively small increase in pressure and a relatively large amount of superheat, in which case a compressor of relatively low efficiency may be used deliberately. Also, the relative amounts of added superheat and pressure in the steam as returned to the engine may be determined by passing the steam through a suitable throttling or pressure reducing device which may convert a part or even all of the added pressure into added superheat before the steam is returned to the engine.

The superheat added to the steam due to the action of the pump and/or throttling device may be considered as being derived mechanically, as distinguished from heat added by means of a heat exchange device such as a superheater, and for convenience the heat added by compression and/or throttling will be designated as mechanically added heat or a like term.

When the engine to which the invention is applied has more than two expansion stages, a plurality of pumps may be employed for withdrawing steam from different receivers and returning reheated steam to the engine, and in cases where it is expedient, heat in addition to that added mechanically may be added through the medium of a superheater.

In order to secure the power necessary to drive the pump or pumps by the aid of which the steam is reheated, I employ an exhaust steam turbine which expands the steam to a much lower final pressure than that to which it can be expanded in a reciprocating engine cylinder and which therefore increases the useful heat drop available in steam of given initial pressure and temperature. Not only does this increase in the available heat drop represent a potential increase in the economy of the power plant as a whole, as compared with the reciprocating engine alone, but the manner in which the additional energy that is made available by the turbine is employed serves to increase the efficiency with which the reciprocating engine makes use of that portion of the total heat drop that occurs in the reciprocating engine.

For a better understanding of the detailed nature of the invention and of the several ways in which it may be applied advantageously in practice, I have illustrated, by way of example, in the accompanying drawings forming a part of this specification, several forms of apparatus embodying the invention which I will now proceed to describe.

In the drawings:

Fig. 1 is a more or less diagrammatic plan view partly in section of a triple expansion engine embodying the invention;

Fig. 2 is a vertical section showing the arrangement of the cylinders and valves of the engine shown in Fig. 1;

Fig. 3 is a section showing part of the engine structure shown in Fig. 1, with a modified valve arrangement in the engine receivers;

Fig. 4 is a view similar to Fig. 1, showing an-

other arrangement of apparatus embodying the invention;

Fig. 5 is a view similar to Fig. 1, showing still another arrangement of apparatus embodying the invention;

Fig. 6 is a top plan view of an engine similar to the engine shown in Fig. 1, provided with apparatus embodying the invention, and showing such apparatus arranged in the manner in which it has been installed in actual practice;

Fig. 7 is a vertical central section of the turbo-compressor unit shown in Fig. 6; and

Fig. 8 is a section showing in a modified arrangement part of the engine structure shown in Fig. 1.

Referring now more particularly to Figs. 1 and 2, I have shown more or less diagrammatically the application of the invention to a three-cylinder triple expansion reciprocating engine of an ordinary known kind. The engine comprises a high pressure cylinder 10, an intermediate pressure cylinder 12 and a low pressure cylinder 14 arranged for serial expansion of steam there-through in the order named. Admission to and exhaust of steam from the high pressure cylinder 10 is controlled by a slide valve 16 of the piston type which admits steam to the cylinder from the high pressure steam chest 18 through the channels 20 and 22, and which connects these channels with the intermediate pressure receiver indicated generally at 24 for exhausting steam from the high pressure cylinder to this receiver. Receiver 24 is divided by means of a partition 26 into a space 24a and a space 24b, and a valve 28 is provided opening toward the space 24b to permit flow of steam directly from space 24a to space 24b when the pressure in the former space exceeds that in the latter. The space 24a provides an exhaust chamber for the high pressure cylinder, and the space 24b provides an inlet chamber or steam chest for the intermediate pressure cylinder 12. Admission of steam to and exhaust of steam from cylinder 12 is controlled by the slide valve 30, which serves to admit steam from the space 24b to the steam passages 32 and 34 and to exhaust steam from the cylinder through these passages to a second receiver indicated generally at 36 by way of the central exhaust passage 38. The receiver 36 comprises passages 40 and 40a extending around the intermediate pressure cylinder 12, and the receiver is divided into spaces 36a and 36b by means of a partition 42 in passage 40a and a valve 44 in passage 40, which valve opens toward the space 36b to permit direct passage of steam from space 36a to space 36b when the pressure in the former space exceeds the pressure in the latter. The space 36b provides a steam chest for the low pressure cylinder 14 and the admission of steam to and exhaust of steam from the low pressure cylinder is controlled by the slide valve 46 which acts to admit steam to the cylinder passages 48 and 50, and which also serves to exhaust steam from these passages by way of the exhaust steam space 52 to the exhaust steam pipe 54 leading from the engine.

The inlet of a power driven pump 56 which is preferably in the form of a rotary compressor is connected by means of a conduit 58 to the space 24a of receiver 24, and the outlet of the pump is connected by means of conduit 60 to the space 24b of this receiver. A throttling device 62, preferably in the form of a pressure reducing valve, is located in conduit 60.

The inlet of a second pump 64 is connected by conduit 66 to the receiver space 36a of receiver 75

36, and the outlet of the pump is connected by means of conduit 68 to the receiver space 36b of this receiver. A throttling device 70 is located in conduit 68. The throttling devices 62 and 70 are preferably located in the respective conduits adjacent to the discharge ends thereof.

An exhaust steam turbine, indicated at 72, is connected to pumps 56 and 64 as by shaft 74 and serves to drive these pumps. The turbine is operated by exhaust steam supplied thereto through the exhaust steam conduit 54 and the steam, before being admitted to the blading of the turbine, is preferably dried as by a separator indicated generally at 76, which may be of any suitable form. The water removed from the exhaust steam is conducted from the separator through a suitable pipe 78 and may advantageously be used for any suitable purpose.

The steam exhausted from turbine 72 is conducted through conduit 80 to the usual condenser 82, in which the steam is condensed by water supplied and removed through the usual circulating devices 84 and 86. Since the turbine is capable of usefully expanding the steam to a very low absolute pressure, the condenser is advantageously provided with a vacuum pump 88 in the usual manner for removing air and other non-condensable gases, and maintaining in the condenser a high degree of vacuum. The exhaust steam pipe 54 is advantageously connected to the condenser by means of a by-pass conduit 90, in which is located a control valve 92.

It will, of course, be understood that the several steam conducting conduits, the pumps and turbine, as well as the engine itself, are suitably lagged with heat insulating material in the usual way to reduce the radiation losses to a minimum. Portions of such lagging are indicated diagrammatically at 93 in Fig. 1. For the sake of clarity in the drawings, only small sections have been shown in this figure and omitted from the remaining figures.

High pressure steam is admitted to the steam chest 18 through the supply pipe 94, and in describing the operation of this embodiment of the invention it will be assumed that the steam supplied through pipe 94 is superheated steam having a sufficient amount of superheat so that the steam, as exhausted to the receiver space 24a, still contains some degree of superheat, or is at least dry saturated steam.

Assuming the engine to be in operation with the turbine 72 being driven by exhaust steam from the reciprocating engine and in turn driving pumps 56 and 64, the steam from the receiver space 24a is drawn into the pump 56 through conduit 58 and there is heated and compressed. The reheated steam from pump 56 is returned through conduit 60 to the receiver space 24b, from which space it is admitted to the intermediate pressure cylinder for further expansion. The steam expanded in the intermediate pressure cylinder and exhausted to the space 36a is conducted, through conduit 66 to the inlet of the pump 64, in which the steam is again heated and compressed and delivered through conduit 68 to the receiver space 36b for further expansion in the low pressure cylinder 14.

The increase in the amount of pressure of the steam due to the action of the pumps 56 and 64 may vary, and the efficiency of the pumps in effecting pressure is not of primary importance. The reason for this is that all of the power input to the pumps (neglecting radiation losses) must reappear in the form of either additional

pressure or heat energy in the steam, or both. If the pump is inefficient and a substantial amount of internal friction is produced in the steam during compression, the heat developed by this friction will be absorbed by the steam itself and its temperature will be raised accordingly. Friction due to flow through the conduits also tends to raise the steam temperature. Since we have assumed that the steam in conduit 58 is dry saturated steam or steam having some superheat, the additional heat imparted to the steam will be in the form of heat or superheat.

It will readily be apparent that apparatus of the kind just described is of a nature such that the invention can easily be applied to an existing engine, and one of the advantages of the invention is that the benefits of it may be obtained without unduly increasing the pressure of the reheated steam to be expanded in a given part of the engine. The amount of pressure increase in the steam as it is returned to the receiver space 24b as compared with the pressure at which the steam is exhausted from the high pressure cylinder to space 24a can be determined by the use of a throttling device such as that indicated at 62. If the compressor is highly efficient and discharges the steam to conduit 60 at a higher pressure than is desired for admission to cylinder 12, the pressure may be reduced by means of the throttling valve 62 without loss, since the throttling device, in reducing the pressure of the steam, increases its temperature in a well known manner.

It is evident that if it is desired the work of the pump 56 may be converted substantially entirely into added temperature in the steam by using the throttling device 62 to reduce the steam in conduit 60 to substantially the same pressure as that at which steam is admitted to the receiver or by constructing the pump with so low an operating efficiency that its output is transferred into heat absorbed by the steam. In the latter case, the use of the partition 26 and valves 62 and 28 is not necessary, as shown by the modified arrangement in Fig. 8.

With the inlet of conduit 58 and the outlet of conduit 60 located in the manner indicated, the steam will tend to flow from the receiver to the pump and from the outlet of the conduit 60 to the intermediate pressure valve 30 in the manner described, even without the partition for separating the receiver into two different spaces, provided the steam is not returned to the receiver at a pressure materially above that at which it is withdrawn.

If, as has been assumed, the high pressure steam supplied through pipe 94 is superheated, so that the steam exhausted from the high pressure cylinder contains some superheat, the amount of additional superheat added mechanically by the pump 56 and the throttling device 62, particularly when the latter is adjusted to convert most of the additional pressure into heat, may enable the steam to expand in the intermediate pressure cylinder while retaining some superheat as exhausted from this cylinder. The dry steam exhausted from cylinder 12 to the receiver space 36a is then compressed in pump 64 and returned to the receiver space 36b for further expansion in the low pressure cylinder 14. As in the case of the compression of the steam between the high and intermediate pressure cylinders, the compression of the steam between the intermediate and low pressure cylinders may be controlled so that the desired relative proportions of additional temperature and

pressure may be obtained in the steam as delivered to the receiver space 36b.

The by-pass conduit 90 under the control of valve 92 permits the engine to be operated without intermediate reheating or compression of the steam, since if valve 92 is opened steam can flow directly to the condenser, thus stopping the turbine 72 and the pumps 56 and 64. When this occurs, valves 28 and 44 open due to the difference in pressure between the different receiver spaces, and steam flows through the receivers in the usual manner. The valves 28 and 44 may be opened and closed under the influence of the difference in pressures existing in the several receiver spaces or they may be manually controlled. To this end they may be provided with any suitable form of external control members, as diagrammatically indicated at 28a and 44a in Fig. 3.

In addition to adding superheat mechanically, superheat may also be added in certain instances by means of superheaters of the heat exchange or thermal type, and in Fig. 4 I have illustrated an embodiment of the invention in which superheat is added thermally as well as mechanically. In the apparatus shown in Fig. 4, the construction of the engine is the same as that shown in Figs. 1 and 2, with like parts designated by like reference characters, and need not be again described in detail. Further, the engine to which this form of the invention is in this instance applied, is shown as being operated by steam which is initially superheated. To this end the boilers indicated at 96 are provided with superheaters indicated generally at 98, to which saturated steam from the boilers is delivered through conduits 100 and from which superheated steam is delivered to the high pressure steam chest of the engine through conduit 94. The arrangement of the exhaust steam turbine, pumps and condenser is the same as that shown in Fig. 1, but in this instance the conduits 60 and 68, instead of delivering the steam from the pumps 56 and 64 directly to the receiver spaces 24b and 36b respectively, are connected respectively to the inlet headers 102 and 104 of the superheaters 106 and 108 located in the uptake flue connected to the boilers by the usual breeching indicated at 110. The outlet headers 112 and 114 of the superheaters are connected respectively by conduits 60a and 68a to the receiver spaces 24b and 36b, and throttling valves 62 and 70 are advantageously placed in these conduits respectively adjacent to their outer ends.

In this form of the apparatus additional superheat from the superheaters 106 and 108 is obtained without incurring the disadvantages incident to the usual reheating between cylinders with superheaters of this kind, since the energy necessary to force the steam through these superheaters is derived from exhaust steam, the energy of which would otherwise be lost. Due to the recovery of additional energy of the exhaust steam from the engine, steam at intermediate pressures can be withdrawn from the engine, reheated and returned thereto for further expansion without loss of pressure and even with increase of pressure, if desired. It will immediately be evident that the additional energy of the exhaust steam which is recovered through the medium of the exhaust steam turbine is usefully returned irrespective of whether additional thermal superheaters such as are illustrated in Fig. 4 are employed or not, and that in either case the recovered energy is returned in a form such that the economy of operation of the reciprocating engine is en-

hanced. If it is desired to use only one superheater, the best economical result is obtained by superheating the steam delivered from the low pressure pump 64.

In Fig. 5 I have illustrated another application of the invention to an engine similar to that shown in Figs. 1 and 4. In this embodiment the general arrangement is the same as that shown in Fig. 1, except that in the partition 26 separating the receiver spaces 24a and 24b I have shown a plurality of valves of a type different from that shown in Fig. 1. In this form the valves 116 are of the poppet type and are seated by springs 118 adapted to normally maintain the valves closed, but which permit the valves to open when the pressure in chamber 24a exceeds that in 24b by a predetermined amount. Likewise, poppet valves 120 closed by springs 122 control flow of steam through the passages 40 and 40a. It will be evident that the use of either of the types of valves illustrated is optional in any of the embodiments herein described. The present embodiment of apparatus is adapted for use with an engine which is initially supplied either with saturated steam or with steam superheated to such a low degree that the steam as exhausted to the receiver space 24a is wet saturated steam. It is important to the securing of the desired results that the energy imparted by the pump to the steam withdrawn from the receiver is imparted in the form of added temperature and/or pressure, and is not utilized for the evaporation of the moisture content of wet steam admitted to the pump. To this end, the separator 124 is interposed between the receiver space 24a and the inlet of the pump 56 for insuring admission to the pump of dry steam. A second separator 128 is shown in the inlet conduit 66 leading to the pump 64, this separator being supplied with a suitable drain pipe 130. Since the steam from which the water is separated in both separator 124 and separator 128 is at a pressure considerably above atmospheric, it will be evident that the water outlets from the separators must be suitably trapped in known manner to prevent loss of steam through the water drains. Such traps for drains 126 and 130 are indicated diagrammatically at 127 and 131 respectively.

Except for the provision of separators 124 and 128 for insuring the delivery to the pumps of dry steam, the apparatus shown in Fig. 5 operates in the manner already described in connection with Fig. 1 and is susceptible to the same variations with respect to the relative amounts of added pressure and superheat supplied to the steam by the aid of the pumps. It will also be apparent that in case the desired operating temperatures and pressures of the steam in an installation such as that shown in Fig. 4 are such that there is any possibility of wet steam being delivered to the pumps, separators such as those shown at 124 and 128 may be employed. In this connection, it is pointed out that in general the use of separating means for insuring the supply of dry steam to the pumps is to be preferred in all cases, since even when steam withdrawn from a receiver will contain superheat under normal full load operating conditions of the engine, other operating conditions including emergency operating conditions may result in wet steam being withdrawn, in which event the presence of a separator is a highly desirable factor.

It will be understood that while for purposes of illustration I have shown apparatus for withdrawing and reheating steam between each two

adjacent stages of a triple expansion engine, the employment of reheating between more than one set of adjacent stages is optional, and that the invention is equally applicable to compound and quadruple expansion engines, and the number of times that the steam is withdrawn and reheated during its expansion in any given engine is a factor determined by the particular steam conditions and operating characteristics of the particular engine to which the invention is applied.

Turning now to Fig. 6, I have illustrated a form of apparatus embodying the invention which I have applied commercially to existing marine engines with highly satisfactory results. In this embodiment the engine is shown in top elevation, the high, intermediate and low pressure cylinders being indicated at 10, 12 and 14 respectively. In this instance the steam is compressed and reheated only between the high pressure and intermediate pressure cylinders and is withdrawn from the high pressure receiver space 24a through conduit 58 to the compressor end of a turbo-compressor unit 132, which combines in a single unit the exhaust steam turbine 72 and the pump device 56. The turbo-compressor unit is advantageously mounted as shown directly on the condenser 82 and the compressed and reheated steam is delivered from the pump end of the turbo-compressor to the receiver space 24b through conduit 60. The turbo-compressor is supplied with steam through the exhaust steam conduit 54 in which is located the separator 76 and a by-pass conduit 90 with valve 92 is advantageously provided to permit direct exhaust of steam from the engine to the condenser. Conduits 58 and 60 are preferably provided with valves 134 and 136 respectively, and the latter valve may, if desired, be employed as a throttling device. The turbo-compressor shown in Fig. 6 is illustrated on enlarged scale in section in Fig. 7, and advantageously comprises a turbine wheel 133 mounted on a shaft 140 which also carries the rotor 142 of a rotary or centrifugal compressor, to the inlet of which steam is admitted through conduit 58. The separator 124 is shown partially in section and may advantageously be of the type provided with a plurality of spirally arranged vanes 128 for causing separation of the water from the steam due to centrifugal action. The specific form of the separator is not important to the invention, and any suitable type of steam drying arrangement may be employed. For example, the first stage of the compressor may be arranged to act as a tangential dryer, the moisture removed from the steam being discharged through the drain 144. Such tangential dryer may be used in addition to a separate dryer such as that indicated at 124 to insure as complete a separation as possible of entrained moisture from the steam.

From a consideration of Fig. 6 it will be evident that the invention provides simple and practical means whereby the efficiency of an existing marine engine installation may be substantially increased. As will be observed from this figure, the amount of engine room floor space required for the engine after the apparatus necessary to carry the invention into effect is installed is substantially no greater than for the reciprocating engine alone. The turbo-compressor unit is a relatively small and compact device which may be in substantially all cases readily installed as shown on top of the existing condenser, and the weight of the unit is such that comparatively little strengthening of the con-

denser top is required in order to support the weight of the unit. Since there is no mechanical connection between the moving parts of the turbo-compressor unit and the reciprocating engine, the turbo-compressor unit may be of the high speed type, and consequently of relatively light weight for a given power. Furthermore, the mechanical independence of the turbo-compressor unit with respect to the reciprocating engine makes possible the operation thereof at varying speeds with respect to the speed of operation of the reciprocating engine. Consequently, no manual control or automatic control devices are required for the compressor equipment in order to take care of the variations in operation conditions occasioned by operation of the reciprocating engine at varying speeds or in reverse direction.

The compact arrangement that is possible with the present invention results in a minimum amount of external steam piping, and consequently losses due to radiation of heat are maintained at a minimum and the cost of the installation is also made relatively low.

In applying the invention to an existing engine the structural changes necessary to the engine itself are relatively few and simple, consisting usually only of the insertion of the partition or partitions and valves advantageously employed to divide one or more of the receivers of the engine into separate steam spaces. In case of engines of the kind in which the receivers are in the form of pipes external of the main engine cylinder castings, the conversion of an engine to operation in accordance with the invention is more readily accomplished than is the case with engines of the kind illustrated having internal receivers.

Another important advantage of the invention in connection with its applicability to existing engines is the fact that the benefits of the invention are not dependent upon increasing to a great extent the pressure of the steam in the reheating process. Consequently, the invention may be employed with existing engines without danger of over-stressing the engine parts and without having to substantially reconstruct the engine in order to permit it to operate safely.

From the foregoing description it will be evident that the invention may be applied in many different specific ways, and it is accordingly to be understood that the invention embraces all variations in the form of apparatus and the mode of operation that may fall within the scope of the appended claims. It is further to be understood that certain features of the invention may in some instances be employed to the exclusion of others.

What I claim is:

1. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a condenser, a low pressure turbine receiving steam from a low pressure cylinder of the engine and exhausting steam to said condenser, a pump driven by said turbine, a conduit for conducting at least the major portion of the steam exhausted from one of said cylinders to the suction side of the pump, and a conduit for conducting steam from the discharge side of the pump to the means for admitting steam to the cylinder next in the series after the cylinder exhausting the steam conducted to the pump.

2. In a steam power plant, a reciprocating

steam engine having a plurality of cylinders for serial expansion of steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a condenser, a low pressure turbine receiving steam from a low pressure cylinder of the engine and exhausting steam to said condenser, and means for returning energy derived from said turbine to steam partially expanded in said engine comprising a pump driven by said turbine, a conduit for conducting at least the major portion of the steam exhausted from one of said cylinders to the suction side of said pump, and a conduit for conducting steam from the discharge side of the pump to the means for admitting steam to the cylinder next in the series after the cylinder exhausting the steam conducted to the pump, the last mentioned means being constructed to impart to the steam in the form of heat of superheat a substantial portion of the energy derived from the turbine.

3. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of steam therein including a high pressure cylinder, means for admitting steam to and exhausting steam from each of said cylinders, a condenser, a low pressure turbine receiving steam from a low pressure cylinder of the engine and exhausting steam to said condenser, a pump driven by said turbine, a conduit for conducting at least the major portion of the steam exhausted from said high pressure cylinder to the suction side of the pump and a conduit for conducting steam from the discharge side of the pump to the means for admitting steam to the cylinder next in the series after the high pressure cylinder.

4. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of steam therein and a receiver between two cylinders adjacent in the series, said receiver being divided to provide a first receiver space for receiving steam exhausted from one of said cylinders and a second receiver space adapted to supply steam to another of said cylinders for further expansion therein, a compressor, means for driving the compressor, a conduit for conducting steam from said first receiver space to the compressor, a conduit for conducting steam from the compressor to said second receiver space, and valve means providing for direct flow of steam from said first receiver space to said second receiver space when the pressure in the first receiver space exceeds the pressure in the second receiver space.

5. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of steam therein and a receiver between two cylinders adjacent in the series, said receiver being divided to provide a first receiver space for receiving steam exhausted from one of said cylinders and a second receiver space adapted to supply steam to another of said cylinders for further expansion therein, a compressor, means for driving the compressor, a conduit for conducting steam from said first receiver space to the compressor, a conduit for conducting steam from the compressor to said second receiver space, and spring loaded valve means for automatically permitting flow of steam directly from said first receiver space to said second receiver space when the pressure in the first receiver space exceeds the pressure in the second receiver space by a predetermined amount.

6. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for

serial expansion of steam therein and a receiver, a partition for dividing said receiver into a first receiver space for receiving steam exhausted from one of said cylinders and a second receiver space adapted to supply steam to another of said cylinders for further expansion therein, a compressor, means for driving the compressor, a conduit for conducting steam from said first receiver space to the compressor, a conduit for conducting steam from the compressor to said second receiver space, and spring loaded valve means associated with said partition for automatically permitting direct flow of steam from said first receiver space to said second receiver space when the pressure in the first receiver space exceeds the pressure in the second receiver space by a predetermined amount.

7. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a condenser, a low pressure turbine receiving steam from a low pressure cylinder of the engine and exhausting steam to said condenser, and means for heating steam partially expanded in said engine comprising a pump driven by said turbine, a conduit for conducting steam exhausted from one of said cylinders to the suction side of said pump, a conduit for conducting steam from the discharge side of the pump to the means for admitting steam to the cylinder next in the series after the cylinder exhausting the steam conducted to the pump, and throttling means on the discharge side of the pump for reducing the pressure and increasing the heat of superheat of the steam delivered by the pump.

8. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of steam therein, a turbine for expanding steam finally exhausted from the engine to a pressure below that to which it can be expanded in the engine, and means for withdrawing substantially all of the steam exhausted from one of said cylinders in partially expanded state and returning it to the engine for further expansion therein in the cylinder next in the series after the cylinder from which the steam was exhausted, the last mentioned means including means driven by said turbine for compressing the steam withdrawn from the engine and superheating it to a degree providing a substantial degree of superheat at the pressure to which the steam is compressed.

9. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of steam therein, a turbine for expanding steam finally exhausted from the engine to a pressure below that to which it can be expanded in the engine, and means for withdrawing substantially all of the steam exhausted from the high pressure cylinder and returning it to the engine for further expansion therein in the cylinder next in the series after the high pressure cylinder, the last mentioned means including means driven by said turbine for compressing the steam withdrawn from the engine and superheating it to a degree providing a substantial degree of superheat at the pressure to which the steam is compressed.

10. In a steam power plant, a reciprocating steam engine having a first cylinder and a second cylinder, receiver space connecting the outlet of the first cylinder with the inlet of the second cylinder, a steam turbine, a conduit for conduct-

ing steam finally exhausted from the engine to the turbine, a condenser, a conduit for conducting the exhaust from the turbine to the condenser, compressor means driven by said turbine, a conduit for conducting substantially all of the steam exhausted from said first cylinder to said compressor means, a conduit for conducting said steam from said compressor means to the inlet of said second cylinder, said compressor means being constructed to increase the pressure of the steam as returned to the engine and to impart thereto a substantial degree of superheat at its compressed pressure, and means in said receiver space for preventing flow to said first cylinder of the compressed steam returned to the engine.

11. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a condenser, an exhaust steam turbine for expanding steam to a lower pressure than that to which it can be expanded in the low pressure cylinder of the engine, said turbine receiving steam exhausted from the low pressure cylinder of the engine and exhausting to said condenser, a compressor driven by said turbine, means for conducting at least the major portion of the steam exhausted from one of said cylinders at intermediate pressure and for delivering it in substantially dry state to said compressor whereby to cause the heat due to compression to add superheat to the steam, and means for conducting the steam from the compressor to the means for admitting steam to the cylinder next in the series after the cylinder exhausting to the compressor.

12. In a steam power plant, a reciprocating engine having a plurality of cylinders for serial expansion of steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a condenser, an exhaust steam turbine for expanding steam to a lower pressure than that to which it can be expanded in the low pressure cylinder of the engine, said turbine receiving steam exhausted from the low pressure cylinder of the engine and exhausting to said condenser, a compressor driven by said turbine, a conduit for conducting at least a major portion of the steam exhausted at intermediate pressure from one of said cylinders to said compressor, a separator in said conduit for drying the steam supplied to the compressor, whereby to cause the heat due to compression to add superheat to the steam, and a conduit for conducting the steam from the compressor to the means for admitting steam to the cylinder next in the series after the cylinder exhausting to the compressor.

13. In a steam power plant, a reciprocating steam engine having a first cylinder and a second cylinder, a receiver space connecting the outlet of the first cylinder with the inlet of the second cylinder, a steam turbine, a conduit for conducting steam finally exhausted from the engine to the turbine, a condenser, a conduit for conducting the exhaust from the turbine to the condenser, compressor means driven by said turbine, a conduit for conducting substantially all of the steam exhausted from said first cylinder to said compressor means, a water separator in the second mentioned conduit for insuring delivery to the compressor means of substantially dry steam, a conduit for conducting steam from said compressor to the inlet of said second cylinder, said compressor means being constructed to increase the pressure of the steam as returned to the en-

gine and to impart thereto a substantial degree of superheat, and means in said receiver space for preventing flow to said first cylinder of the compressed steam returned to the engine.

14. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a condenser, a low pressure turbine receiving steam from a low pressure cylinder of the engine and exhausting steam to said condenser, means for returning energy derived from said turbine to steam partially expanded in said engine comprising a pump device driven by said turbine, a conduit for conducting steam exhausted from one of said cylinders to the suction side of the pump device, and a conduit for conducting steam from the discharge side of the pump device to the means for admitting steam to the cylinder next in the series after the cylinder exhausting the steam conducted to the pump device, and means providing resistance to flow of steam pumped to the engine for converting pressure energy in the steam derived from the pump device to heat energy.

15. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of the steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a receiver between two consecutive cylinders, a partition dividing said receiver into two chambers, an anterior cylinder in the series exhausting into the first of said chambers, a pump device, a conduit connecting said first chamber with the suction side of said pump device, and a second conduit connecting the pressure side of said pump device with said second chamber which contains the means for admitting steam to the next cylinder in the series, said pump device being constructed with so low an operating efficiency that its output is substantially transformed into heat absorbed by the steam.

16. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of the steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a receiver between two consecutive cylinders, a partition dividing said receiver into two chambers, an anterior cylinder in the series exhausting into the first of said chambers, a pump device, a conduit connecting said first chamber with the suction side of said pump device, a second conduit connecting the pressure side of said pump device with said second chamber which contains the means for admitting steam to the next cylinder in the series, and throttling means in said second conduit.

17. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of the steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a pump device, a conduit for leading exhaust steam from one of said cylinders to the suction side of said pump device, a second conduit connecting the pressure side of said pump device with the means for admitting steam to the next cylinder in the series, and throttling means in said second conduit.

18. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of the steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a receiver between two consecutive cylinders, a partition dividing said

receiver into two chambers, an anterior cylinder in the series exhausting into the first of said chambers, a steam turbine driven by steam finally exhausted from said reciprocating steam engine, a turbo-compressor driven by said steam turbine and arranged to compress the steam exhausted into said first chamber, a conduit connecting said first chamber with the suction side of said turbo-compressor, a second conduit connecting the pressure side of said turbo-compressor with said second chamber to admit therein steam at a higher pressure than the steam exhausted into said first chamber, a condenser adapted to condense the exhaust steam of said steam turbine, and a by-pass pipe provided with a stop valve and connecting the exhausting means of the last cylinder in the series with said condenser.

19. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of the steam therein, means for admitting steam to and exhausting steam from each of said cylinders, a receiver between two consecutive cylinders, a partition dividing said receiver into two chambers, an anterior cylinder in the series exhausting into the first of said chambers, a steam turbine driven by steam finally exhausted from said reciprocating steam engine, a valve in said partition wall adapted to automatically open in the direction of the normal steam flow between the cylinders when the steam pressure in the inlet portion of the receiver exceeds a predetermined minimum, a pump device driven by said steam turbine, a conduit connecting said first chamber with the suction side of said pump device, a second conduit connecting the pressure side of said pump device with said second chamber which contains the means for admitting steam to the next cylinder in the series, a condenser adapted to condense the exhaust steam of said steam turbine, and a by-pass conduit provided with a stop valve and connecting the exhausting means of the last cylinder in the series with said condenser.

20. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of the steam therein, a receiver space between two consecutive cylinders, means dividing said receiver space into a first chamber and a second chamber, the first one of said two cylinders exhausting to the first of said chambers and the second cylinder of said two cylinders receiving steam from the second of said two chambers, a steam turbine driven by steam finally ex-

hausted from said reciprocating steam engine, a compressor driven by said steam turbine, a conduit for conducting steam from said first chamber to the suction side of said compressor, and a second conduit for conducting steam from the pressure side of said compressor to said second chamber.

21. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of the steam therein, a receiver space between two consecutive cylinders, means dividing said receiver space into a first chamber and a second chamber, the first one of said two cylinders exhausting to the first of said chambers and the second cylinder of said two cylinders receiving steam from the second of said two chambers, a steam turbine driven by steam finally exhausted from said reciprocating steam engine, a compressor driven by said steam turbine, a conduit for conducting steam from said first chamber to the suction side of said compressor, and a second conduit for conducting steam from the pressure side of said compressor to said second chamber, said compressor being constructed with relatively low operating efficiency whereby to utilize only a portion of the energy derived from said turbine to increase the pressure of the steam and to utilize a substantial portion of the energy derived from said turbine to impart to the compressed steam a substantial degree of heat of superheat and to thereby provide for substantially superheated steam operation of the second of said two cylinders.

22. In a steam power plant, a reciprocating steam engine having a plurality of cylinders for serial expansion of the steam therein, a receiver space between two consecutive cylinders, means dividing said receiver space into a first chamber and a second chamber, the first one of said two cylinders exhausting to the first of said chambers and the second cylinder of said two cylinders receiving steam from the second of said two chambers, a steam turbine driven by steam finally exhausted from said reciprocating steam engine, a compressor driven by said steam turbine, a conduit for conducting steam from said first chamber to the suction side of said compressor, and a second conduit for conducting steam from the pressure side of said compressor to said second chamber, and valve means providing for direct flow of steam from said first chamber to said second chamber when the pressure in the first chamber exceeds the pressure in the second chamber.

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