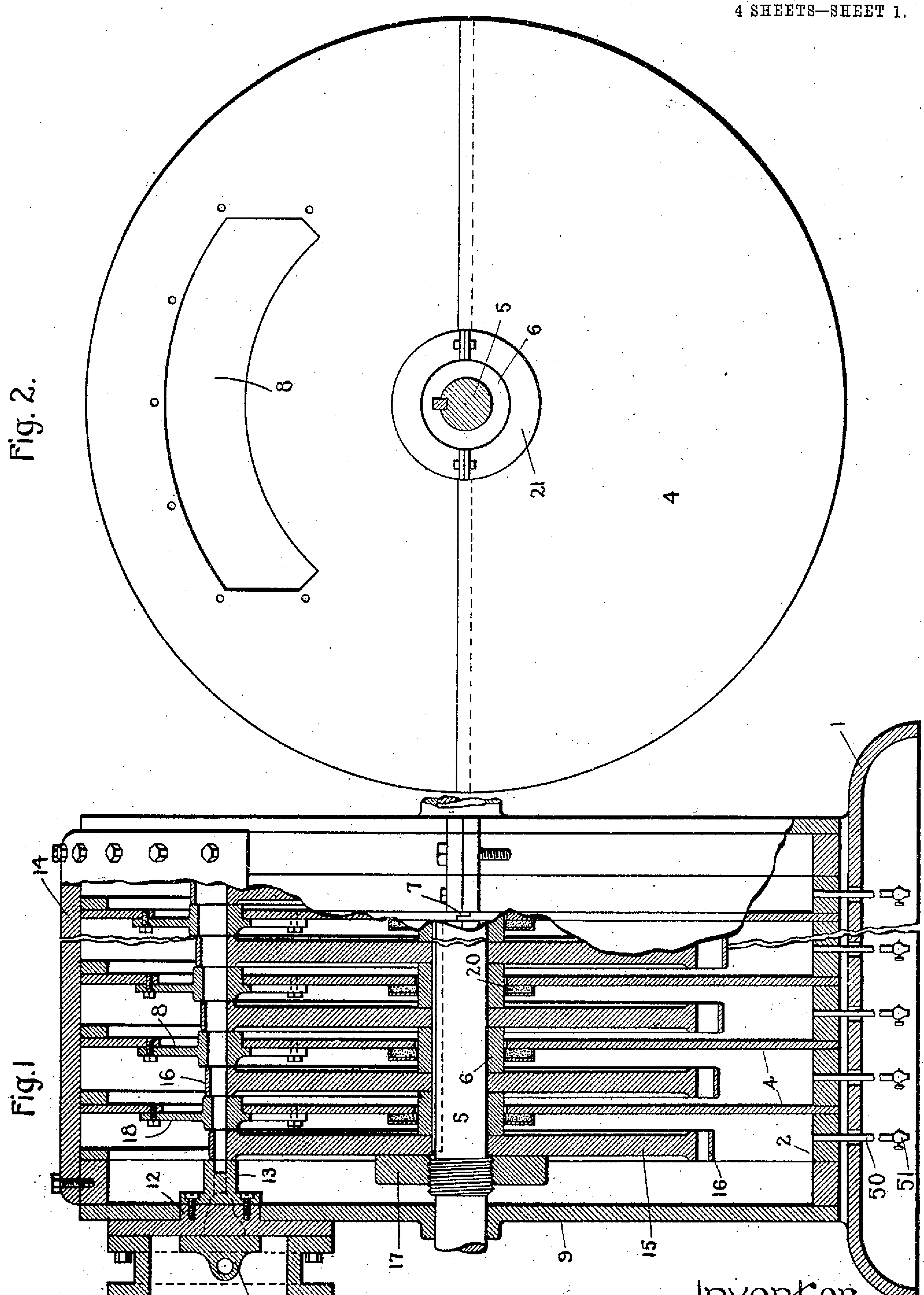
A. R. DODGE.

ELASTIC FLUID TURBINE.

APPLICATION FILED NOV. 7, 1902.

912,090. Patented Feb. 9, 1909.

4 SHEETS—SHEET 1.



Witnesses.

J. Ellis Glenn.

Alex. F. Macdonald.

Inventor:

Austin R. Dodge.

by Albert G. Davis

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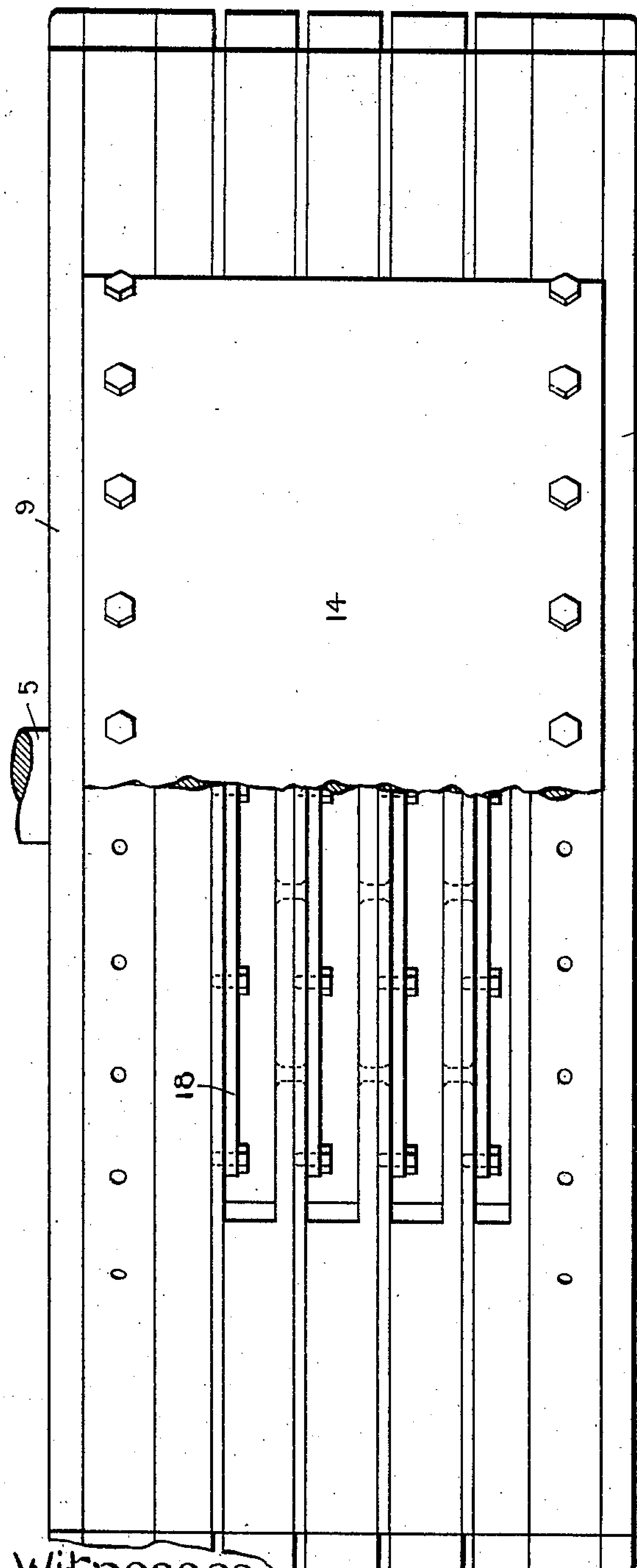

Fig. 3.

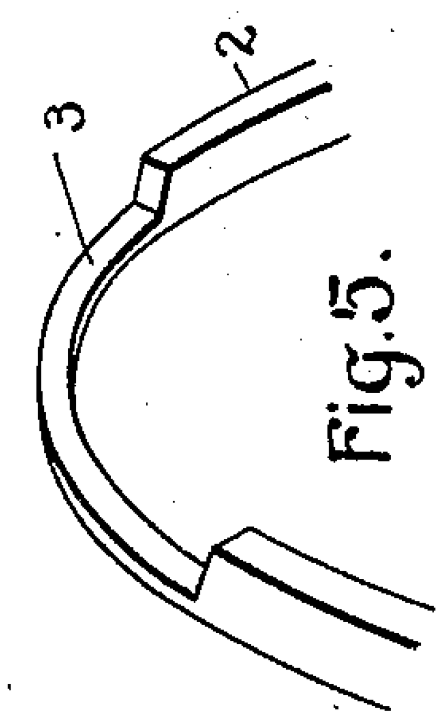

Fig. 5.

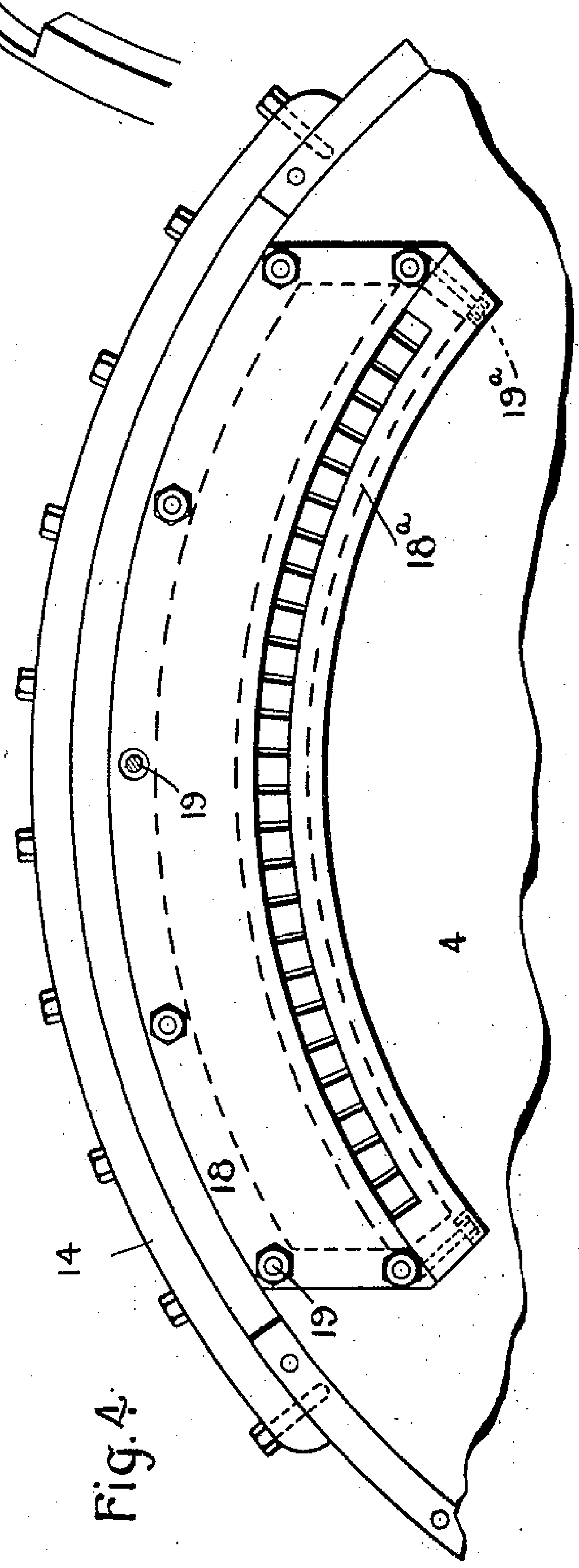

Fig. 4.

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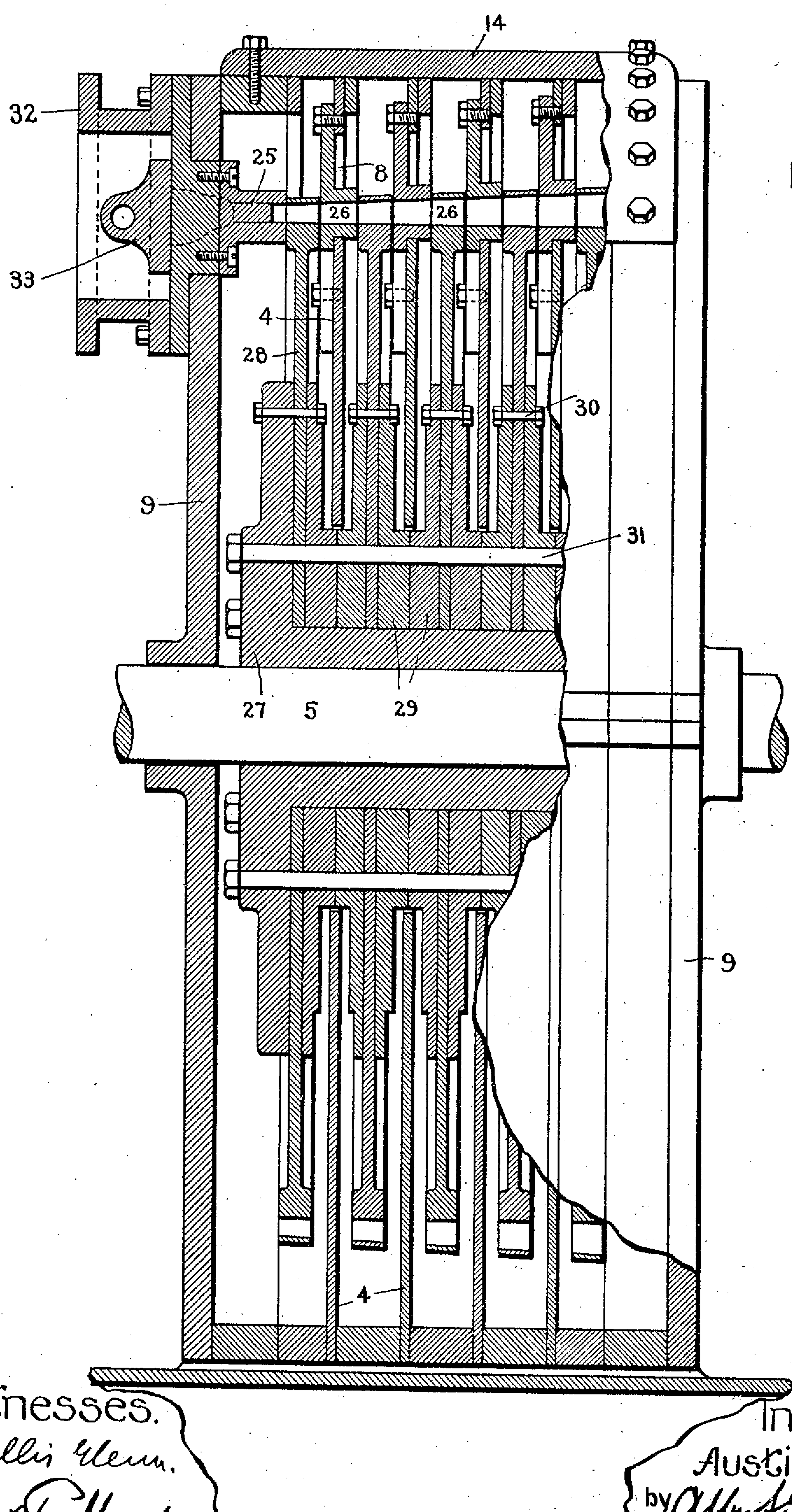

Fig. 6.

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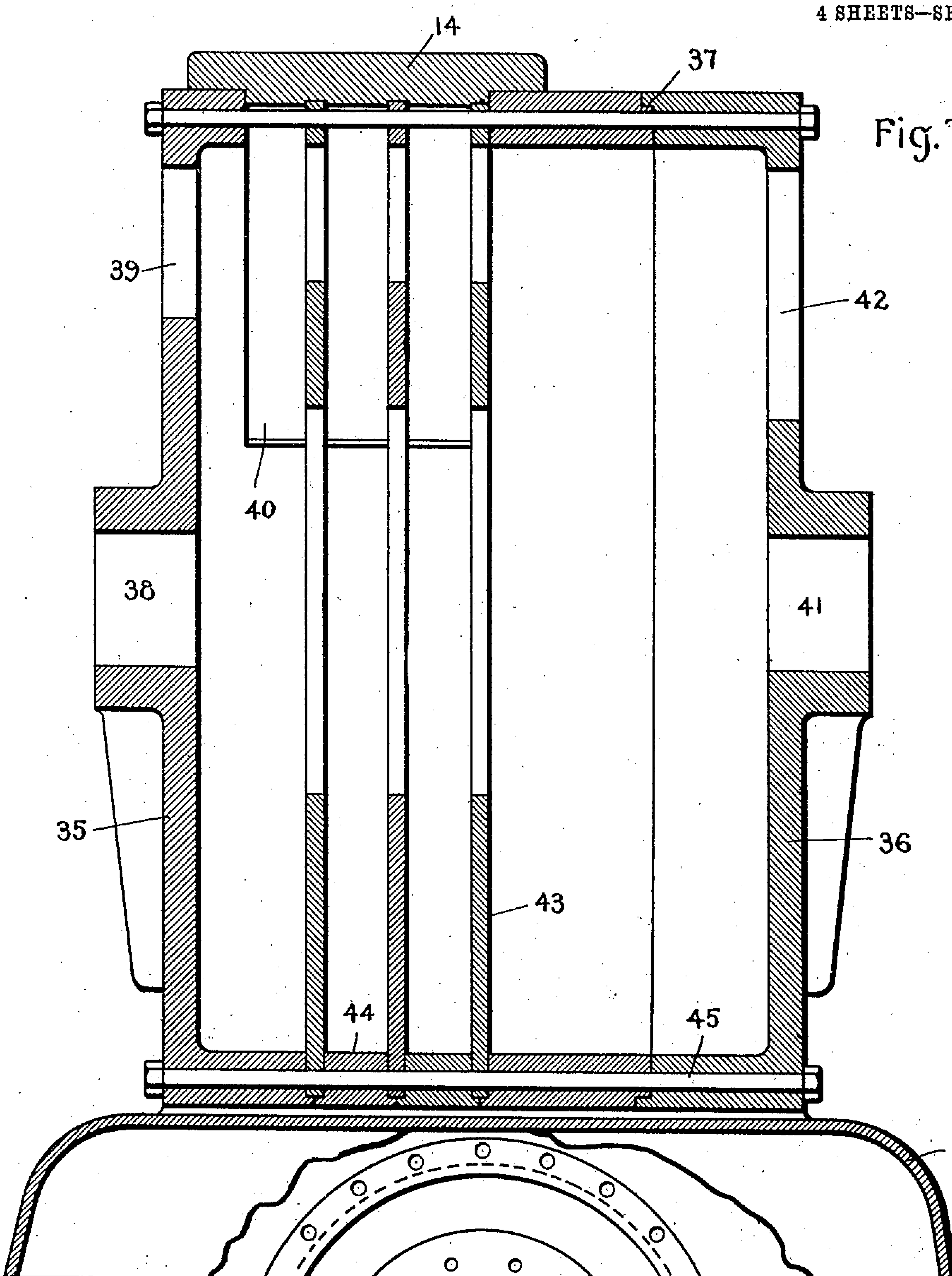

Fig. 7.

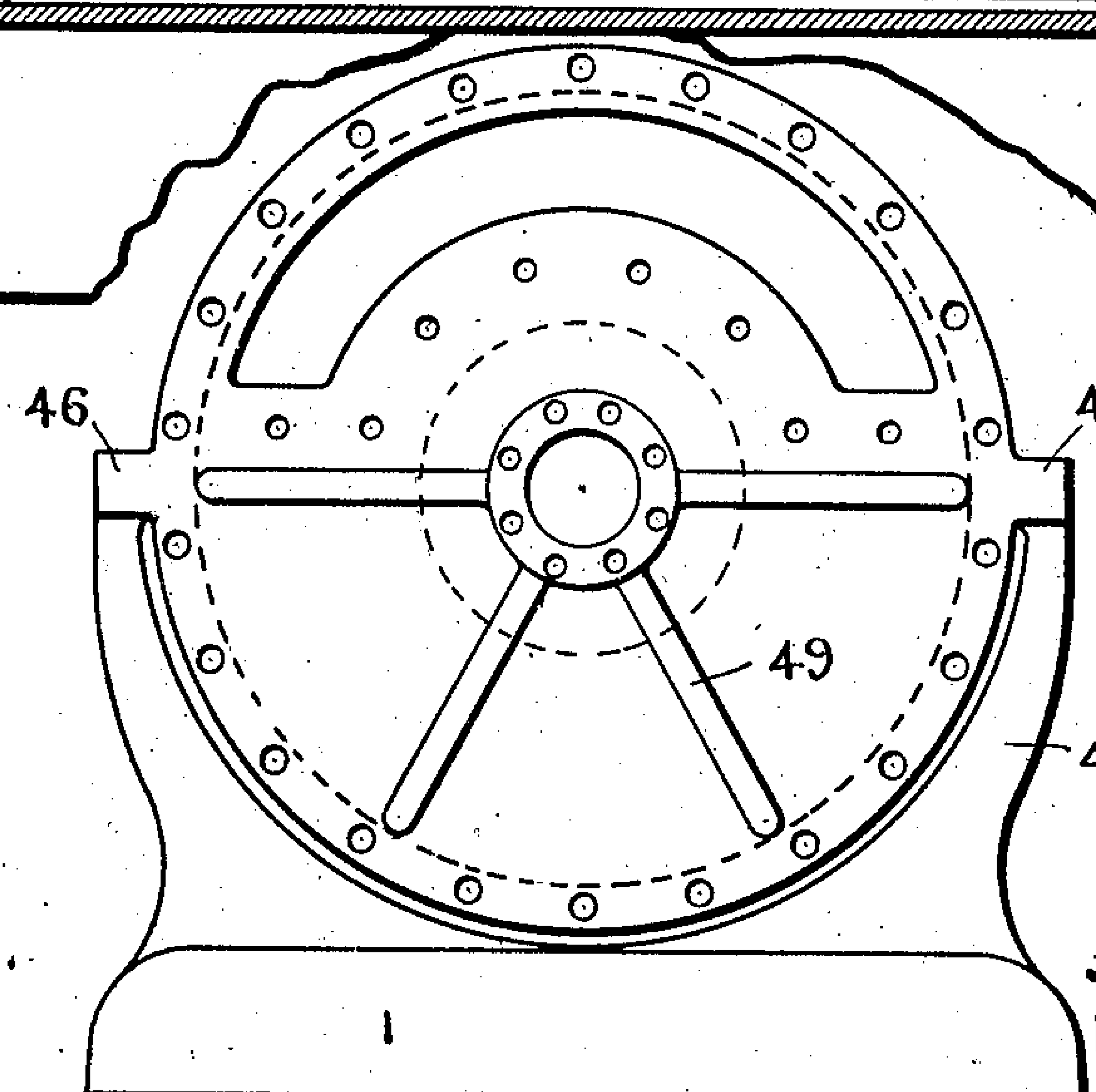

Fig. 8.

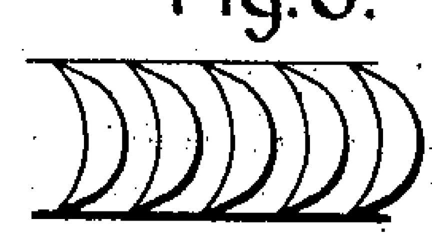

Fig. 9.

Witnesses

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UNITED STATES PATENT OFFICE.

AUSTIN R. DODGE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELASTIC-FLUID TURBINE.

No. 912,090. Specification of Letters Patent. Patented Feb. 9, 1909.

Application filed November 7, 1902. Serial No. 130,371.

To all whom it may concern:

Be it known that I, AUSTIN R. DODGE, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Elastic-Fluid Turbines, of which the following is a specification.

Theoretically the efficiency of an elastic fluid turbine of the jet or impact type would be greatest if the pressure of the motive fluid delivered by the nozzle or nozzles was all, or virtually all, converted into *vis viva* or velocity, and the bucket wheel had a peripheral speed equal to one-half the speed of the fluid stream. Owing to mechanical considerations it is impractical to build elastic fluid turbines on these lines, but comparable results are now attained with turbines having a number of wheels in the same shell with expanding nozzles and intermediate buckets properly associated therewith. In turbines of this character the velocity of the motive fluid due to the expansion in the nozzle is fractionally abstracted thus giving a relatively low speed. Turbines constructed on these lines are commonly divided into two or more stages, each stage being provided with a plurality of rows of moving buckets. Situated between the rows of moving buckets and separated therefrom by relatively small clearances, are stationary or intermediate buckets which change the direction of the motive fluid received from one row of buckets preparatory to delivering it to the succeeding row of buckets. Clearance spaces between the several rows of moving and stationary buckets are a necessity for mechanical reasons, and these spaces permit a certain amount of motive fluid to enter the shell without doing useful work, although the fluid from the first stage is collected and used in the second, and so on. This means that the efficiency of the machine is impaired.

To minimize the effect of leakage between moving and stationary parts, I divide the turbine casing into a plurality of stages, and provide each stage with a single bucket wheel. Fluid is delivered to each wheel at a moderate predetermined velocity and all or substantially all of the velocity due to the nozzle is abstracted by the wheel. In this manner the turbine is given a low speed and the motive fluid which is lost in one stage due to leakage is utilized in the next, and so on, the only complete loss being in the last stage, but since it is only a very small amount as compared to the total amount of fluid used, it can be disregarded.

I have discovered by test that the leakage between the moving and stationary buckets or parts of an elastic fluid turbine is determined largely by the pressure in the shell in which the wheel or wheels are located, it being greater when the shell pressure is less than that of the fluid stream, and decreasing in amount as the shell pressure is increased up to the pressure of the fluid stream. In other words, where the nozzle end pressure and the shell pressure are the same, the leakage will be reduced to a minimum. The shell pressure can be regulated in a variety of ways. I have found the simplest way to be by properly proportioning the nozzle area between the shell in question and the adjacent shell of lower pressure. Owing to the fact that the leakage referred to is controllable to a large degree by the pressure of the shell in which it takes place, it follows that the clearances between the nozzles and the buckets can be made an amount which is sufficient to compensate for all internal strains, expansions, etc., without detracting from the efficiency of the apparatus as a whole.

The number of stages in the turbine varies with the terminal pressures between which it is to work. It is desirable in this connection to have the pressures between one stage and the next relatively small, so as not to cause undue straining of the parts. By dividing the turbine into a comparatively large number of stages, the peripheral speed of the turbine wheels can be made low because the velocity of the stream of motive fluid can also be made low, and this without impairing the economy of operation.

When a comparatively large number of stages are employed, the nozzles are so proportioned that they will deliver the stream or streams of motive fluid to the moving buckets at a moderate speed, and by reason of the relatively large number of stages, the major portion of the energy can be extracted from the motive fluid, resulting in high economy in operation. By the use of non-expanding nozzles or those expanding only a very small amount, I can obtain a higher efficiency than where a large amount of expansion is employed, because in the latter case the expansion of the steam causes it to lose its initial superheat wholly or in large part before striking the bucket wheel.

An elastic fluid turbine having a single wheel per stage with nozzles between stages which do not expand, or expand to only a very small extent, can be governed by throttling over wide variations in load and show efficiencies for the varying loads which are commercially acceptable. This is due to the fact that nozzles of the character described are not so sensitive to pressure changes in their functioning as are nozzles wherein the pressure of the fluid is substantially all converted into *vis viva* or velocity.

By using a single wheel per stage and properly proportioning and arranging the parts, the water of condensation discharged by the first or high-pressure nozzle is utilized to impart motion to the first wheel, after which it is collected in the shell and can be drawn off from time to time. Any water due to condensation in the succeeding nozzles or intermediates is utilized in the same manner. It is important to remove the water as soon as possible, since by so doing the loss of energy due to reconversion is obviated.

With respect to certain features, my invention includes any sort of non-expanding nozzle, meaning thereby a nozzle having a cross-sectional area at the inlet end which is the same or larger than that of the discharge end. In certain other aspects, my invention also includes any sort of expanding nozzle, meaning by "expanding", a nozzle having one cross-sectional area at the throat and a larger area at the discharge end, and this irrespective of how the expansion is obtained.

With a turbine designed in accordance with the conditions above specified, I am able to obtain a very high efficiency by abstracting a large per cent. of the available energy from the fluid, and at the same time to provide a turbine with a relatively low peripheral speed.

One object of the present invention is to provide a turbine which will efficiently transform the energy of an elastic fluid into mechanical power.

A further object of the invention is to improve the construction of turbines by simplifying their construction and decreasing their first cost, and also to provide a turbine in which the parts are so arranged and related that they may be readily alined and adjusted, or taken down for the purpose of inspection or repair.

In the accompanying drawings, representing an embodiment of my invention, Figure 1 is a vertical section of a turbine having a straight-bored nozzle, with certain of the parts in elevation; Fig. 2 is a side elevation of one of the diaphragms or partitions; Fig. 3 is a plan view of a turbine with certain of the parts broken away; Fig. 4 is a partial elevation looking toward the delivery end of the intermediate buckets; Fig. 5 is a perspective view showing how the rings of which the casing is composed are cut away to receive the intermediate nozzles or buckets; Fig. 6 is a vertical section of a turbine having an expanding nozzle, with certain of the parts shown in elevation; Fig. 7 is a vertical section showing a modified construction of the turbine casing; Fig. 8 is an end view showing the means employed to support the casing; and Fig. 9 is an end view of the buckets.

Referring more particularly to Figs. 1 and 2, 1 represents the base on which the moving and stationary parts of the turbine are supported. The casing for the machine comprises a plurality of rings 2 which are cut away at 3, as is more clearly illustrated in Figs. 3 and 5. The object in cutting away this ring is to enable the intermediate buckets and their supports to be inserted in place. It also enables the person assembling the machine to see the exact relation which the parts bear one to the other and facilitates adjustment. As many of these rings are provided as there are stages, and situated between the finished faces of each pair of rings is a diaphragm or partition 4. These diaphragms are held in place by bolts or other means which may be employed to hold the parts of the casing together. Each diaphragm is provided with a central opening to receive the main shaft 5, and also the sleeve 6 which acts as a spacer or distance piece between adjacent wheels. I find it desirable to construct these diaphragms of two pieces, in order that the machine may be more readily taken down for the purpose of inspection or repair. I prefer to divide the diaphragm on a horizontal plane, since the nozzles and intermediates are carried by the upper part of the machine, but it is obvious that the line of division can be situated at any other point if it is found desirable. The meeting faces of the parts of the disk are shouldered, as shown at 7. The joint between the parts should be relatively long, so as to prevent the steam or other motive fluid from passing from one side to the other.

The diaphragms, being situated between the rings 2, are rigidly supported at all points near their circumference, and under ordinary conditions of service this support is sufficient, because the difference in pressure between one shell and the next is comparatively small. If the pressure is increased, the diaphragms may be increased in thickness, or otherwise strengthened. Each diaphragm is provided with an opening 8 which is designed to receive the intermediate nozzles or buckets. These nozzles or buckets are employed to change the direction of the motive fluid, and may be given a suitable form. I have found that where the buckets are substantially crescent-shaped, as shown in Fig. 9, satisfactory results can be obtained. The compartments in the casing are preferably made as small as possible and of the same size in order to reduce the cooling surfaces to a minimum. It is also desirable to make them counterparts in construction on account of the low first cost. When it is desired to make a machine for different terminal pressures more rings are added to or taken away from the structure; in this manner a certain flexibility is given to the machine.

The ends of the machine are closed in by end plates or walls 9, which also carry the bearings for the main shaft. To the upper part of the left-hand end plate 9 is detachably secured a steam chest 10, and mounted therein is a valve 11 which is adapted to be moved to and fro over the mouth of the nozzle by any suitable means, for the purpose of varying the volume of motive fluid supplied thereto. The shouldered projection 12 of the nozzle support extends through the opening in the casing head. The nozzle 13 is of the straight-bored type, that is to say, the cross-sectional area at the throat is the same as that at the delivery end, and it is secured to the support 12 by suitable bolts. The steam or other motive fluid is caused to expand in the nozzle and a certain amount of pressure is converted into velocity. This expansion of the motive fluid is adiabatic because it neither has heat imparted thereto nor abstracted therefrom. The upper part of the casing is provided with a detachable cover 14 which is secured in place by a number of bolts. The object in making this cover detachable is to permit the interior of the turbine to be inspected and also to permit the adjustment of the intermediates.

Mounted on the shaft 5 and keyed thereto, are a number of wheels 15 of suitable construction. These wheels are provided with peripheral buckets of any suitable form. I have found that a form resembling that of the intermediate buckets shown in Fig. 9 operates very satisfactorily. The ends of these buckets are provided with a cover 16 which confines the motive fluid to a path substantially parallel with the axis of revolution. The first bucket-wheel is situated in front of the nozzle 13, and in close proximity thereto, a sufficient clearance however being allowed. I have found that a clearance of from .05 to .06 of an inch is satisfactory.

On the opposite side of the wheel and in operative relation thereto, is a stationary intermediate or nozzle, which is designed to receive the motive fluid as it is discharged from the first wheel and reverse its direction and discharge it against the vanes or buckets of the second wheel. This action is repeated throughout the turbine. It is to be noted that the passages in the succeeding wheels and also in the succeeding intermediates increase slightly in depth. The object of this is to compensate for the increased volume of the steam due to its decreased pressure. The intermediates or nozzles are so designed that they will hold back or maintain a pressure in the compartment from which they receive fluid that approximates the pressure of the fluid stream that is discharged against the buckets in said compartment and thereby reduce the leakage to a minimum. In order that each succeeding nozzle or intermediate may collect the steam discharged from the preceding wheel, which steam has a certain residual velocity, and to obviate too great a radial depth of the buckets, they cover a greater arc in each succeeding stage so as to include a greater number of moving buckets.

The wheels, in addition to being keyed to the shaft, are retained against longitudinal movement of the shaft by means of the nut 17, it being understood that the last wheel in the series engages with a suitable shoulder or its equivalent on the main shaft. Between each of the wheels is a sleeve or spacer 6, and this preserves the relation between adjacent wheels and prevents them from entering into frictional engagement with the stationary intermediate buckets. The wheels are preferably of the same width so as to simplify the construction of the machine as a whole. Each wheel is situated in a compartment by itself, which for convenience I have termed a shell; and each shell has a pressure, when the apparatus is in operation, which is different from that of every other shell.

Referring now to Figs. 3, 4 and 5, the construction and arrangement of the diaphragms and the detachable intermediates will be more clearly seen. The cut-away portion 3 in each casing ring extends over an arc which is somewhat greater than that covered by the intermediates themselves. This cut-away portion is made large enough to permit a hand or a wrench or both to be inserted for the purpose of adjusting the retaining bolts, and at the same time enables the workman to see the exact relation of parts one to the other. Each intermediate is provided with a flange 18 that is bolted to the adjacent diaphragm. As many bolts are provided as are necessary to hold the parts in rigid alinement, and by making the holes in the flange slightly larger than the bolts (Fig. 4), the intermediate as a whole can be given a limited amount of adjustment sufficient to properly aline the parts. As shown, about one-half of the intermediate projects through the opening in the diaphragm, and the face thereof is situated in close proximity to the adjacent wheel, and in such relation that it will deliver the motive fluid at the proper angle. It is to be noted that all of the retaining bolts 19 which secure the intermediate to the diaphragm are situated beyond the periphery of the wheel, and by reason of this construction the intermediates can be removed without disturbing the position of the wheel. This is an important feature in case of accident, and any of the buckets become damaged, and also where it is desired to run the machine under different conditions of operation, that is to say, intermediates can be provided which cover a greater or less number of wheel or moving buckets, and for one power one intermediate can be used, and for a different power an intermediate covering a different number of buckets can be used. This same feature is also carried out in the nozzle structure, and I may use a nozzle that covers a few or many buckets, as is best suited for the conditions of operation.

The construction has great advantages where it is desired to make comparative tests between machines using different angular portions of the wheels. The intermediate buckets are cut from a segmental ring 18^a which is bolted to the flange 18 by the bolts 19^a.

In order to prevent the free passage of motive fluid from one shell to another except through the intermediate buckets, the diaphragms 4 are arranged to make a snug fit with the separators 6 which surround the main shaft. A clearance of .01 of an inch will work satisfactorily, but I do not wish to be understood as limiting myself to this or any other specific clearance. In order to further reduce the leakage at this point, I provide a special packing 20, comprising a body of carbon which makes a close working fit with the separator 6. This carbon is retained in a two-part holder 21 (Fig. 2), the parts of which are bolted together in any suitable way. The packing is free to move with the shaft in a plane at right angles thereto; in other words, it floats and compensates for any irregularity in the movement of the shaft. I have found that it is necessary to permit this packing to be free, otherwise the vibration of the shaft would soon destroy the carbon and render the packing useless. The packing is held against the diaphragm by the fluid-pressure in the shell in which it is located, and since the pressure in the adjacent shell is always lower, no other retaining means are necessary.

Referring to Fig. 6, I have shown my invention in connection with a turbine having a nozzle 25 which has a certain amount of expansion. I have found that with a machine having the proper number of stages and working with 150 pounds boiler pressure, non-condensing, an expansion of from 1 to 1.04 will be sufficient, but I do not wish to be understood as limiting myself to this or to any other specified expansion, because the same can be varied to suit the conditions of operation, and the conditions will naturally vary with the boiler and terminal pressures, and also for other reasons which need not be specifically mentioned.

The working passage 26 through the bucket wheels and stationary intermediates is also slightly expanded in order to take care of the increased volume of steam due to the decreased pressure, and also where necessary to convert a certain amount of the pressure into velocity, the arrangement being such that all or substantially all of the velocity due to any given nozzle or intermediate is abstracted by the adjacent bucket wheel.

The wheels are provided with peripheral buckets which are covered as before, but the means employed for securing the wheels to the shaft 5 have been slightly modified. Mounted on the shaft is a sleeve 27 provided with a flange that extends at right angles thereto. This sleeve is rigidly connected with the shaft and forms a rigid support for the several wheels. In the present instance each wheel is provided with a relatively thin web 28 which engages with the sleeve 27. Between the adjacent wheel webs are spacers comprising two disks 29, each of said disks having a hub which projects toward the other. The hubs of the disks are so designed that when the parts are assembled they are in contact and prevent the escape of motive fluid at this point. The diaphragms 4 are situated between the faces of the adjacent disks, and are separated from the hubs by a small clearance, such as will prevent the escape of any substantial amount of motive fluid. The disks are bolted together and to the wheel webs by bolts 30, and the structure as a whole is united by the bolts 31 that extend through the flange of the main sleeve and parallel with the shaft 5.

Mounted on the left-hand end of the head of the machine is a steam chest 32, of any suitable construction, containing a valve 33 which is designed to vary the volume of fluid supplied to the nozzle without changing its velocity.

Referring to Fig. 7, I have shown a slight modification in the construction of the casing. 35 and 36 represent end heads which also form a part of the cylindrical casing. Each head is provided with interlocking shoulders 37 which engage with corresponding shoulders on the next succeeding ring. By reason of this construction a tight steam joint is provided, and the structure is substantial enough to resist all strains to which it may be subjected. A detachable cover 14 is provided which closes in the several compartments or shells. The head 35 is provided with a bearing 38, and also with an opening 39 to receive the nozzle. In addition to this it is cut away at 40 to permit the intermediates to be inserted in place and bolted to the diaphragms. The head 36 is provided with a bearing 41 for the main shaft and with an opening 42 to which the exhaust conduit is connected. The casing as a whole is divided up into compartments or shells by the diaphragms 43. The first diaphragm is fitted into a recess formed in the head 35 and in one of the rings 44, one-half of the recess being formed in the head and the other part in the ring. The opposite faces of each ring are correspondingly cut away or recessed to receive a diaphragm. Situated on the upper side of the casing is a cover which engages with the diaphragms and forms a part of the several compartments or shells. Extending through the casing and parallel with the main shaft are bolts 45 by means of which the structure as a whole is clamped together. In the present illustration these bolts also extend through the diaphragms near their periphery.

A casing constructed as just described has many features of advantage. The work can be done in an ordinary boring mill by relatively unskilled workmen, since it does not require special accuracy in the finish, and the structure as a whole can be quickly assembled or taken down as occasion demands. In addition to this the diaphragms are retained in place by the same means which secure the parts of the casing together, thus doing away with the necessity of a second set of retaining means. By seating the diaphragms in a groove or recess formed between the adjacent parts of the casing, they are rigidly supported at all points on the periphery, and the liability of leakage is reduced to a minimum.

Referring to Fig. 8, I have shown a means whereby the turbine casing as a whole can be supported, and the effects of internal stresses and strains reduced to a minimum. The casing is provided with lateral projections 46 and 47, one projection being situated on one side of the center and the other on the opposite side. I have found it desirable to provide each of the ring-like parts which form the casing with these projections. It is unnecessary however to provide the diaphragms with similar projections, but in the case of such structures as that shown in Fig. 3, they can be employed if desired. These projections are arranged to be bolted to upright standards 48 that are formed on or secured to the base 1. The end heads of the casing are provided with radially extending strengthening ribs 49.

In supporting the turbine casing at opposite points, the turbine parts can expand equally in all directions, and the danger due to the parts getting out of alinement is reduced to a minimum.

When the machine is in operation there will be a certain amount of water collected in the several shells or compartments, which water is the result of condensation of the steam. In order to drain the separate compartments, pipes or conduits 50 are connected thereto. Each one of these pipes or conduits may be provided with a cock 51 for controlling the passage of water.

In carrying out my invention in what I consider the most practical form, nozzles or intermediates of a non-expanding type are provided between each shell or compartment and the next, and these are arranged in the same straight line and usually at the same or substantially the same distance from the center of rotation. The high pressure nozzle delivering motive fluid from the boiler to the first wheel is also non-expanding and in line with the others. This alining of the nozzles is done so that the fluid-carrying passage or passages will be as free as possible from sharp bends and turns, which bends or turns cause a decrease in efficiency due to eddy-currents and friction. When this is done, the general direction of the motive fluid through the machine will be parallel with the driving shaft and the discharge will take place at a point where it is relatively unrestricted. It is to be understood, however, that the intermediates or nozzles cause a certain change in the direction of the motive fluid as it passes from one wheel to the next.

As above pointed out, the fluid stream should issue from the high-pressure or first nozzle and also from the succeeding nozzles at a relatively low speed. If this speed is too low, however, it will result in an excessively large number of stages, if all of the available energy is to be abstracted, which means a machine of high first cost, and one which is difficult to operate for mechanical considerations, due principally to the changes in the relation of parts caused by internal strains and the wear on the bearing surfaces. The cost of maintenance is also high. On the other hand, if the velocity of the motive fluid per stage is too high, it either means two or more rows of moving buckets and one or more intermediates to abstract the velocity fractionally, or a single wheel for the machine. Where several rows of buckets in each stage are employed small clearances are necessary, and in the case of a single wheel with high velocity of the fluid stream there is a loss of energy owing to the residual velocity remaining in the steam after being discharged, and consequently a decrease in efficiency.

Within the limits attainable by the use of an ordinary commercial boiler and condenser, I have found that when a non-expanding nozzle is employed to convey fluid from one shell or compartment to the next, and there is a pressure difference between shells of 42%, the velocity of the fluid stream is, roughly speaking, 1400 feet per second. In other words, when the succeeding shell has a pressure equal to 58% of the preceding shell, the fluid will be transferred from the high-pressure shell to the low-pressure shell at a speed of about 1400 feet per second. If the second shell has a pressure which is less than 58% of the first, the fluid will still maintain the same velocity, and this holds true whether the change in pressure be small or large. On the other hand, if the pressure of the second stage is greater than 58% of the first, then the velocity of the fluid will be correspondingly decreased.

It will be apparent from the foregoing that there is what may be termed a "critical point or pressure" in regard to the passage of steam through a nozzle, and I make use of this in designing my improved type of turbine, and each shell is operated at this pressure or as near to it as possible. By properly utilizing the same velocity in each of the shells or stages, and providing each of the passages with the proper cross-sectional area, as shown, the work performed by the several stages will be equal.

Reference has already been made to certain advantages accruing from the use of a single wheel per stage, and to the means for preventing or reducing leakage. Another and material advantage in my improved construction resides in the fact that the brake action between the moving and stationary surfaces, due to the water of condensation, is eliminated. There is also a certain stability to the machine which simplifies the matter of governing. This is largely due to the fact that the changes in terminal pressures within resaonable limits do not upset the critical pressure relations of the shells.

By properly designing and proportioning the intermediates or nozzles, I am not only able to eliminate all or substantially all of the leakages incident to large clearances by maintaining the proper shell pressure, but am able to preserve the critical relation as to pressures between shells.

Another feature of advantage in my improved construction resides in the fact that the residual energy of the steam in the form of velocity after it has left one wheel is available for use in the succeeding stage and is not lost in latent heat as is the case where a number of wheels are provided for each stage.

From tests I have demonstrated that with a nozzle delivering steam at a velocity of about 1400 feet per second against a wheel having a bucket velocity of about 400 feet per second, I can abstract 70% of the available energy from the steam. I do not mean to say that this is all the energy that can be abstracted, it is merely used as an illustration showing a high degree of economy attainable with machines constructed in accordance with my invention.

In the preferred form of my invention, I combine the parts in such a manner as to utilize the advantageous features referred to above, and eliminate the objectionable features of high speed fluid jets, sharp bends, etc. in the working passage which impair the efficiency.

A turbine constructed to include my invention in its broadest aspect comprises a plurality of shells, each working at substantially the critical pressure with respect to the adjacent shells of higher and lower pressure, with a bucket wheel for each shell, a high-pressure nozzle, and an intermediate or nozzle between each of the shells which is of a character to permit the motive fluid to flow through it without choking and at the same time preserve the critical relation as to pressures between the shells.

A turbine having eight stages will operate satisfactorily and in accordance with my invention where the boiler pressure is 165 pounds absolute, with an exhaust pressure due to a condenser of one pound absolute.

By increasing the bucket speed above 400 feet per second I can obtain a greater efficiency but owing to the great centrifugal strains incident thereto I do not consider it advisable.

The method of operating an elastic fluid turbine under certain of the conditions specified herein is not claimed herein for it forms the subject-matter of my Patent No. 795,256, dated July 18, 1905.

In accordance with the provisions of the patent statutes, I have described the principle of operation of my invention, together with the apparatus which I now consider to represent the best embodiment thereof, but I desire to have it understood that the apparatus shown is only illustrative, and that the invention can be carried out by other means.

What I claim as new and desire to secure by Letters Patent of the United States, is—

1. In a turbine, the combination of a casing, diaphragms dividing the casing into compartments, detachable intermediate buckets, means for securing the buckets to the diaphragms, bucket wheels for the compartments, and a detachable cover for the casing which forms a part of a compartment.

2. In a turbine, the combination of a casing, a detachable nozzle for delivering motive fluid to the wheel, means for securing the nozzle to the casing, diaphragms dividing the casing into separate compartments or shells, detachable intermediate buckets, means for securing the intermediate buckets to the diaphragms, a bucket wheel for each shell, and a detachable cover for the casing which forms a part of the compartments.

3. In a turbine, the combination of a casing, a nozzle which is secured to the end face of the casing for delivering motive fluid to the wheel and is removable from the outside, means for securing the nozzle to the

casing, diaphragms which divide the casings into compartments, and bucket wheels in said compartments.

4. In a turbine, the combination of a casing, a nozzle which is detachably secured to an exterior surface of the casing, diaphragms which divide the casing into compartments, wheels for the compartments, and a detachable cover which forms a part of the compartments.

5. In a turbine which is divided into stages, the combination of a single wheel for each stage, a nozzle for delivering fluid to the first wheel, and a detachable cover which forms a part of the closure for a plurality of stages.

6. In a turbine, the combination of a wheel-carrying shaft, a casing, a plurality of two-part diaphragms for dividing the casing into wheel compartments, admission nozzles, a detachable cover for the casing which exposes one or more wheels, and nozzles or intermediates carried by the diaphragms.

7. In a turbine, the combination of a casing, a wheel-carrying shaft, two-part diaphragms which divide the turbine into stages and are situated between the wheels, and a detachable cover which engages with a diaphragm and forms a part of a compartment.

8. In a turbine, the combination of a casing, a wheel-carrying shaft, two-part diaphragms which divide the turbine into stages and are situated between the wheels, and a detachable cover which engages with a plurality of the diaphragms.

9. In a turbine, the combination of a casing comprising separable rings or parts, with a diaphragm dividing the turbine into stages which is held between the rings or parts, and a nozzle or intermediate which is secured to the diaphragm and is removable without taking down the machine.

10. In a turbine, the combination of a casing comprising separable parts, each part being provided with a groove or recess, and a diaphragm for dividing the turbine into stages which is held between the parts.

11. In a turbine, the combination of a casing comprising a plurality of separable parts, a plurality of diaphragms each of which is situated between two adjacent parts for dividing the casing into compartments, means for clamping the parts of the casing and the diaphragms together, and a removable cover for the casing which is common to the two or more compartments.

12. In a turbine, the combination of a casing comprising a ring or part having a cut-away portion, a diaphragm arranged to engage therewith, and a detachable intermediate that is bolted to the diaphragm at a point adjacent to the cut-away portion of the ring or part.

13. In a turbine, the combination of a casing, removable diaphragms which divide the turbine into stages, a bucket wheel for each stage in which the end thrust is substantially balanced, a nozzle which delivers motive fluid to a portion only of the buckets of the first wheel, and is removable from the outside of the casing, means for securing the nozzle to the casing, intermediates which are secured to the diaphragms for receiving motive fluid from one wheel and delivering it to the next, and means for securing the intermediates to the diaphragms.

14. In a turbine, the combination of a casing comprising parts which are recessed on adjacent faces, a diaphragm situated in the recess thus formed, a nozzle or intermediate carried by the diaphragm, and retaining bolts which pass through the parts of the casing and also the diaphragm.

15. In a turbine, the combination of a casing comprising rings which have interlocking shoulders or projections, other rings which are provided with cut-away portions that form recesses, diaphragms which are situated in said recesses, and a detachable cover which engages with the diaphragms.

16. In a turbine, the combination of a casing comprising a plurality of rings which are placed side by side and bolted together, each of said rings being provided with a cut-away portion, and a detachable cover which closes in the cut-away portion of the rings.

17. In an elastic-fluid turbine, the combination of a plurality of wheels, each provided with buckets, a separate compartment for each wheel, fluid-discharging devices between the compartments, one or more of which are adjustable toward and away from the shaft to aline the passages therein with those in the wheels, and means for securing the devices in place.

18. In an elastic fluid turbine, the combination of a casing, a plurality of diaphragms dividing the casing into compartments, a wheel for each compartment, and adjustable intermediates which are bolted to the diaphragms.

19. In an elastic-fluid turbine, the combination of a bucket wheel, a device arranged to discharge motive fluid against the wheel to produce motion, a shell or casing which incloses the wheel, and a means constructed and arranged to maintain a pressure within the shell or wheel casing that approximates the pressure of the fluid at the delivery end of the fluid-discharging device for reducing leakage.

20. In an elastic-fluid turbine of the multi-stage type, the combination of a plurality of bucket wheels, a nozzle arranged to discharge fluid under pressure against the first wheel, a separate compartment or shell for each wheel, and other nozzles or devices which are constructed and arranged to receive fluid from one wheel compartment or shell and deliver it to the next, the nozzles or de-

vices for succeeding stages after the first being proportioned and arranged to maintain a shell pressure which approximates that of the fluid stream entering the stage from the preceding nozzle to reduce leakage.

21. In an elastic-fluid turbine, the combination of two or more stage compartments working at different pressures, a bucket wheel for each stage, said wheels being arranged to perform equal amounts of work, a nozzle or device for discharging fluid against the first wheel to produce rotation, and stage nozzles or devices for discharging fluid against the succeeding wheels after the first to produce rotation, the stage nozzles or devices being non-expanding in character and of such cross-sectional area that a pressure difference of at least forty-two per cent. is maintained between shells or stages, substantially as set forth.

22. In combination, a wall, a rotating member, and a body of carbon which is sleeved on said member and engages the wall.

23. In a turbine, the combination of a casing, diaphragms which divide the turbine into stages, a wheel for each stage, and carbon packings which float with the shaft and are held in engagement with the diaphragm by the pressure within the compartment in which it is located.

24. In a multi-stage elastic-fluid turbine, the combination of a plurality of stage compartments working at different pressures, a bucket wheel for each stage, said wheels being arranged to perform equal amounts of work, a non-expanding admission nozzle for discharging fluid against the first bucket wheel, and non-expanding stage nozzles which receive motive fluid from one stage and discharge it against the wheel buckets of another, the nozzles of the several stages having such a cross-sectional area that pressure differences of at least forty-two per cent. are maintained and a fluid velocity of substantially fourteen hundred feet per second.

25. In an elastic-fluid turbine, the combination of a bucket wheel, a casing containing a wheel compartment, a non-expanding nozzle or passage discharging motive fluid against the wheel, and a passage or conduit conveying fluid from the wheel compartment, which is of such a cross-sectional area that it will maintain a pressure in the compartment not exceeding fifty-eight per cent. of the pressure at the inlet end of the nozzle, substantially as and for the purpose described.

26. In an elastic-fluid turbine of the multistage type, the combination of a plurality of stage compartments, a wheel for each compartment, said wheels being arranged to perform equal amounts of work, an admission nozzle or device, and nozzles or devices conveying fluid from one stage to the next, the nozzles between stages being non-expanding in character and of such cross-sectional area that pressure differences of at least forty-two per cent. are maintained between the stages.

27. In an elastic-fluid turbine, the combination of a plurality of stage compartments working at substantially the critical pressure with respect to the adjacent stages of higher and lower pressure, a bucket wheel for each stage, a high-pressure nozzle for imparting a relatively low velocity to the fluid and discharging it against the wheel buckets of the first stage, and a nozzle or device between each of the succeeding stages for imparting a relatively low velocity to the motive fluid, which is of a character to permit the motive fluid to flow through it without choking, and is of such cross-sectional area as to preserve the critical relation as to pressures between the stages, and at the same time discharge such an amount of motive fluid as will cause the wheels to perform equal amounts of work.

28. In an elastic-fluid turbine, the combination of a plurality of stage compartments working at substantially the critical pressure with respect to the adjacent stages of higher and lower pressure, a bucket wheel for each stage, a high-pressure nozzle for imparting a relatively low velocity to the fluid and discharging it against the wheel buckets of the first stage, a nozzle or device between each of the succeeding stages for imparting a relatively low velocity to the motive fluid, which is of a character to permit the motive fluid to flow through it without choking and is of such cross-sectional area as to preserve the critical relation as to pressures between the stages, and at the same time discharge such an amount of motive fluid as will cause the wheels to perform equal amounts of work, and a governing mechanism for regulating the admission of fluid to the high-pressure stage.

29. In an elastic fluid turbine, the combination of a plurality of separate shells each working at a pressure different from that of every other shell, a bucket wheel for each shell, a nozzle arranged to deliver fluid to the wheel in the first shell, and nozzles which receive fluid from the shell of higher pressure and discharge it against the bucket wheel of the adjacent shell of lower pressure at a velocity dependent upon said difference in pressures, each succeeding nozzle after the first being of such area and form as to hold back an amount of motive fluid which will maintain the critical relation of pressures between shells.

30. An elastic-fluid turbine comprising a casing that is divided into stages, means admitting motive fluid to and exhausting it from the turbine, and buckets in the stages for converting velocity of the motive fluid into useful work as it passes through the

turbine, in combination with means for maintaining such a pressure difference between the stages as will insure a constant velocity of the fluid with varying loads.

31. An elastic-fluid turbine comprising a casing that is divided into stages, means admitting motive fluid to and exhausting it from the turbine, and buckets in the stages for converting the velocity of the motive fluid into useful work as it passes through the turbine, in combination with a throttling governor for regulating the supply of motive fluid to the initial stage, and means for maintaining such a pressure difference between stages as will insure a constant velocity of the fluid with varying loads.

32. An elastic-fluid turbine comprising a casing that is divided into stages, means admitting motive fluid to and exhausting it from the turbine, and buckets for abstracting all or substantially all of the velocity of the motive fluid as it passes through each stage and converting it into useful work, in combination with means for maintaining a critical difference in pressure between stages to keep the velocity of the fluid entering the stages constant during changes in load the pressure in each stage being substantially that of the fluid entering it and a governing means controlling the admission of motive fluid to the initial stage.

33. An elastic fluid turbine comprising a casing that is divided into stages, means admitting motive fluid to and exhausting it from the turbine, and buckets in the stages for converting velocity of the motive fluid into useful work as it passes through the turbine, in combination with a stage nozzle for directing the motive fluid against the buckets, the said nozzle being constructed and arranged to maintain a stage pressure equal to that of the fluid stream entering it from the preceding nozzle.

34. In a turbine, the combination of a casing provided with a series of normally fixed partitions, each having a series of nozzles adapted to expand the motive fluid adiabatically and discharge it into the annular chambers between said partitions at a pressure equal to that in said chambers, a wheel mounted to rotate in said casing and provided on its periphery with a series of vanes, each having a series of buckets to receive the fluid pressure issuing from said nozzles, the width of each vane being appreciably less than that of the annular chamber in which it revolves.

In witness whereof, I have hereunto set my hand this fifth day of November, 1902.

AUSTIN R. DODGE.

Witnesses:
BENJAMIN B. HULL,
HELEN ORFORD.