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2,467,092

STEAM POWER PLANT

Filed Dec. 16, 1944

3 Sheets-Sheet 1.

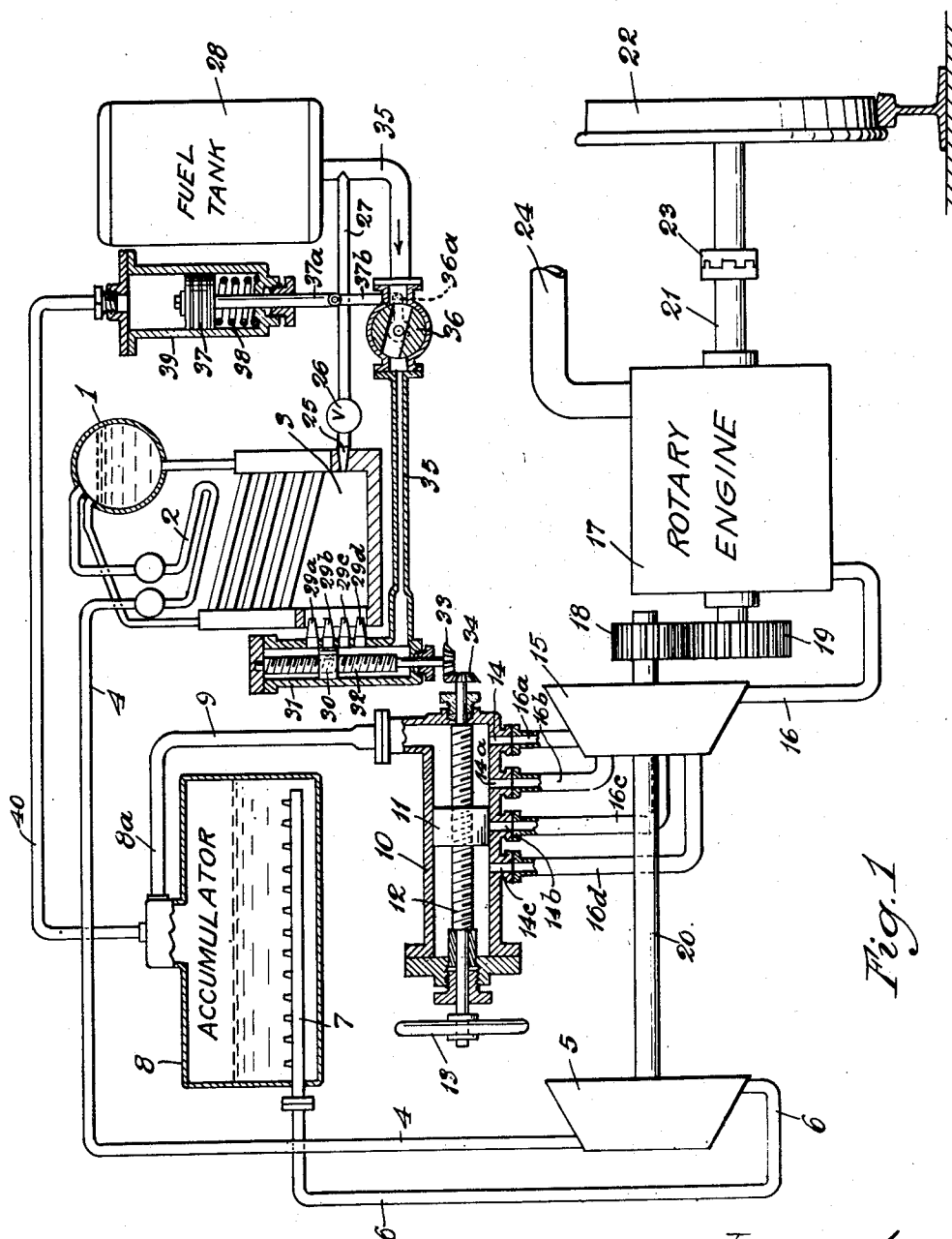


Fig. 1

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3 Sheets-Sheet 2

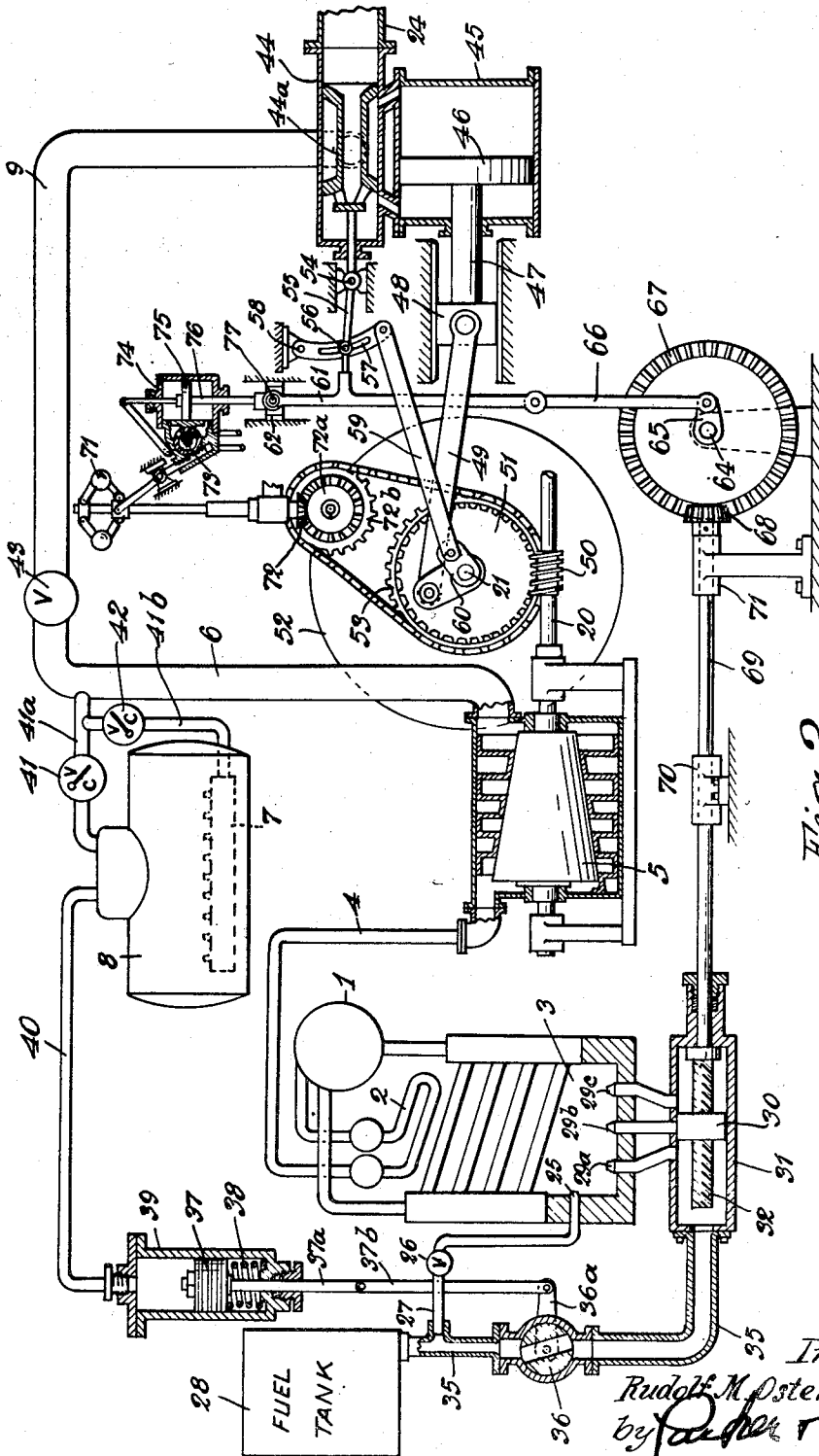


Fig. 2

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Fig. 3

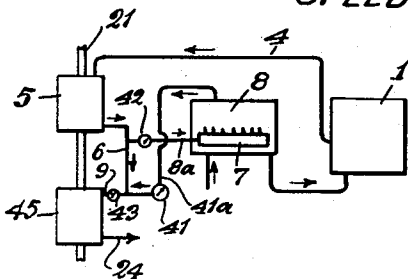


Fig. 5

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UNITED STATES PATENT OFFICE

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STEAM POWER PLANT

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Application December 16, 1944, Serial No. 568,419

9 Claims. (Cl. 60—20)

1

The invention relates to a steam power plant and to a method of power production. The object is to provide a variable speed power drive with torque-speed characteristics, such as are useful for the propulsion of locomotives and other rail vehicles, as well as for steam hoists, rolling mills, and similar uses, all of which require substantial torques throughout their speed range. A particular object of this invention is, moreover, to provide such a variable speed power drive as will make it practicable to utilize extremely high steam pressures, thereby reducing the steam consumption per horse-power hour as fully as possible.

An incidental object of this invention is to provide simple automatic steam generating means, particularly useful for this variable speed drive.

The highest possible steam economy of such drives is of great value—for instance, when applying them to locomotives, since it tends to decrease the size, cost, and weight of the entire machine. It is also a substantially increased steam economy which makes the condensation of the operating steam and its re-use as boiler feed a practical possibility in moving power plants, like locomotives, which has not been possible of attainment heretofore, in the absence of a drive which combines both the requisite torque speed characteristics and high steam economy.

A further object is to combine means of steam generation with steam expanding propulsion means of the smallest possible weight and to regulate the steam generation in relation to the steam expansion in such a manner that the plant works with the highest possible thermal efficiency at maximum load and then satisfies the power requirement with the smallest possible amount of steam and fuel. In present day railroad haulage, for instance, the amount of power required to sustain the desired high train speeds is so large, and in contrast to it the amount of power which is being derived from each pound of steam generated in the boilers so small, due to existing practical limitations of the steam generation pressure, that boilers very much heavier than would be needed for satisfactory adhesion of the locomotive driving wheels, have to be employed. At the same time a further enlargement of the boiler capacity is not effective enough with a

2

variable cutoff piston engine such as present steam locomotives are driven by, since these have to be worked with lengthened cutoffs and with thereby decreased steam expansion when they are required to apply more torque to the drivers in an effort to produce more horsepower. Hence, though more steam be admitted to them, the power developed by them is not proportionally increased. A locomotive, then, which is equipped to utilize steam of much increased pressure and temperature, and to expand that steam completely to a near-atmospheric pressure exhaust during maximum power demand, is badly needed.

Obviously it is not possible to expand steam from a very high pressure, like 2000# per square inch for instance, to near atmospheric pressure in a piston displacement engine without using at least triple or quadruple expansion cylinders—which is not mechanically practical enough on a locomotive, nor is it possible to lubricate piston engines at any such admission pressures. Steam turbines, on the other hand, can be built small and light enough for such high steam admission pressures, as well as for relatively high steam temperatures, but they have a satisfactory efficiency when operated with a constant admission pressure, only over a fairly narrow speed range. For that reason, they are usually operated at a constant speed and are made to drive variable speed shafts like the driving axles on locomotives through electric or hydraulic variable speed transmissions. It is one of the specific objects of my invention to make steam turbines serve efficiently when made to drive a variable speed shaft by direct gearing, thereby saving the complication, cost and weight of a variable speed transmission. As will be described later, this object is reached by varying the pressure of steam generation in proportion to the speed of rotation of the drive shaft.

However, since locomotive propulsion means should also be capable of exerting their largest torque in starting to drive, and of maintaining that torque during acceleration (which, in the case of a locomotive will consume a quite indefinite amount of time, depending as it does upon various operating factors), the amount of steam required during the acceleration period is also eminently important. Steam turbines can not, with any admission pressure, produce a substan-

tial torque without allowing substantial amounts of steam to pass through them to the exhaust, and the internal energy of which steam is all wasted at the very start, and a progressively larger percentage of which internal steam energy is only converted into mechanical power as the turbine speeds up towards that speed for which its vanes are designed. To eliminate the waste of steam energy as a result of a variable speed turbine operation, by means of a serial expansion of the operating steam, first in a variable pressure turbine and thereafter in a displacement engine—which latter can produce and maintain an adequate torque with a quantity of steam that is zero at the very start and which increases with the speed of the locomotive—is another specific object of my invention.

The invention is illustrated more or less diagrammatically in the accompanying drawings wherein:

Fig. 1 is a diagram illustrating one form of the invention;

Fig. 2 is a diagram illustrating a modified form of the invention;

Fig. 3 and Fig. 4 are diagrams illustrating the variation of the steam generating pressure of the exhaust pressure and of the turbine and engine torques in relation to the speed of the load shaft;

Fig. 5 is a diagrammatic showing illustrating the steam flow in a system embodying the invention, as shown in Figure 2.

Like parts are indicated by like symbols throughout the specification and drawings.

Referring now to Fig. 1, a fuel-fired boiler 1 equipped with a superheater 2 and a furnace 3 supplies superheated steam through a pipe 4 to primary expansion turbine 5, the exhaust from said turbine 5 passes through pipe 6 into nozzle pipe 7 located below the water level of a steam accumulator 8. Steam from the accumulator passes through a pipe 8a into pipe 9 and from pipe 9 to a distribution valve 10 in which a piston 11 is shifted by means of screw spindle 12 and hand wheel 13. In its movement the piston uncovers successively by moving from right to left in the drawing, ports 14, 14a, 14b and 14c, and thereby allows the steam to reach the turbine part 15 of the secondary expansion turbo-rotary engine through pipes 16a, 16b, 16c and 16d. These pipes 16a to 16d supply steam to various segments of the first bucket wheel of turbine 15 either through expanding nozzles as in an impulse turbine or through other efflux openings like in a reaction turbine, and their combined steam is exhausted through pipes 16 and admitted therein to the rotary engine 17 connected by gears 18 and 19 with the shaft 20 that carries the runner of both the turbines 5 and 15. The number of ports 14 or the number of supply pipes 16 leading steam to the turbine, has no bearing upon the invention and may be suitably varied in following standard steam turbine practice. The rotary engine 17 may be of any known design but preferably of a uniflow design, and which must produce a positive torque in any position of its rotor, such as for instance the engine described in United States Patent 2,177,977. The rotor of said rotary engine is carried on variable speed drive shaft 21 which is so characterized in the drawing by having been shown coupled to a locomotive driving wheel 22 through coupling 23. The steam from the rotary engine passes through the exhaust pipe 24 and may be condensed or otherwise dealt with. Coordinated with the fur-

nace 3 of the fuel fired boiler 1 is one fuel burner 25 controlled by hand-operated throttle valve 26 and being supplied through pipe 27 from fuel tank 28, which, for greatest simplicity of showing is assumed to contain combustible gas. In another wall of the furnace 3, a series of fuel burners 29a, 29b, 29c and 29d are provided, and these serial burners are controlled by a piston 30, being made to travel within a cylinder 31 by rotation of the screw spindle 32. This screw spindle 32 is rotated by bevel gear 33, which latter meshes with a bevel gear 34 on the shaft of the steam distributing screw spindle 12, thereby bringing it about that when steam is admitted from the accumulator 8 through one port 14 to the secondary expansion stage including the turbine 15 and the engine 17, one of the serial burner nozzles receives fuel from pipe 35, which latter connects with the fuel cylinder 31. When steam is admitted through two of the ports, two burner nozzles will receive fuel, etc. The fuel pipe 35 receives its supply from fuel tank 28 through throttle valve 36. The latter's throttling vane is variably adjusted by steam piston 37 moving against spring 38 in regulating cylinder 39, by the pressure of the steam which comes to it through pipe 40 from the steam space of the accumulator 8. The piston 37 is connected to the lever 36a of the valve 36 by a piston rod 37a and a link 37b.

Although I have shown an operative form of my invention, it will be recognized that many changes in the form, shape and arrangement of parts can be made without departing from the spirit of the invention, and my showing is therefore to be taken as, in a sense, diagrammatic.

The use and operation of my invention in the form of Figure 1 are as follows:

With the drive shaft 21 at rest, fuel is admitted through hand operated valve 26 to the pilot burner 25 and lighted by hand, both the boiler 1 and accumulator 8 having been filled with feed water to the indicated water levels, and a moderate steam pressure of say 150 to 200 pounds will be raised, the steam produced in the boiler 1 will then be flowing through the superheater, through pipe 4, through stationary turbine 5, through pipe 6 into nozzle pipe 7 and therewith communicate its heat to the water in the accumulator 8 and eventually produce a pressure within it equal to the one in the boiler. Since no steam is flowing permanently through the turbine 5, no torque will be produced upon the shaft 21. When the operator wishes to start the shaft 21 to revolve against a resisting torque, he turns hand wheel 13 and thereby, uncovers one of the ports 14 and supplies fuel also to one of the burners 29, which latter is automatically lighted by the flame of the pilot burner. This operation causes steam of accumulator pressure to flow through the turbine 15 into the rotary engine, and at the very start of the shaft the pressure against the pistons of the rotary engine builds up to the one equal to that existing in the accumulator and in the boiler. The rotary engine is so dimensioned that it can produce the maximum allowable torque with that pressure, and therefore the shaft starts to revolve together with the rotary engine, the turbine 15 and the turbine 5. At the same time, the increased firing capacity in the furnace of the boiler, due to the opening of one of the burners 29, tends to raise the pressure of steam generation within the boiler. If the steam generation pressure rises too fast in relation to the speed of turbine 5, and in relation to its ability to abstract

5

the increased velocity with which the steam will pass through it as a result of an increased admission pressure, its exhaust pressure is going to rise, and therewith an amount of heat rejected to the accumulator. The accumulator pressure will then try to follow the rise of the steam generation pressure, and the piston 37 in the steam regulating cylinder 39 will be forced downward against the calibrated spring 38, thereby throttling the fuel flow to the one lighted burner. The reduction of fuel supply will then halt the further rise of steam generation pressure, lessen the steam flow through turbine 5 and thus tend to maintain the accumulator pressure constant with the thus checked amount of steam generation pressure. It is the sense of this regulating arrangement to adjust the steam generation pressure by firing control always at such a level that, at any speed of the shaft 21, and therewith at any speed of the primary turbine 5, the latter passes to the accumulator, only that weight of steam that is withdrawn from the accumulator by the secondary expansion propulsion means. The result is that the boiler will always be fired proportionally to the steam demand of the secondary expansion propulsion means, and that all of the heat in the primary turbine exhaust is recaptured in the accumulator.

Referring now to the use and operation of the invention as shown in Figure 2, it is seen that the boiler with its superheater and with its furnace, equipped in this instance with only three serially operated burners and one pilot burner—with its fuel distributing device, with its fuel pressure regulating cylinder acted upon by the accumulator pressure, and with its fuel tank, also the primary turbine and the accumulator, are all identified by the same reference numbers as in Figure 1. The primary expansion turbine exhaust pipe 6 has, however, two branches, one numbered 41a, leading through check valve 41 to the accumulator steam space and another, numbered 41b, leading through check valve 42 to the nozzle pipe 7 below the accumulator water level, and the other one through stop valve 43 to valve chamber 44 of a secondary expansion piston displacement engine 45, the piston 46 of which drives onto the variable speed shaft 21 through piston rod 47, cross head 48 and main rod 49. The primary expansion turbine jointly drives shaft 21 by worm 50 and gear 51, which latter is keyed to shaft 21 together with a fly wheel 52 and a sprocket wheel indicated at 53. The steam distributing valve 44a is shown to be actuated by a suitable valve motion device; the valve is guided by crosshead 54 and moved reciprocatingly by rod 55 attached at one end of it to link block 56. The link 57 is, as usual, pivoted at 58 and is oscillated by rod 59 and crank 60. The position of link block 56 within the link 57 may be shifted by moving the rod 61—which is guided at 62—in a vertical direction, in the drawing. The rod 61 will, upon being shifted, rotate a shaft 64 by means of a crank 65 and a main rod 66. On said shaft 64 is keyed a bevel gear 67 which meshes with a smaller bevel gear 68. The latter is keyed to a shaft 69 carried in bearings 70 and 71, and this same shaft also carries the screw spindle 32 which shifts the fuel distributing piston 30 during its rotation, thus bringing it about that the means for varying the firing intensity is mechanically interlocked with the means for varying the amount of steam passed through the engine per stroke of its piston.

As the total weight of steam that is withdrawn from the accumulator by the variable cutoff dis-

6

placement engine is, however, not proportional to the cutoff alone but to the product of the cutoff and the engine speed, and to which steam weight the firing should be roughly proportional in order to maintain a virtually constant accumulator pressure, it is advisable to increase the total burner capacity with a decrease of the engine cutoff automatically, and in response to the speed of the drive shaft. Thus a centrifugal governor 71 has been added in Figure 2, which governor is driven by bevel gears 72 and 72a, the latter being revolved by a sprocket wheel 72b that is driven from sprocket wheel 53. The fly balls of the governor 71 occupy a different position for every speed of the drive shaft, and, in moving from position to position, a rotary lap valve 73 on the cylinder 74 of a servomotor is turned by various angles. A piston 75 is thereby made to shift by oil or air pressure until the balance of pressure on both sides of the piston 75 is re-established in a manner known to all skilled in the art. Piston 75 carries rod 76 flexibly connected to rod 61 at 77 and varies the valve travel as well as the burner capacity in response to the engine speed.

The objects of my invention could in this form as shown in Figure 2 also be realized if the engine cutoff and the firing capacity were manually controlled either jointly or separately, and this could be accomplished by a skillful and conscientious operator. However, since, with a variable cutoff displacement engine, a variation of the cutoff at the will of the operator—such as is practiced on all existing steam locomotives—does not force the operator to use the steam most efficiently in the engine at advanced speeds thereof, the object of the highest possible overall expansion ratio of my plant might be defeated; if the operator fired the boiler sufficiently hard so as to maintain at advanced speed a constant accumulator pressure with an excessive cutoff and torque of the engine, the primary turbine 5 would add enough of its own to exceed the total allowable maximum torque. On the other hand, when the secondary expansion stage consists of a steam turbine with positively controlled steam admission and vane impingement, coupled to a constant cutoff displacement engine, as in Figure 1, the amount of steam withdrawn from the accumulator with any given number of opened turbine nozzles, while not entirely independent of the piston displacement, is relatively more independent of it than with a displacement engine, the steam admission of which is entirely governed by cutoff regulation. This may be explained as follows: the ports 14, 14a, 14b and 14c (Fig. 1) and the therewith connected turbine admission ports or nozzles have fixed throughflow areas, and in accordance with the laws of steam-flow, the weight of steam which they can pass is zero while the pressure in the turbine casing and against the stationary pistons of the rotary engine has built up to the accumulator pressure; the pounds of steamflow increase with the piston displacement, but only up to that displacement with which the pressure within the turbine casing and against the engine pistons has dropped to about 58% of the accumulator pressure. During expansion of the steam below this just mentioned "critical" pressure, the weight of the steam-flow remains constant in spite of an increase of the piston displacement, but the steam continues to expand more and more in the turbine. As the piston displacement increases, the speed of the turbine 15, of course, increases similarly, and more and more of the steam's kinetic

energy is abstracted by the turbine vanes, which causes the pressure against the rotary engine pistons to become lower and lower. Thus the displacement engine transfers more and more of its torque producing function—which it had exercised so efficiently in starting the drive shaft—to the turbine 15, which latter would have exercised this function most inefficiently in starting the shaft by itself, but which can contribute torque to the joint drive more and more efficiently as the drive shaft speed increases. With a proper number and a proper dimensioning of the ports 14, the pipes 16 and the turbine nozzles or ports connecting with them in relation to the piston displacement of the rotary engine, one can vary the speed range within which the steam weights withdrawn from the accumulator vary with the piston displacement, and one can obtain, in the case of the arrangement of Fig. 1, a close enough proportionality between the steam throughflow areas as created by piston 11 in its movement, and the fuel quantity needed to maintain a virtually constant accumulator pressure, without the employment of a shaft speed responsive device.

In order to add further to a clear understanding of the just described torque producing method in operating a variable speed traction shaft, Figs. 3 and 4 are referred to. In Fig. 3 a typical variation of the steam generation pressure, of the accumulator pressure, and of the final exhaust pressure in relation to the shaft speed are shown, and so marked. In Fig. 4 the component and resulting torques are shown in relation to shaft speed, i. e. the primary turbine torque, the torque produced in the secondary expansion stage, and the total resulting torque on the load shaft. One curve refers to the performance of the plant as shown in Fig. 1 only and indicates the torque of the rotary engine.

Fig. 2 is a greatly simplified showing of a power plant specified in my Patent No. 2,418,477 of April 8, 1947, whereas Fig. 1 is novel in that it employs a rotary engine in combination with a turbine as secondary expansion stage of an otherwise similar plant. The means of regulating the supply of feed water to the accumulator and to the boiler, in order to replace the water that has been evaporated, has been purposely omitted in the showing of this invention in both Figures 1 and 2, in order not to complicate the drawings, as it is not claimed as a part of this invention. However, it is essential to point out that a plentiful supply of water should be carried in the accumulator in order to make the arrangement workable. Also, it should be pointed out that the reason for imparting all of the heat of the steam exhausted by the primary turbine to the water in the accumulator, and then to withdraw this same heat in the shape of steam for use in the secondary expansion stage instead of connecting the primary turbine exhaust with the secondary expansion stage inlet directly, and instead of supplying the accumulator only with the excess steam which is exhausted by the turbine and which cannot be admitted to the secondary expansion stage, as indicated in the showing of Fig. 2, is purposely resorted to because a rotary engine of the type which it is intended to use, cannot be practically operated with greatly varying steam temperatures. Therefore it is necessary, when using a rotary engine, to desuperheat the steam exhausted by the primary turbine, and this may be accomplished by bubbling its ex-

haust steam through the water within the accumulator.

This application is a continuation in part of my co-pending application Serial No. 373,883, filed January 10, 1941, for Steam power plant, now issued as said Patent No. 2,418,477.

Where in the specification and claims the expression "wholly impinged" is used, that expression is to be taken as meaning that the blades of the turbine are ungoverned. One example of a wholly impinged turbine is one in which there is a fixed number of blades with fixed nozzle openings which are all constantly opened and of unvarying capacity and without any governing means. In one sense, therefore, the expression "wholly impinged" may be taken as meaning an ungoverned turbine.

I claim:

1. In combination in a steam power plant, a wholly impinged primary expansion turbine comprising a primary expansion stage and, compounded therewith, a secondary turbine and a secondary expansion piston engine comprising a secondary expansion stage, a drive shaft, said turbines and engine mechanically coupled to the said drive shaft, a boiler for the unthrottled supply of superheated steam to the primary expansion stage, means for firing said boiler, an accumulator of steam of lower than boiler pressure connected into the pipe between a plurality of expansion stages, means for variably supplying steam to the vanes of the secondary turbine, therewith co-acting means for similarly varying the firing rate in the boiler furnace, automatic means responsive to the accumulator pressure, and supplementary to the aforementioned means for varying the firing rate, which adjust the firing whenever the accumulator pressure varies from a predetermined value.
2. In combination in a steam power plant, a primary expansion turbine comprising a primary expansion stage and, compounded therewith, a secondary turbine and a secondary expansion piston engine comprising a secondary expansion stage, a drive shaft, said turbines and engine mechanically coupled to the said drive shaft, a boiler for the unthrottled supply of superheated steam to the primary expansion stage, means for firing said boiler, an accumulator of steam of lower than boiler pressure connected into the pipe between a plurality of expansion stages, means for variably supplying steam to the vanes of the secondary turbine, therewith co-acting means for similarly varying the firing rate in the boiler furnace, automatic means responsive to the accumulator pressure, and supplementary to the aforementioned means for varying the firing rate, which adjust the firing whenever the accumulator pressure varies from a predetermined value.
3. In combination in a steam power plant, a wholly impinged primary expansion turbine comprising a primary expansion stage and, compounded therewith, a secondary turbine and a secondary expansion constant cutoff piston engine comprising a secondary expansion stage, a common drive shaft, both turbines and engine being coupled to the said drive shaft, a boiler for the unthrottled supply of superheated steam to the primary expansion stage, means for firing said boiler, an accumulator of steam of lower than boiler pressure connected into the pipe between the two expansion stages, means for variably supplying steam to the vanes of the secondary turbine, therewith co-acting, means for similarly varying the firing rate in the boiler furnace,

automatic means responsive to the accumulator pressure, and supplementary to the aforementioned means for varying the firing rate, and for adjusting the firing whenever the accumulator pressure deviates from a predetermined value.

4. In combination with a variable speed power shaft, a wholly impinged primary expansion turbine and a secondary expansion turbine and a rotary piston displacement uniflow engine, said turbines and said engine being mechanically coupled to said shaft, a boiler adapted to generate superheated steam, means for feeding unthrottled steam from said boiler to said primary turbine, a steam accumulator, an exhaust connection from said primary turbine to said accumulator, a connection from said accumulator to said secondary turbine, and a variable control in said last-mentioned connection whereby the supply of steam to said secondary turbine is varied, a connection from the exhaust of said secondary turbine to said rotary engine, means for supplying variable quantities of fuel to said boiler, actuated by said variable control, and means in response to pressure in said accumulator cooperating in the variation of the firing of said boiler.

5. In combination with a variable speed power shaft, a wholly impinged primary expansion turbine and a secondary expansion turbine and a rotary piston displacement uniflow engine, said turbines and said engine being mechanically coupled to said shaft, a boiler adapted to generate superheated steam, means for feeding unthrottled steam from said boiler to said primary turbine, a steam accumulator, an exhaust connection from said primary turbine to said accumulator, a connection from said accumulator to said secondary turbine, and a variable control in said last-mentioned connection whereby the supply of steam to said secondary turbine is varied, a connection from the exhaust of said secondary turbine to said rotary engine, means for supplying variable quantities of fuel to said boiler, other means operating in response to pressure in said accumulator which cooperate in the firing of said boiler, said first-mentioned means being connected to the means for varying the supply of steam to said secondary turbine, whereby the latter and said first-mentioned means for varying the firing of said boiler are operated simultaneously and in a predetermined relation to each other.

6. In combination, in a variable speed steam driven vehicle, a drive shaft, means to drive said shaft, comprising a primary expansion wholly impinged steam turbine and a secondary expansion piston displacement engine having a variable cutoff, a boiler, means for varying its rate of firing, a conduit supplying said turbine with unthrottled steam from said boiler, an accumulator of steam connected both to the exhaust of said turbine and to the admission of said engine, the means for varying the engine cutoff being interlocked with the means employed for varying the rate of boiler firing so as to obtain a rough proportion between the steam demand of the engine and the rate of steam generation in the boiler, and an additional firing regulating means for finely adjusting said proportion, the latter firing regulating means being adapted to respond to the pressure within the accumulator to keep the accumulator pressure virtually constant at all speeds and power outputs of said drive shaft.

7. In combination in a steam power plant, a primary expansion turbine and, compounded therewith, a secondary expansion turbine and a

tertiary expansion constant cutoff piston engine, a drive shaft, said turbines and engine being mechanically coupled to the said drive shaft, a boiler adapted to supply superheated steam, unthrottled, to all of the vanes of said primary expansion turbine, a closed unfired vessel adapted to be partially filled with water and having a steam space above said water, a connection from said vessel through which the primary expansion turbine is adapted to discharge all of its exhausted steam, a connection from the steam space through which steam is supplied to the secondary expansion turbine, means for varying, without throttling, the quantity of steam which is thus admitted from the accumulator to the secondary expansion turbine, and co-acting means for varying the firing rate in the boiler furnace in rough proportion to said admitted steam quantity, automatic means responsive to the accumulator pressure for finely adjusting the firing rate established by the first-mentioned fire regulation means whenever the accumulator pressure varies from a predetermined value.

8. In combination in a steam power plant, a wholly impinged primary expansion turbine and, compounded therewith, a secondary expansion turbine and a tertiary expansion piston displacement engine with fixed cutoff, a common drive shaft, both turbines and engine being coupled to the said drive shaft, a boiler adapted to supply superheated steam, unthrottled, to the primary expansion turbine, mechanical means for firing said boiler, an accumulator of steam, connections through which it receives its steam charge from the exhaust of the primary expansion turbine and through which it furnishes steam to the admission side of the secondary turbine, means for varying, without throttling, the quantity of steam which is admitted from said accumulator to said secondary expansion turbine, and co-acting means for varying the firing rate in the boiler furnace in rough proportion to the steam quantities which pass from the accumulator to the secondary expansion turbine, and automatically operative supplementary fire regulating means which are responsive to the accumulator pressure and adjust the firing rate established by the first-mentioned fire regulation means correctively so as to keep the accumulator pressure virtually constant at all speeds and power outputs of said drive shaft.

9. In combination in a steam traction power plant, a wholly impinged primary expansion turbine and, compounded therewith, a secondary expansion turbine and a tertiary expansion rotary piston displacement engine of fixed cutoff, a common drive shaft, both turbines and engine being coupled to the said drive shaft, a boiler adapted to supply superheated steam, unthrottled, to the primary expansion turbine, mechanical means for firing said boiler, an accumulator of steam, connections through which it receives its steam charge from the exhaust of the primary expansion turbine and through which it furnishes steam to the admission side of the secondary expansion turbine, means for varying, without throttling, the quantity of steam which is admitted from said accumulator to said secondary expansion turbine, and co-acting means for varying the firing rate in the boiler furnace in rough proportion to the steam quantities which pass from the accumulator to the secondary expansion turbine, and automatically operative supplementary fire regulating means which are responsive to the accumulator pressure and adjust

11

the firing rate established by the first-mentioned fire regulation means correctively so as to keep the accumulator pressure virtually constant at all speeds and power outputs of said drive shaft.

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