Nov. 6, 1928.

1,690,787

H. M. KNIGHT

TIDAL HYDRAULIC AIR COMPRESSOR

Original Filed Oct. 7, 1921

4 Sheets-Sheet 1

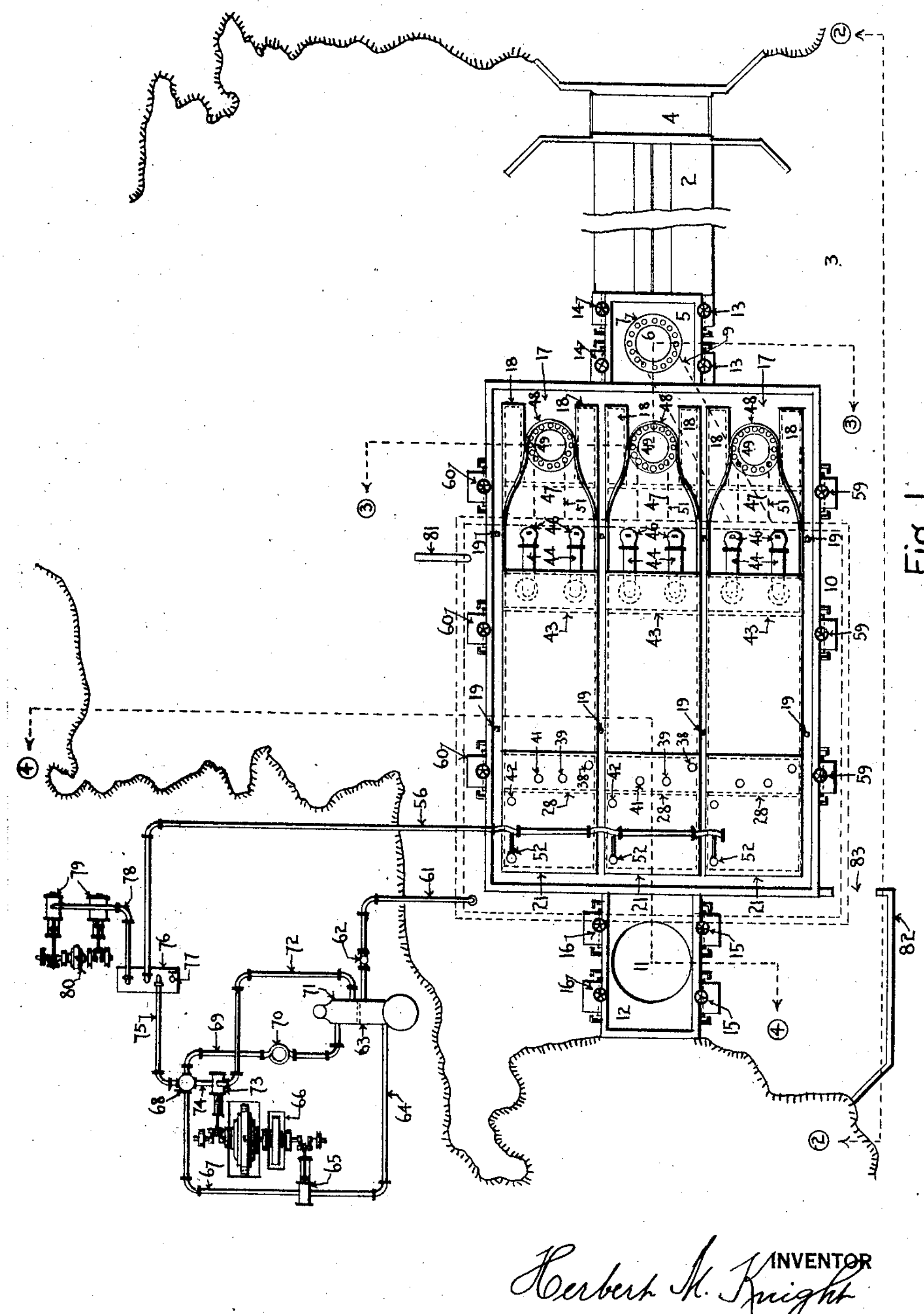

Fig. 1

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TIDAL HYDRAULIC AIR COMPRESSOR

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4 Sheets-Sheet 2

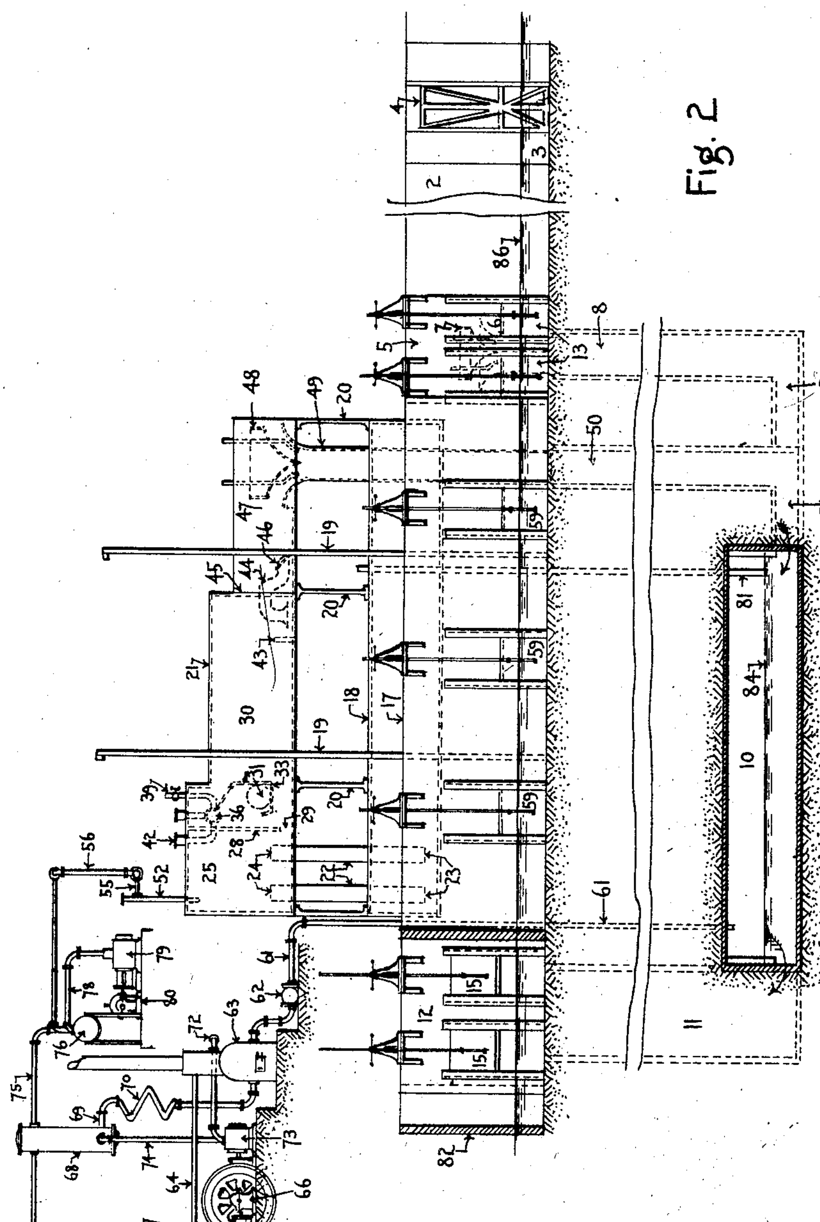

Fig. 2

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TIDAL HYDRAULIC AIR COMPRESSOR

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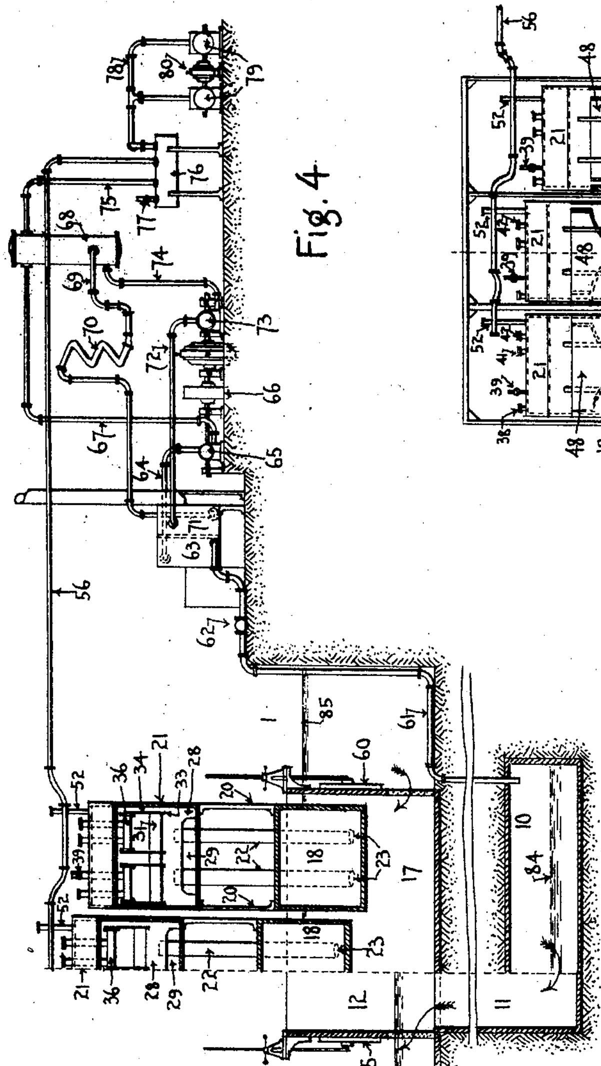


Fig. 4

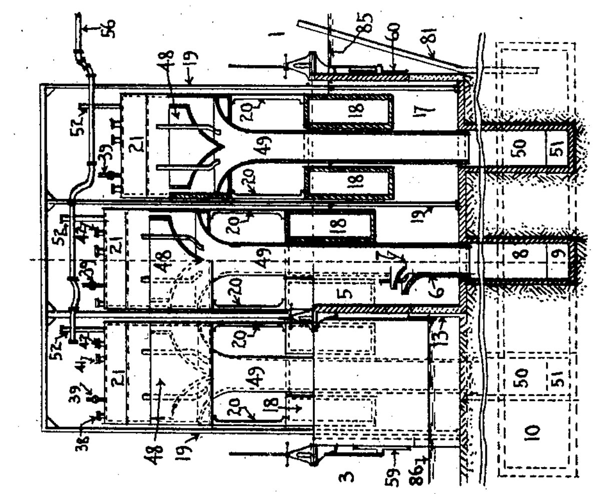


Fig. 3

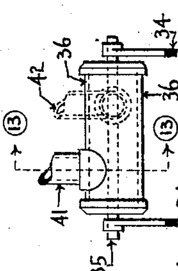


Fig. 11

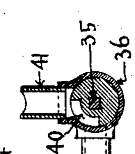
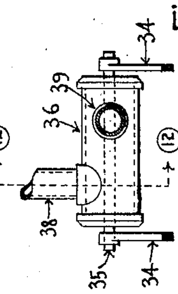


Fig. 13



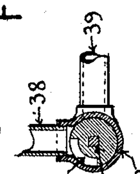


Fig. 12

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Nov. 6, 1928. **1,690,787**

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TIDAL HYDRAULIC AIR COMPRESSOR

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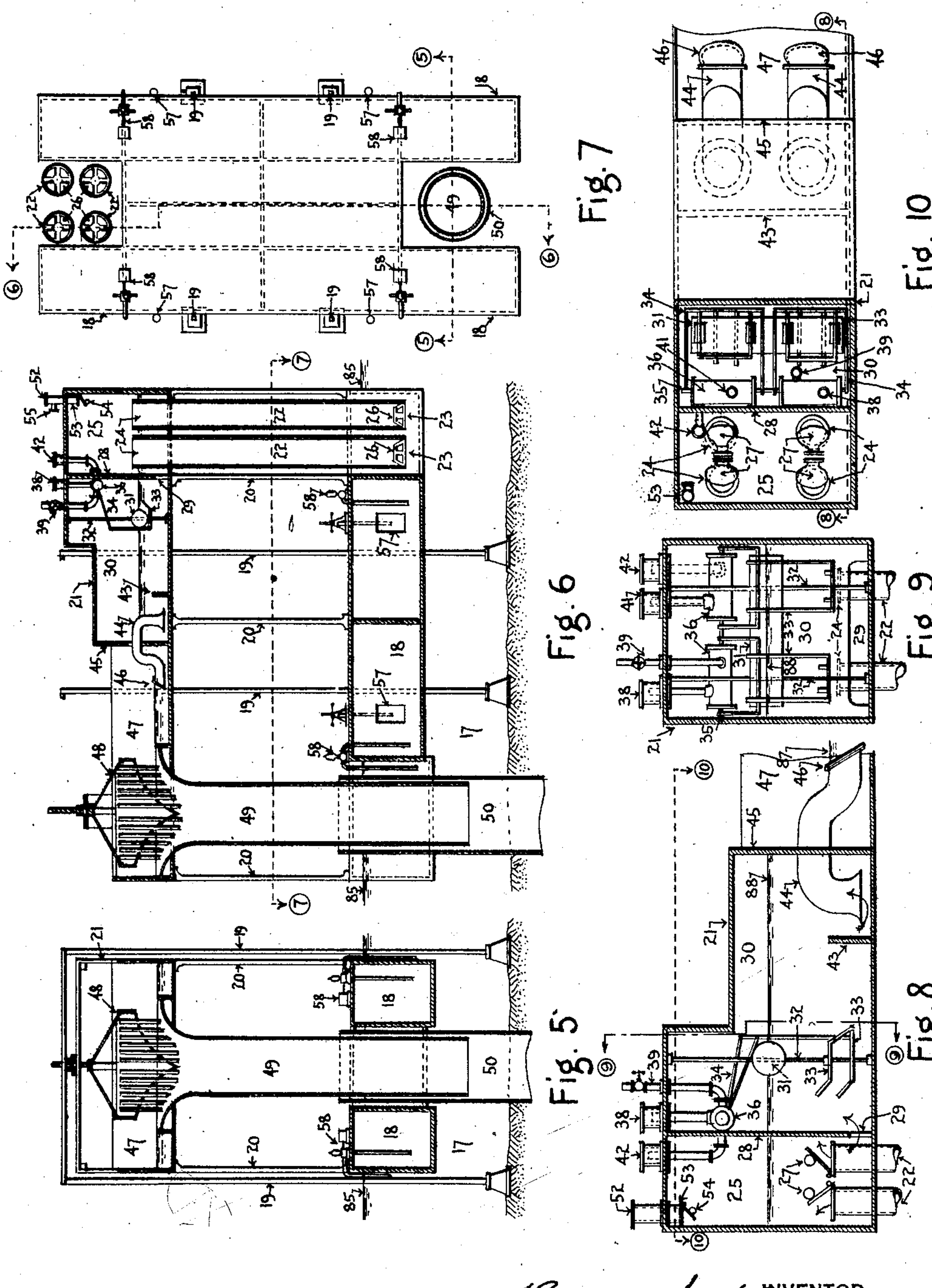

INVENTOR

Herbert M. Knight

Patented Nov. 6, 1928. 1,690,787

UNITED STATES PATENT OFFICE.

HERBERT M. KNIGHT, OF MONTCLAIR, NEW JERSEY.

TIDAL HYDRAULIC AIR COMPRESSOR.

Application filed October 7, 1921, Serial No. 506,006. Renewed April 3, 1928.

This invention relates to hydraulic air compressors and has specific application to that type of hydraulic compressor known as a tidal compressor.

One of the objects of this invention is to produce a tidal compressor which shall be operative on both the flood and ebb tides. Another object of the invention is to produce a tidal compressor in which the water is elevated above the tidal stage, giving a greater head than that which is possible from the normal tidal fluctuation. Another object of the invention is to produce a tidal compressor which shall be continually operative, during operating periods, under a constant head rather than a variable head. Another object of the invention is to produce a tidal compressor in which the tidal elevations shall be equalized before each tidal change. Another object of the invention is to produce a tidal power plant composed of two inter-related parts, a tidal compressor operated under an augmented head induced by low pressure air exhausted in an air expansion engine and an air expansion engine exhausting below atmosphere after pre-heating, refrigerating and regeneration. Other objects of the invention will appear from the following description and from the accompanying drawings.

The accompanying drawings, Figs. 1 to 13 inclusive illustrate the usual and preferred embodiment of the invention but are not to be considered as inclusive of any and all forms in which the invention may be embodied, nor as exclusive of forms other than that indicated.

I illustrate my invention by the accompanying drawings in which Fig. 1 is a plan view of my tidal compressor plant, Fig. 2 is an elevation of such a tidal compressor plant on the line 2—2 of Fig. 1; Fig. 3 is a cross-section on the line 3—3 of Fig. 1; Fig. 4 is a cross-section on the line 4—4 of Fig. 1; Fig. 5 is a cross-section of a supporting pontoon on the line 5—5 of Fig. 7; Fig. 6 is a longitudinal section of a pontoon and its supported water elevating apparatus on the line 6—6 of Fig. 7; Fig. 7 is a horizontal section on the line 7—7 of Fig. 6; Fig. 8 is a longitudinal section of the water elevating means on the line 8—8 of Fig. 10; Fig. 9 is a cross-section of the water elevating means on the line 9—9 of Fig. 8; Fig. 10 is a horizontal section of such water elevating means on the line 10—10 of Fig. 8; Fig. 11 is an elevation of the automatic valve of the water elevating apparatus; Fig. 12 is a cross-section of this valve on the line 12—12 of Fig. 11 and Fig. 13 is a cross-section of this valve on the line 13—13 of Fig. 11.

Referring to the drawings in which similar numbers refer to similar parts; 1, is a tidal estuary closed by a dam 2, from the sea 3, and having a lock 4, in said dam.

In a fore-bay basin 5, connected with the dam, is located an initial compressor 6, having a head-piece 7, telescoping in a down-take pipe 8, connected by a passage 9, with a separation chamber 10. An up-take pipe 11, discharges into a tail-race basin 12. Gates 13, are located on the seaward side of the fore-bay basin and other gates 14, are located on the estuary side thereof. Gates 15, are located on the seaward side of the tail-race basin and other gates 16, are located on the estuary side thereof.

A fore-bay basin 17, floats pontoons 18, located between guides 19. Posts 20, attached to the pontoons support a water elevating apparatus 21. Supply pipes 22, have their lower ends 23, immersed in the water of the fore-bay and their upper ends 24, open into a vacuum chamber 25. Foot-valves 26, are located near the lower extremities of the supply pipes and flap-valves 27, are upon their upper ends. A partition 28, having a sealed opening 29, in the bottom thereof separates the vacuum chamber from the float chamber 30. A float 31, traverses vertically upon the guides 32. Float arms 33, engage the float at its highest and lowest points of travel. Valve-arms 34, are attached to the float-arms and also to the arbor 35, of a divided automatic valve 36. A port 37, operates to open and close communication between a pipe 38, freely open in the roof of the float-chamber and a pipe 39, regulatably open to the atmosphere, and a port 40 operates in alternation with the previous port to open a close communication between a pipe 41, freely open in the roof of the float-chamber and a pipe 42, freely open in the roof of the vacuum chamber. A weir 43, is located in the float chamber trapping the sealed opening in the dividing partition between the vacuum chamber and the float-chamber. Siphon draft-tubes 44, pass through the end casing 45, of the float chamber and discharge beneath a flap-valve 46, into a discharge conduit 47, leading to a head-piece 48, suspended over a telescoping section 49, supported by the pontoon and which descends into the down-take pipe 50, connected by a passage 51, with the separation chamber. An outlet 52, with its face 53, near the roof of the vacuum chamber, is protected by a flap-valve 54, and has a connection 55, with a pipe 56, leading to a source of vacuum. Flood-gates 57, and pumps 58, regulate the immersion and trim of the pontoons. Gates 59, are located on the seaward side of the fore-bay basin and other gates 60, are located on the estuary side thereof.

An air supply main 61, leads from the separation chamber, a regulating valve 62, being located thereon, and enters a pre-heater 63. A high-pressure main 64, leads to the initial cylinder 65, of an air engine 66. An exhaust main 67, leads from the initial cylinder to a freezer 68. A dry-air main 69, leads through an atmospheric interchanger 70, to the heat regenerator 71. A supply main 72, leads to the supplementary expansion cylinder 73. An exhaust main 74, leads from the supplementary expansion cylinder to the freezer. A low pressure exhaust main 75, leads from the freezer to the vacuum tank 76. A vacuum regulating valve 77, is attached to said vacuum tank. A vacuum pipe 78, is connected to the cylinders 79, of a vacuum pump 80. A blow-off pipe 81, connects the separation chamber with the atmosphere. A wave protection wall 82, is located seaward of the tail-race basin, having openings 83, therein. The lowest point of the water surface of the separation chamber is at 84, which is the bottom of the blow-off pipe. An elevation of the water surface within the fore-bay basin and on one side of the dam is at 85, while 86, represents the water surface on the other side of the dam and within the tail-race basin. The water surface of the discharge channel is at 87, and that of the float-chamber 88.

A hydraulic compressor is an apparatus designed to entrain air by the passage of water under a head through a tubular head-piece, the combined air and water descending a down-take pipe to a considerable depth, below the tail-race level, the air being gradually compressed in its descent, the air and water being discharged into a separation chamber, in which the entrained air is liberated and rises above the water surface, due to the slowing up of the stream of water in the chamber, after which separation, the water rises in an up-take column to the tail-race level. The power utilized is that represented by the amount of water and the difference in elevation between the fore-bay and the tail-race, or, in the case of a tidal compressor, the difference in elevation between the surface of the water above and below the dam, and the pressure of the air in the separation chamber is that represented by the weight of the column of water whose height is the difference between the elevation of the water in the separation chamber and the elevation of the surface of the water in the tail-race. Such hydraulic compressors are generally installed upon streams above their tidal basins, and in locations where constant, or nearly constant relation exists between the elevations of the fore-bay and tail-race, respectively. But in the case of a tidal compressor this is entirely otherwise, the estuary fluctuating from the maximum elevation at flood to the minimum of ebb tide twice daily. A tidal compressor under such conditions is subjected to a constantly varying head during both the flood and the ebb tides. It becomes necessary, due to the varying head, to wait a long time at each turn of the tide, before a sufficient fall has developed to make the operation of the compressor either possible or satisfactory, such waiting cutting down materially the effective hours of operation. As most tidal fluctuations are comparativelly small in amount, such delay, in order to secure a working head, makes the utilization of tidal powers of doubtful value, as ordinarily developed.

This invention overcomes the usual and manifest defects of ordinary tidal power development by the following means. A dam is erected across the mouth of a tidal estuary, locks being provided therein for the passage of vessels at all water stages.

By the construction of such a dam, a tidal head can be produced on both the ebb and the flood tides, and a condition established resulting in four operative periods during a 24 hour day. But these four operative periods may be of comparatively short duration, especially where the amplitude of tidal fluctuation is slight, due to the fact that a certain period of time must be allowed in which to establish a difference between the elevations of the water on the two sides of the barrage, sufficient to produce an adequate working head. This may be as much as one-half of the tidal period, so that continuous operation may not be possible above three hours at any one time. By my invention these difficulties are overcome, a constant working head maintained and a considerable lengthening of the operative period secured by use of a means for augmenting the normal head, as represented by the difference in the elevations of the water on either side of the barrage, by elevating the water before passage through the hydraulic compressor.

The operation of this water elevating means is as follows: Connected with the dam is a fore-bay basin. This fore-bay basin is completely enclosed by walls higher than the point of highest tide, the only means of connection therewith being through gates connecting with the estuary and with the sea, respectively. When the water is higher in the estuary the gates connecting therewith are open and water enters the fore-bay therethrough, the sea-ward gates being closed, and, conversely, upon the reversal of the tide and during the flood, these estuary gates are closed and the sea-ward gates are opened permitting water to enter the fore-bay from the sea. Such water, so entering the fore-bay, either from the estuary or from the sea, finds its exit through the hydraulic compressor. It is thus seen that the fore-bay, with its compressor mechanism, becomes the channel through which the tidal currents ebb and flow, and, consequently that such flow in reverse direction twice daily results in four tidal power periods. The inlets of the hydraulic compressors are located within this fore-bay, extending downwardly therefrom to and through the separation chamber and upwardly through the up-take shaft to the tail-race.

The tail-race is similar to the fore-bay, in that it is a completely enclosed basin surrounded with walls sufficiently high to prevent overtopping by tides, and having gates on opposite sides thereof connecting with the sea and the estuary respectively. The operation of these gates is similar to the operation of the fore-bay gates, except that these gates are always in reverse position, relatively, to the fore-bay gates, that is, when the estuary gates of the fore-bay are open the estuary gates of the tail-race are closed and the sea-ward gates open, and vice versa. It is therefore apparent that water entering the fore-bay through the estuary gates thereof finds exit sea-ward through the sea-ward gates of the tail-race, after having passed through the hydraulic compressor, and, vice versa the only passage for the escape of the tidal flow both in ebb and flood being through the said fore-bay, hydraulic compressor and tail-race.

In the fore-bay float a multiple of pontoons supporting a chambered structure elevated upon posts attached to the deck of the pontoons. These pontoons are divided into compartments provided with gates for flooding and connected with pumping means, through both of which agencies the immersion and trim of the pontoons may be secured. Guide posts on the sides and reaching to a firm supporting attachment prevent listing or overturning of the pontoons and limit the height of their rise. These pontoons are provided with pockets in which are located water supply pipes and the telescope pipe from the head-piece of the hydraulic compressor.

The chambered structure supported upon the pontoon consists, in the main, of an air tight box, which at one end is connected by downwardly extending supply pipes with the water of the fore-bay, and at the opposite end with the head-piece of the hydraulic compressor, which said head-piece is attached to and elevated upon the said pontoon. The supply pipes have their bottom extremities completely immersed in the water of the fore-bay and their upper ends discharge into the first chamber of the water elevating apparatus, known as the vacuum chamber. These supply pipes are protected against a back, or return flow, by means of foot-valves located near their bottom ends, and, as an added precaution, by flap-valves at their heads. A vacuum in the vacuum chamber causes water to rise in the supply pipes which discharges into the vacuum chamber, and, upon a change in the pressure in this vacuum chamber, the foot and flap valves operate to close the supply pipe, preventing a return of water to the fore-bay. The vacuum in the vacuum chamber is produced and maintained by means of the expansion of the air in the air engine, which is a part of the power plant.

The chambers of the water elevating apparatus are two, the vacuum chamber above referred to, and a float chamber adjacent to the vacuum chamber and having two means of communication therewith, one through an automatic valve, the other through the water sealed opening in the bottom of the dividing wall which separates the two chambers. In the roof of the vacuum chamber is a connection with the vacuum producing means in connection with the air expansion engine. The float chamber contains a float, held to a fixed location by guides, but free to rise and fall with the water in the float chamber, the said float operating through float-arms and valve-arms to open and close the ports of the automatic valve. This automatic valve is in two parts, one part opening and closing connection between the vacuum chamber and the float chamber and the other part opening and closing connection between the float chamber and the atmosphere.

The action of the water elevating apparatus is as follows:—a vacuum having been induced in the vacuum chamber, water rises in the supply pipes from the fore-bay and overflows into the vacuum chamber. The float in the float chamber is at the bottom of its travel and the automatic valve is in such a position that a free connection exists between the air in the float chamber and that in the vacuum chamber, while the other half of the valve which controls connection between the float chamber and the atmosphere is closed. As the pressure in the vacuum chamber and the float chamber are the same, the water discharged into the vacuum chamber through the supply pipes enters the float chamber through the sealed opening in the partition wall, and gradually rises, maintaining an equality of level in both chambers, the float rising with the rising water. When the float approaches the highest point of its travel it impinges upon the upper float-arms actuating the valve-arms which begin to close the port in the half of the automatic valve connecting the two chambers, and finally completely shuts off all connection between them. Further rise of the float opens the other half of the valve giving connection between the atmosphere and the roof of the float chamber. Air under atmospheric pressure immediately rushes into the float chamber, pressing downward upon the surface of the water therein. At once there is a tendency for the water to return into the vacuum chamber which is still under less than atmospheric pressure. This return into the vacuum chamber causes the water surface to rise closing the flap-valves of the supply pipes. Its further rise shuts the flap-valve on the throat of the vacuum supply connection, and finally, the residue of air in the chamber, having no outlet is compressed to atmospheric pressure. The water supply pipes being protected at top and bottom, no water returns to the fore-bay. The float chamber, which like the vacuum chamber is a hermetically sealed vessel, has siphon-draft-tubes in the wall opposite the partition separating the two chambers. As soon as the atmospheric pressure begins to act upon the surface of the water in the float chamber these tubes begin to operate, discharging the contents of the float chamber into the conduit leading to the head-piece of the compressor, and continue operating, drawing the water from the float chamber, until the float, in its falling, impinges upon the lower set of float-arms. The float-arms actuate the valve-arms and the valve, closing the port connecting the atmosphere and the float chamber and re-establishing connection between the float chamber and the vacuum chamber. The air, at atmospheric pressure, rushes from the float chamber into the vacuum chamber and the water therein immediately falls to the same elevation as that of the float chamber. The flap-valve on the throat of the vacuum connection falls, a vacuum is thereafter quickly established in both the vacuum and float chambers and the process of filling begins again. It is thus seen that by the alternate rise and fall of the float, actuating the automatic valve, conditions are established which result in the alternate filling and emptying of the vacuum and float chambers, and in the supply to the head-piece of the compressor of water raised to an elevation above that of the tidal elevation of the fore-bay.

It is apparent that, when an open connection exists between the vacuum chamber of the water elevating apparatus and the source of vacuum, a vacuum will be induced and maintained in said vacuum chamber.

A weir, the crest of which is slightly above the top of the opening in the dividing wall, protects against the unsealing of this opening during the operation of the draft tubes. These draft-tubes have weighted flapped outlets, always submerged, which, always being under atmospheric pressure are pressed against their seats during the filling of the float chamber, thereby preventing the return of water through the draft-tubes into the float chamber. The free openings of the pipes in the roofs of the vacuum and float chambers are hooded above the ceiling of the chambers, thereby insuring against water rising to and covering said pipes. The air supply pipe from the atmosphere is valved for the purpose of regulating the access of air to the float chamber, such regulation determining the speed and periodicity of operation of the water elevating apparatus.

The compressor head is directly connected with the discharge channel leading from the siphon-draft-tubes, and consists of a vertically regulatable upper portion carrying a multiple of air tubes, suspended above the telescoping section of the down-take pipe. This telescoping section is rigidly attached to the pontoon, rising and falling therewith, and has its lower extremity encased within the shell of the down-take pipe proper, extending thereinto a sufficient distance to insure against withdrawal in the fluctuations of the pontoon. The water discharged from the siphon-draft-tubes after super-elevation by means of the water elevating apparatus passes through the head-piece, entraining air as it passes the mouths of the air tubes, and descends the telescoping section and the main down-take pipe to the separation chamber, where the air is released, the air freed water rising through the up-take pipe and escaping through the gates of the tail-race either to the sea or to the estuary.

But an apparatus as above described would be mechanically impossible and inoperative without an extraneous source of energy, the source of energy employed being some form of fuel, burned either directly in a pre-heater for the sole and only purpose of increasing the power value of the compressed air delivered from the hydraulic compressor, by heating the same, or, by the use of waste heat for heating the air secured from a coal reduction or metallurgical process carried on in connection with the tidal power plant. It is a well known principle of mechanics that air expands readily under the influence of heat, and, due to its being a perfect gas and without latent heating qualities, all, or nearly all of the heat units absorbed by the air in its preliminary and intermediate heatings can be recovered in useful work. Because of this principle it becomes possible to elevate the water to a super-elevation above the tidal crest and to use this elevation in conjunction with a slight difference in the elevation of the tide within and without the dam, and, after accounting for the power expended in securing such super-elevation to obtain a large residue of commercial power.

In this linking of a hydraulic compressor to an air expansion apparatus the following is the procedure employed. A force main leads from the separation chamber to a pre-heater in which either waste heat or fuel is employed to heat the air, the air entering at a point of relative minor temperature and after passing through the pre-heater in a reverse direction to that of the fuel gases, is discharged at a point of maximum temperature. It immediately enters the initial cylinder of a multiple expansion engine, either of a reciprocating or turbine type, where a partial expansion of the air ensues and a considerable drop in temperature results. From this initial, or from an intermediate expansion, the exhaust is lead to a freezer, for the purpose of freezing out any moisture in the expanded air before final expansion to a pressure below atmosphere, as such expansion results in a very low temperature and one which would quickly congeal any residual moisture remaining in the air, and freeze up the engine ports. The agency employed in freezing out this residual moisture is the exhaust from the terminal expansion cylinder, said exhaust being circulated through coils enclosed in a freezer, around the exterior of said coils and within the shell of the freezer, the exhaust from the initial and intermediate cylinders circulate, said contact resulting in the freezing out and deposition of the residual moisture upon the exterior of the coils. The exhaust of the initial or intermediate cylinder, being freed of its moisture, returns to the source of heat, first passing through the coils of an interchanger which is surrounded by air at atmospheric temperature so that the exhaust air is raised to said atmospheric temperature before entrance to the regenerator, which is an extension of the flue of the waste heat or preheater source of energy, and in which regenerator the exhaust air is again heated to approximately the temperature of the initial pre-heat. From the regenerator the air passes finally to the terminal expansion cylinder in which it is expanded to a pressure below atmosphere and to that represented by the vacuum desired to be secured in the vacuum chamber of the water elevating apparatus. This low pressure exhaust after passing through the freezer and being used to freeze out the moisture from the partially expanded air, enters a vacuum tank to which is likewise connected the vacuum pipe leading to the vacuum chamber of the water elevating apparatus, and which is also connected to the supply pipe of a vacuum pump. This vacuum pump maintains the vacuum in the vacuum tank. An automatic valve controls the pressure of the vacuum tank to that desired for the operation of the water elevating apparatus. It is apparent that by linking up the water elevating apparatus and the air expansion engine it is possible to secure the super-elevation of the tidal water and to exhaust the air below atmosphere, the resulting economy being very high.

The following great advantages are secured by the use of a combined hydraulic compressor operating under an augmented fall secured through the super-elevation of the tidal crest and a compressed air expansion unit, in which the air, finally exhausted in vacuuo, is subjected to initial pre-heat and intermediate regeneration, with moisture elimination. It is possible to begin the operation of the compressor very much sooner after the tidal turning, resulting in being able to operate continuously for much of the tidal period, or from 75 to 90% of that time. The compressor always works under a constant head and not under a variable, as is the usual condition. It is possible to secure as commercial power nearly 100% of the power represented in the tidal flow and fluctuation, after allowing for the cost of fuel consumed, which fuel costs may be nothing, as in the case of waste heat installations or, if fuel is consumed for the purpose of heating the air not over one-quarter the cost of the fuel consumed in steam power production. A large amount of the power developed by the tidal compressor may be stored as compressed air in the separation chamber, and drawn upon and used during periods when the compressor, at tidal turning points, is necessarily inoperative.

For the satisfactory operation of the power plant as above described it is essential that a body of air shall be present in the separation chamber to supply air to the expansion engine in order to produce the vacuum necessary to the operation of the water elevating apparatus. Such a body of air in the separation chamber is secured by means of an initial compressor, which is in all essentials similar to the compressors heretofore described, except that it has a fixed compressor head instead of a floating. A separate, and comparatively small fore-bay with gates on opposite sides, supplies water to the compressor, either from the sea or from the estuary. The head is regulatable, although not floating, and, by an adjustment of the gates, can be successfully, if not economically operated through such a period as is necessary in order to store a sufficient amount of air in the separation chamber with which to begin operating the compressed air engine, after which, the initial compressor is shut down and further compression takes place through the main, or floating compressors.

This tidal compressor is protected in all its parts so as to proof against either pressures above or below the limits prescribed, a regulating valve being located upon the force-main, which valve closes at a point of minimum pressure, preventing water being drawn into the engines, and an open blow-off, or escape pipe, leading from the separation chamber to the atmosphere, has its lowest extremity at the elevation of lowest allowable water level in the separation chamber, and discharges air into the atmosphere when this lowest water elevation is reached.

One desirable feature in the operation of a hydraulic compressor, either tidal or otherwise, is the maintenance of a practically constant elevation of the tail race. Fluctuations in this tail-race elevation, such as that induced by heavy wave action from the seaward side when the compressor is discharging into the sea, would produce sudden variations in pressure which might injure the plant. To prevent such wave fluctuations, or at least to reduce them, a wave barrier is introduced on the seaward side, with openings therein, so disposed as to dissipate the waves, and prevent their reaching the tail-race and seriously affecting the elevation of the water therein.

What I claim is:—

1. In a tidal hydraulic air compressor, a fore-bay basin, a tail-race basin, a down-take shaft located in said fore-bay basin, an uptake shaft located in said tail-race basin, a head-piece supported upon and located above the water in said fore-bay basin, means for elevating water from said fore-bay basin, means connecting said water elevating means and said head-piece, means connecting said head-piece and said down-take shaft and means connecting said down-take shaft and said uptake shaft.

2. In a tidal hydraulic air compressor, a fore-bay basin, walls surrounding said basin, gates in said walls connecting said basin with a tidal estuary, other gates connecting said basin with the sea, a tail-race basin, walls surrounding said basin, gates in said walls connecting said basin with a tidal estuary, other gates connecting said basin with the sea, a down-take shaft located in said fore-bay basin, an uptake shaft located in said tail-race basin, a head-piece supported upon and located above the water in said fore-bay basin, means for elevating water from said fore-bay basin, means connecting said water elevating means and said head-piece, means connecting said head-piece and said down-take shaft and means connecting said down-take shaft and said up-take shaft.

3. In a tidal hydraulic air compressor, the combination of a fore-bay basin, pontoons in said basin, head-pieces supported by said pontoons, downtake shafts, means connecting said head-pieces and said shafts, an up-take shaft, a separation chamber connecting said downtake and uptake shafts, means for elevating water from said forebay, means connecting said head-pieces and said water elevating means, a supplementary downtake shaft, a fixed head-piece superimposed above said downtake shaft and separate means connecting said supplementary downtake pipe and said separation chamber.

4. In a hydraulic air compressor, a fore-bay basin, a head-piece, a down-take shaft, means connecting said head-piece and said down-take shaft, an up-take shaft, means connecting said down-take shaft and said up-take shaft, means for elevating water from said fore-bay basin, means connecting said head-piece and said water elevating means and means for producing a vacuum within said water elevating means.

5. In a hydraulic air compressor, a fore-bay basin, a head-piece, a down-take shaft, means connecting said head-piece and said down-take shaft, an up-take shaft, a separation chamber connecting said down-take shaft and said up-take shaft, means for elevating water from said fore-bay basin, means connecting said head-piece and said water elevating means, an initial compressing unit and means connecting said initial compressing unit and said separation chamber.

6. In a tidal hydraulic air compressor, a head-piece, a water elevating means, means connecting said head-piece and said water elevating means, a fore-bay basin, a down-take shaft located in said fore-bay basin, means connecting said head-piece and said down-take shaft, a tail-race basin, an up-take shaft located in said tail-race basin, means connecting said down-take shaft and said up-take shaft, walls surrounding said tail-race basin, gates in said walls and a wave protection wall in front of said gates.

7. In a tidal hydraulic air compressor, a head-piece, a water elevating means, means connecting said head-piece and said water elevating means, a fore-bay basin, a down-take shaft located in said fore-bay basin, means connecting said head-piece and said down-take shaft, a tail-race basin, an up-take shaft located in said tail-race basin, means connecting said down-take shaft and said up-take shaft, walls surrounding said tail-race basin, gates in said walls, a wave protection wall in front of said gates and openings in said protection wall.

8. In a hydraulic air compressor, a fore-bay basin, a head-piece, water elevating means, means connecting said head-piece and said elevating means and a pontoon floating in said fore-bay and supporting said head-piece and said elevating means.

9. In a hydraulic air compressor, a water elevating apparatus, a vacuum chamber in said apparatus, a fore-bay basin, supply pipes connecting said chamber and said basin, valves in said pipes, a float chamber, a partition between said vacuum chamber and said float chamber, a sealed opening in said partition, a float, an automatic valve, means actuated by said float and operating said valve, connections through said valve between said float chamber and the atmosphere and between said float chamber and said vacuum chamber, a source of vacuum, means connecting said vacuum chamber and said source, valves protecting said connecting means, an

outer shell to said float chamber, a discharge conduit and means connecting said chamber and said conduit and passing through said shell.

10. In a hydraulic air compressor, a water elevating apparatus, a vacuum chamber in said apparatus, a water supply basin, supply pipes connecting said chamber and said basin, a float chamber, a partition between said vacuum chamber and said float chamber, a sealed opening in said partition, a float, an automatic valve, means actuated by said float and operating said valve, connections through said valve between said float chamber and the atmosphere and between said float chamber and said vacuum chamber, a source of vacuum, means connecting said vacuum chamber and said source, a discharge conduit and means connecting said float chamber and said discharge conduit.

11. In a tidal hydraulic air compressor, the combination of an initial compressing unit, a fore-bay basin, walls surrounding said basin, gates in said walls connecting said basin with the sea, other gates in said walls connecting said basin with a tidal estuary, a water elevating apparatus, means for producing a vacuum in said apparatus, a head-piece, means connecting said water elevating apparatus and said head-piece, a down-take shaft, means connecting said head-piece and said down-take shaft, a separation chamber, means connecting said down-take shaft and said separation chamber, a tail-race basin, an up-take shaft discharging into said tail-race basin, means connecting said separation chamber and said up-take shaft, walls surrounding said tail-race basin, gates in said walls connecting said basin with the sea, other gates in said walls connecting said basin with a tidal estuary, means connecting said initial compressing unit and said separation chamber and a force main connected to said separation chamber.

Signed at New York, in the county of New York and State of New York, this 6th day of October A. D., 1921.

HERBERT M. KNIGHT.