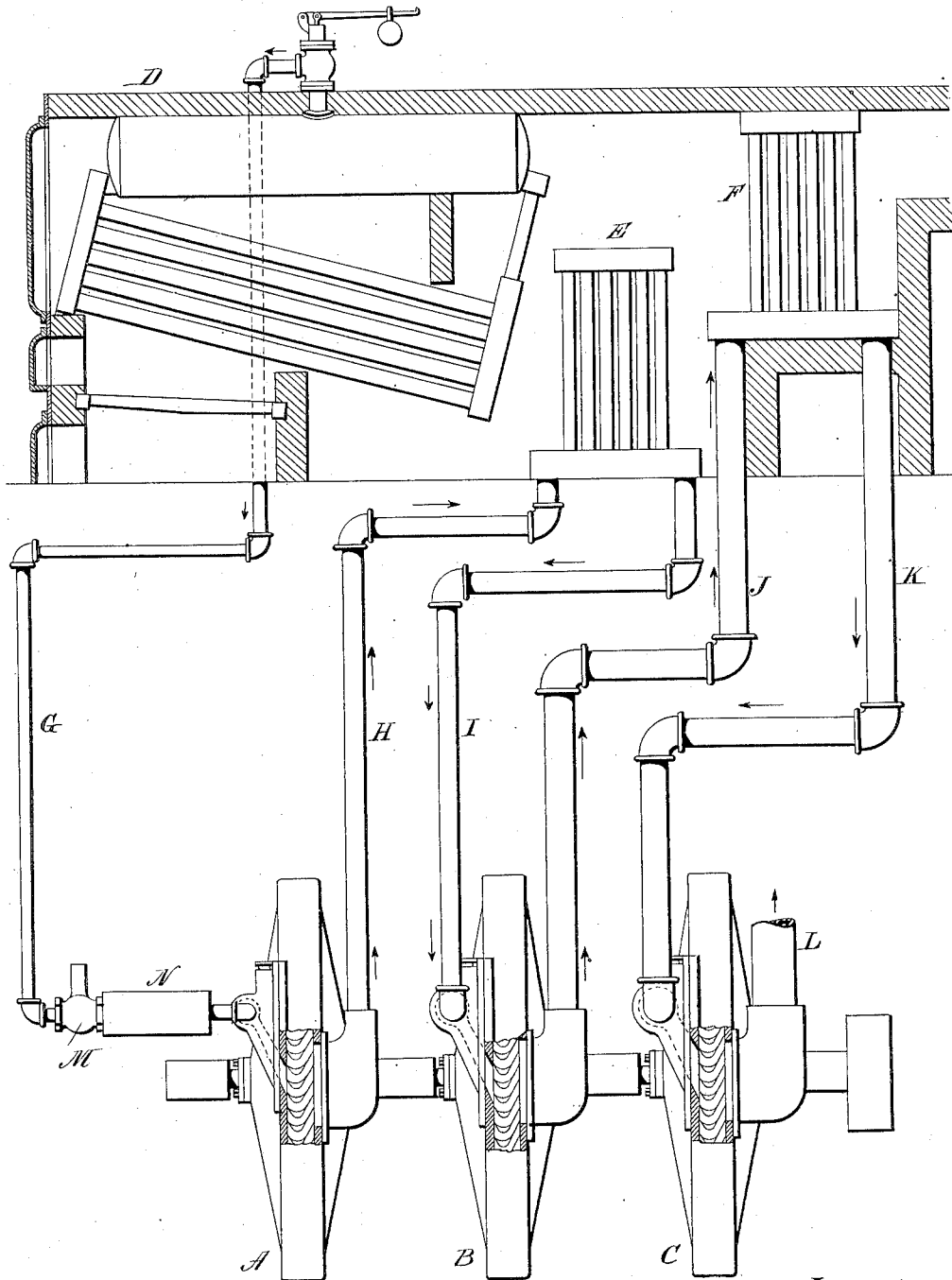


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ELASTIC FLUID TURBINE.
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UNITED STATES PATENT OFFICE.

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ELASTIC-FLUID TURBINE.

1,089,115.

Specification of Letters Patent.

Patented Mar. 3, 1914.

Continuation of application Serial No. 631,481, filed April 9, 1897. This application filed October 2, 1905. Serial No. 280,995.

To all whom it may concern:

Be it known that I, CHARLES G. CURTIS, a citizen of the United States, residing at New York city, in the county and State of New York, have invented a certain new and useful Improvement in Elastic-Fluid Turbines, of which the following is a specification.

The object I have in view is to provide means by which superheated steam may be effectively utilized in my improved compound steam turbine, which is particularly described in Letters Patent numbered 566,967, 566,968 and 566,969, granted September 1, 1896, and to do this in such a way as to obtain the most efficient result as regards economy of steam, and with the most desirable and safe forms of apparatus.

This application is a continuation of an application for patent filed by me April 9, 1897, Serial No. 631,481.

The ordinary method of superheating steam by conducting it directly from the boiler and at boiler pressure through a superheater before admission to the engine is open to both practical and theoretical objections. The tubes or shells constituting the superheater are necessarily subjected to quite a high temperature, in order to raise the temperature of the steam any considerable amount above the temperature of saturation at the given boiler pressure, and the apparatus being under considerable pressure, which becomes very large in the case of high boiler pressures, there is great danger of burning out or bursting. Moreover, superheating carried on in this way cannot be effectively worked with the waste gases from the boiler, owing to their low temperature, and hence an independent firing is required.

My object is to provide means whereby my improved steam turbine may be adapted to the use of superheated steam so as to secure the highest economy of steam, and under such conditions that the superheating operation or operations are carried on at very low pressures and comparatively low temperatures, so that both the temperature and pressure to which the superheater is subjected shall be below the objectionable points, and the superheater may be operated with the waste gases from the boiler.

Instead of passing the steam from the

boiler first through the superheater, according to the usual custom, I cause it first to pass through a portion of the turbine in which it is expanded to a definite extent, and a portion of its pressure and its intrinsic energy is converted into work. If we assume a case where the boiler pressure say is 150 pounds (by gage), and the turbine be operated condensing, the expansion taking place in any three stages, on the principle described in my Patent No. 566,969 above referred to, and all stages developing equal amounts of work, the expansion in the first stage will bring the pressure down to about twenty or twenty-five pounds (gage pressure).

The temperature of the steam at this pressure will be only about 265° F. as compared with a temperature of 365° F. at 150 pounds pressure—a drop of 100°. At this temperature the superheating can be carried on with hot gases which are at a much lower temperature, so that there is much less danger of burning out the superheater tubes, and the pressure is so far reduced that the danger of explosion is greatly reduced. After passing through the first portion of the steam turbine, the steam at the final pressure of this stage, which, in the case supposed is twenty or twenty-five pounds, is conducted through a suitable reheater, which is preferably operated by the waste boiler gases, and in this reheater as much heat may be added as is desired.

The amount of superheat applied to the steam may be sufficient to keep the steam dry during the entire subsequent expansion down to the exhaust, or it may be only sufficient to carry it dry through a part of the subsequent expansion, for example, through the second stage of a three stage expansion. It is desirable, however, in order to obtain an efficient result, to have a degree of superheat at least equal to any condensation during the expansion, for it not only increases the energy of the steam and the velocity with which it can be made to act upon the blades of the turbine, but it diminishes the friction of flow of the fluid against the surfaces of the blades, and thereby reduces the loss of energy from this cause. Whatever quantity of heat may be added in this way, however, will have two effects. First, if there be any water in the steam coming

over from the previous expansion stage, as there will be unless the steam in the previous stage has been sufficiently superheated in some way to prevent condensation during expansion, the first effect will be to re-evaporate the water or condensed portion, increasing the volume of the fluid to this extent; and, second, to raise the temperature of the steam, thus increasing its volume from this cause, and also increasing the intrinsic energy contained in the steam. After passing through the reheater, therefore, the volume of steam has been increased a definite amount, depending upon the amount of moisture in the steam as it enters the reheater and upon the rise of temperature occasioned by the superheat and at the same time its intrinsic energy or capacity to develop velocity and *vis viva* by proper expansion has also been increased. I have found, therefore, that in delivering the steam after superheating to the next portion of my improved turbine, the expansion passage through which the steam is made to flow and in which its velocity or energy is converted into work in the turbine in the next stage must be so designed as to provide for this increased volume of fluid, and must be also so designed as to provide the proper ratio or degree of expansion in the working passage (as described particularly in my Patent Number 566,968), so as to convert the pressure most effectively into velocity by expansion, and obtain the greatest sum total of velocities at the various points of action upon the moving parts of the turbine. The increase of cross-section or ratio of expansion in each portion of the turbine, including the nozzle, must, in order to get efficient results, be somewhat less, in the case of superheated steam or other elastic fluid than in the case of ordinary saturated steam; first, because the increase of volume by a given decline in pressure is less compared with the velocity developed in the case of superheated steam than in the case of saturated steam (the expansion curve in case of superheated steam being represented by the equation

$$P_1 V_1^{1.3} = P V^{1.3},$$

whereas the expansion curve of saturated steam is according to the equation

$$P_1 V_1^{1.11} = P V^{1.11},$$

and hence a less increase of cross-section in the expansion steam passages is required to develop the maximum velocity of flow than if the steam were saturated during expansion; and, second, because the diminution in the jet's velocity by frictional retardation or surface friction, against the walls of the vanes and other parts of the passage may be considerably less than in the case of saturated steam, owing to the fact that the

steam is dry and therefore free from the particles of water which in the case of saturated steam are being developed by condensation and deposited on the surface of the buckets, causing increased friction, it being borne in mind that the greater the frictional retardation at any point, the greater cross-section of passage is, of course, necessary to convey the given volume of fluid. From one or both of these causes, therefore, the necessary increase of cross-section or the ratio of expansion in the steam passageway, to give an efficient result, should be considerably less in the case of superheated steam than in that of saturated steam, and it is highly important that this ratio should be no more than that exactly sufficient under the existing conditions, for if the passageway be too large at any point, the velocity may be only slightly less than it should be, but, nevertheless, the loss of energy may be considerable, because the energy developed or work done increases and diminishes with the square of the velocity. Hence, a very slight loss of velocity causes a much greater loss in efficiency. The proper theoretical ratio of expansion to provide for the correct conversion of pressure into velocity working with superheated steam is, of course, capable of calculation, but, to make provision for the effects of friction and other causes affecting the flow, the proper ratio of expansion as well as the actual cross-section of passageway necessary to convey the fluid should, in each case, be found by trial, depending as it does upon a number of conditions. This can best be done by making the passageway or parts of the passageway in each part of the turbine capable of a double adjustment, as I have described in my patent 589,466, dated September 7, 1897 so that not only may the cross-section or size of the passageway be varied, but the ratio of expansion (in the nozzle at least) may also be varied and best adapted to the particular condition found to exist at each stage in the expansion. The apparatus may be so constructed as to provide this diminished increase of cross-section either in the nozzle itself or in the subsequent parts of the working passage,—or in both combined,—the desideratum being that the expansion finally determined upon should be exactly sufficient and no more than sufficient to develop the maximum velocities at the points of action in the turbine so as to get the benefit, as far as possible, of the additional energy represented by the superheat. The most satisfactory way of doing this is by trying different degrees of expansion under the particular conditions under which the turbine is to work in practice, until the best degree of expansion is found, and the most simple means of trying different ratios of expansion is to construct the nozzle, as

described in my patent 589,466, so that its ratio of expansion may be increased or diminished, and at the same time the virtual cross-section of the passage may be kept constant or maintained of sufficient size to transmit the quantity of steam received from the previous stage, and at the increased volume resulting from the subsequent reëvaporation and superheating. By trying different degrees of expansion, either by varying the nozzle or other parts of the working passage, and at the same time keeping the cross-section of the steam passage in the two or more stages adjusted relatively to each other so as to transmit the same quantity of steam, but under the peculiar conditions existing at the beginning of each stage, and maintain the desired pressure at the end of each stage, the proper relation of the parts may be found which will give the best results.

After passing through the second portion of the turbine, the pressure and temperature will have become still further reduced. In the case proposed, that of a three-stage expansion, the pressure at this point will be about 12 or 14 inches of vacuum, and the temperature, provided the superheat has been exhausted by the previous expansion so that the steam is then saturated, will be only about 163° F. The steam may then be passed through a second reheater, wherein any condensed portion will be evaporated and the temperature of the steam afterward raised to the desired degree, its volume and intrinsic energy being increased to a certain degree, as before.

The third portion of the turbine I construct similarly, so that the working passage through which the steam flows is adapted to carry the steam received from the previous stage, but at the increased volume, and so as to provide the expansion necessary to convert this superheated steam into work in this stage in the most efficient manner. Instead of passing the steam through the second reheater, this may be dispensed with, and all the heat furnished to the steam by the first reheater, but theoretically it is preferable to divide the superheating into stages, because in this way part of the superheating is carried on at a lower temperature than if all the superheating were done at once, and hence hot gases can be used to effect part of the superheating which are at a very much lower temperature, and the heat more readily transferred to the steam, the hot gases coming into contact with the reheaters in the order of the decline in pressure and temperature. The boiler steam may, of course, be superheated by a special superheater before it enters the first portion of the turbine, but I prefer either to dispense with superheating entirely in the first or early stages or to obtain a certain amount of superheating by passing the steam on its

way to the turbine through a reducing valve, using a boiler pressure considerably above the pressure at which the steam enters the turbine. In this way the pressure may be reduced and the steam superheated to a certain extent by "wire drawing" through the reducing valve in the well known way, and a sufficient degree of superheat may practically be obtained in this way to keep the steam dry during the first or early stages of its expansion, and thus materially increase its efficiency.

While the use of steam as the elastic fluid has been so far particularly referred to, I wish it understood that my present invention is applicable to elastic fluid turbines employing other elastic fluids than steam.

The accompanying drawing illustrates an apparatus embodying my invention.

A, B and C represent the three sections of an elastic fluid turbine constructed in accordance with my Patent No. 566,969, and operating, as does the turbine of that patent, to convert and utilize, in successive operations or stages, different portions of the pressure of the elastic fluid into *vis viva*. Each section of the turbine is, as described in said patent, inclosed in a separate fluid-tight shell, and is provided with an expansion nozzle for converting the desired amount of pressure into *vis viva*, and with an expansion working passage through movable vanes, the passageway including the expansion nozzle and expansion working passage of each successive section of the turbine being sufficiently larger than the passageway of the preceding section to accommodate the increased volume of the fluid jet due to its lower pressure, all as described in said patent. The passageway through each of the several sections of the turbine, when used with superheated steam in accordance with my present invention, is, however, given proportions different from those employed when saturated steam is used, as has already been described.

D is the steam boiler, and E and F are reheaters located so as to be heated by the waste products of combustion from the boiler furnace.

G is the pipe conveying the steam to the first section of the turbine; H and I are the pipes connecting the reheater E between the sections A and B of the turbine; J and K are the pipes connecting the reheater F between the sections B and C of the turbine; and L is the final exhaust from the section C of the turbine, which, in case the engine is operating as a condensing engine, will be connected with a condenser or other means for producing less than atmospheric pressure.

M is a reducing valve for "wire drawing" the steam before it enters the first section of the turbine, and N is a chamber located be-

tween the reducing valve M and the first section of the turbine.

Having now described my invention what I claim as new and desire to secure by Letters Patent is:

1. In an elastic fluid turbine, the combination with a turbine having a plurality of stages, means for withdrawing steam from a stage into a reheater, means for returning the reheated steam into a subsequent stage, such stage being of greater area than the area required for saturated steam, but with the increase of ratio of expansion less than that required for saturated steam.

2. In an elastic fluid turbine, the combination with a turbine having a plurality of stages, each comprising a nozzle and a rotor, the nozzles in the several stages being proportioned one to another to pass equal amounts of energy, means for withdrawing steam from one stage into a reheater, and means for returning the reheated steam into a subsequent stage, such stage being of greater area than the area required for saturated steam.

3. In an elastic fluid turbine, the combination with a turbine having a plurality of stages, each comprising a nozzle and a working passage, means for withdrawing steam

from a stage into a reheater, means for returning the reheated steam into a subsequent stage, the working passage of such stage being of greater area than that required for saturated steam, but with the increase of ratio of expansion less than that required for saturated steam.

4. An elastic fluid turbine comprising a plurality of stages, each provided with a nozzle and a rotor having expanding working passages, in combination with a reheater, a means receiving steam from the turbine after it has performed work therein and conveying it to the reheater, and a second means receiving the reheated steam and conveying it to the nozzle of a subsequent stage of the turbine, said nozzle having a cross-sectional area greater than that required for saturated steam, and with its co-operating working passage having a ratio of expansion less than that required for saturated steam.

This specification signed and witnessed this 28th day of September, 1905.

CHARLES GORDON CURTIS.

Witnesses:

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