(No Model.) 5 Sheets—Sheet 1.

C. G. CURTIS.

ELASTIC FLUID TURBINE.

No. 566,967. Patented Sept. 1, 1896.

Fig. 1,

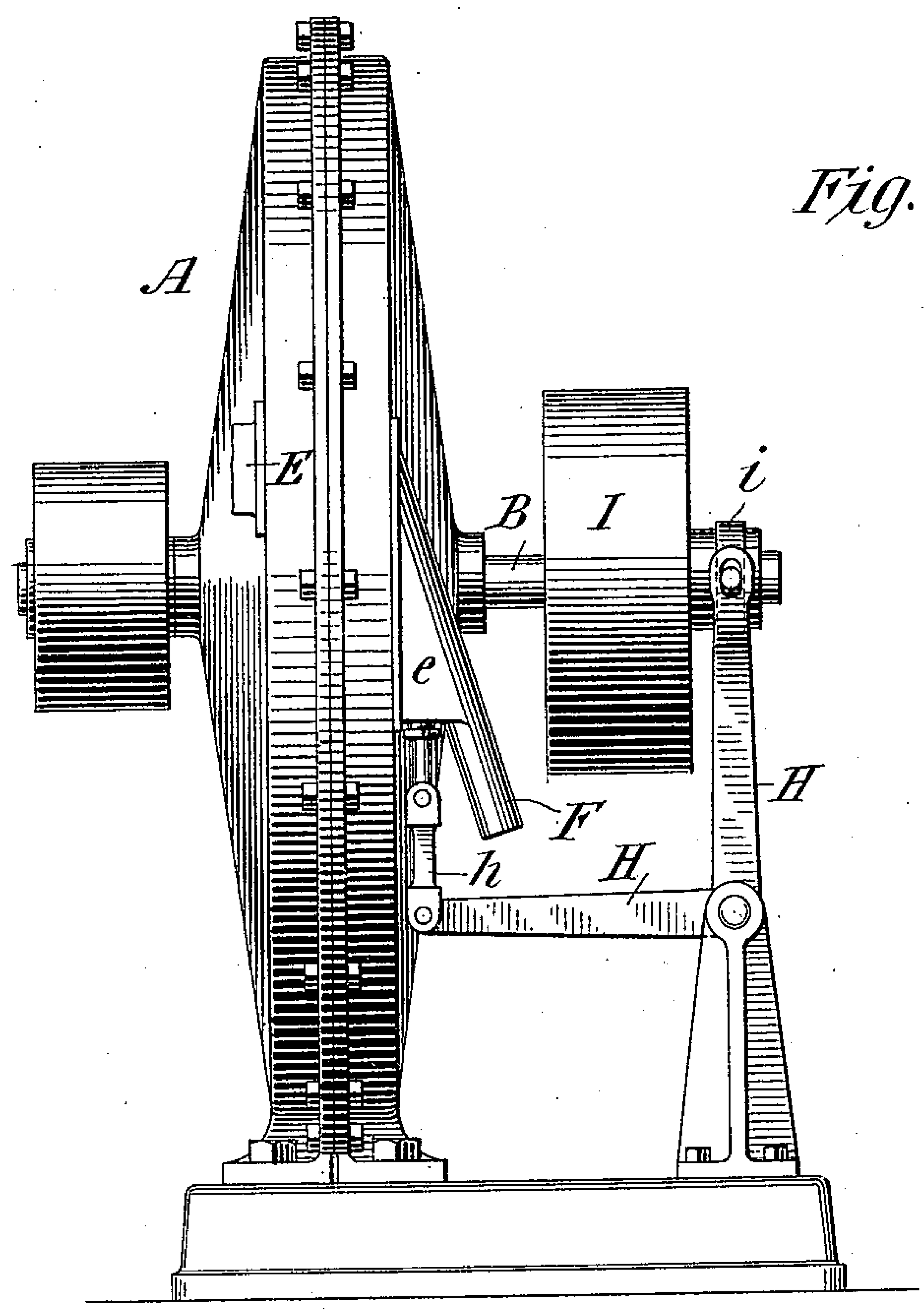


Fig. 2,

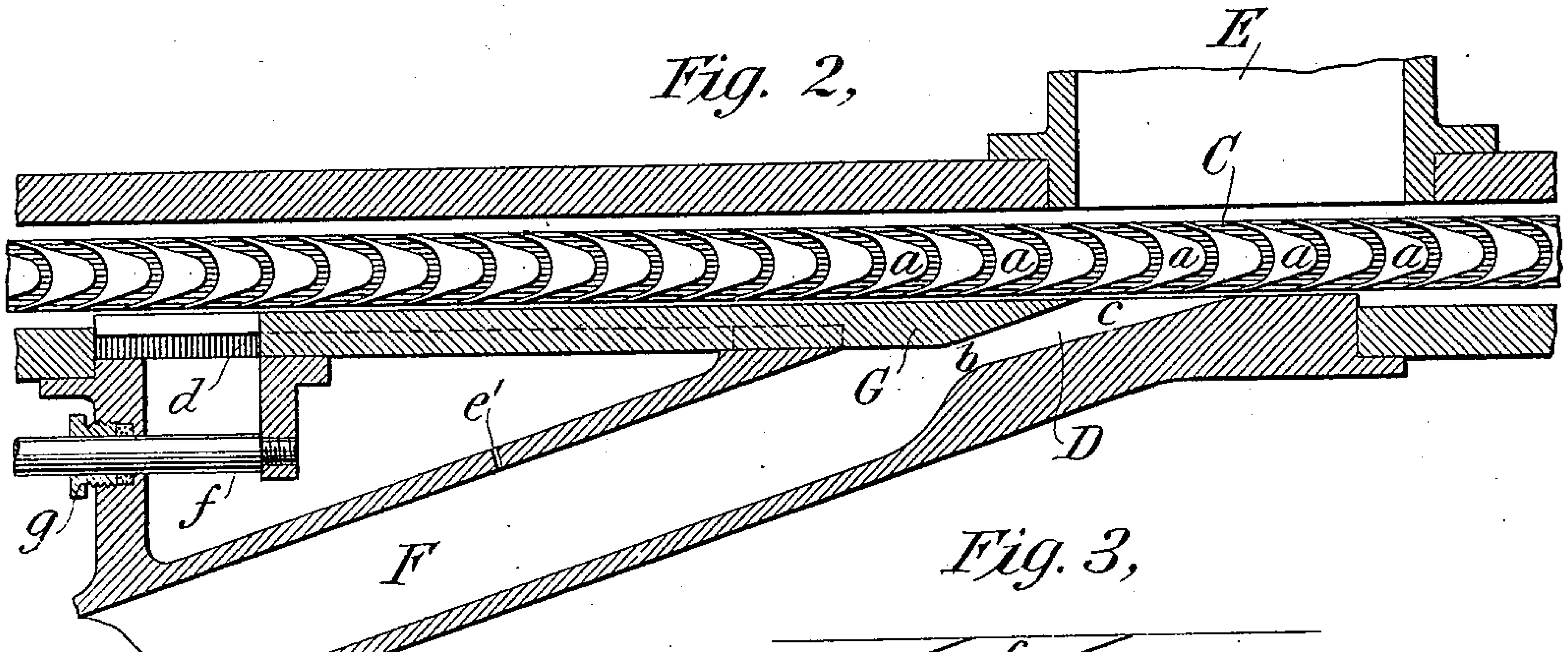
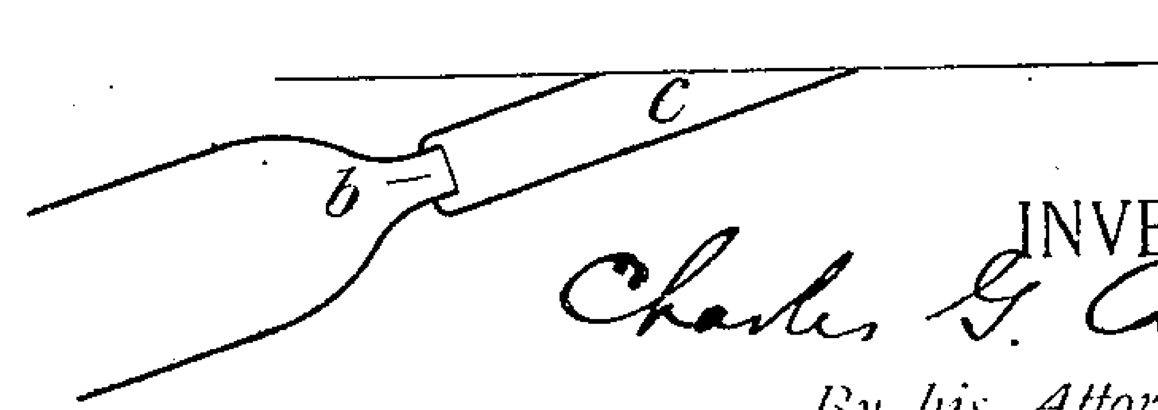


Fig. 3,



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(No Model.)

5 Sheets—Sheet 2.

C. G. CURTIS.
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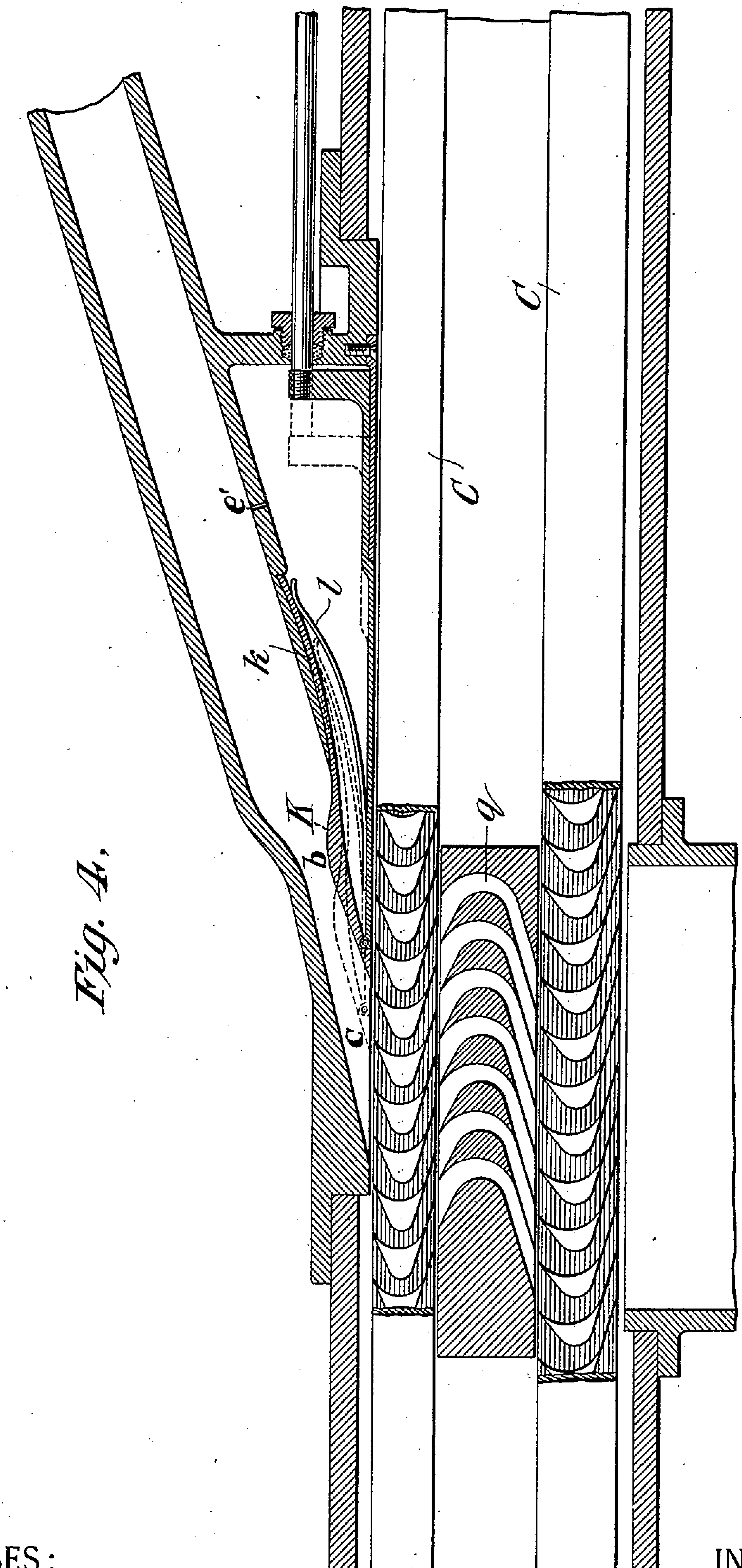

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(No Model.)

5 Sheets—Sheet 3.

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ELASTIC FLUID TURBINE.

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Fig. 5,

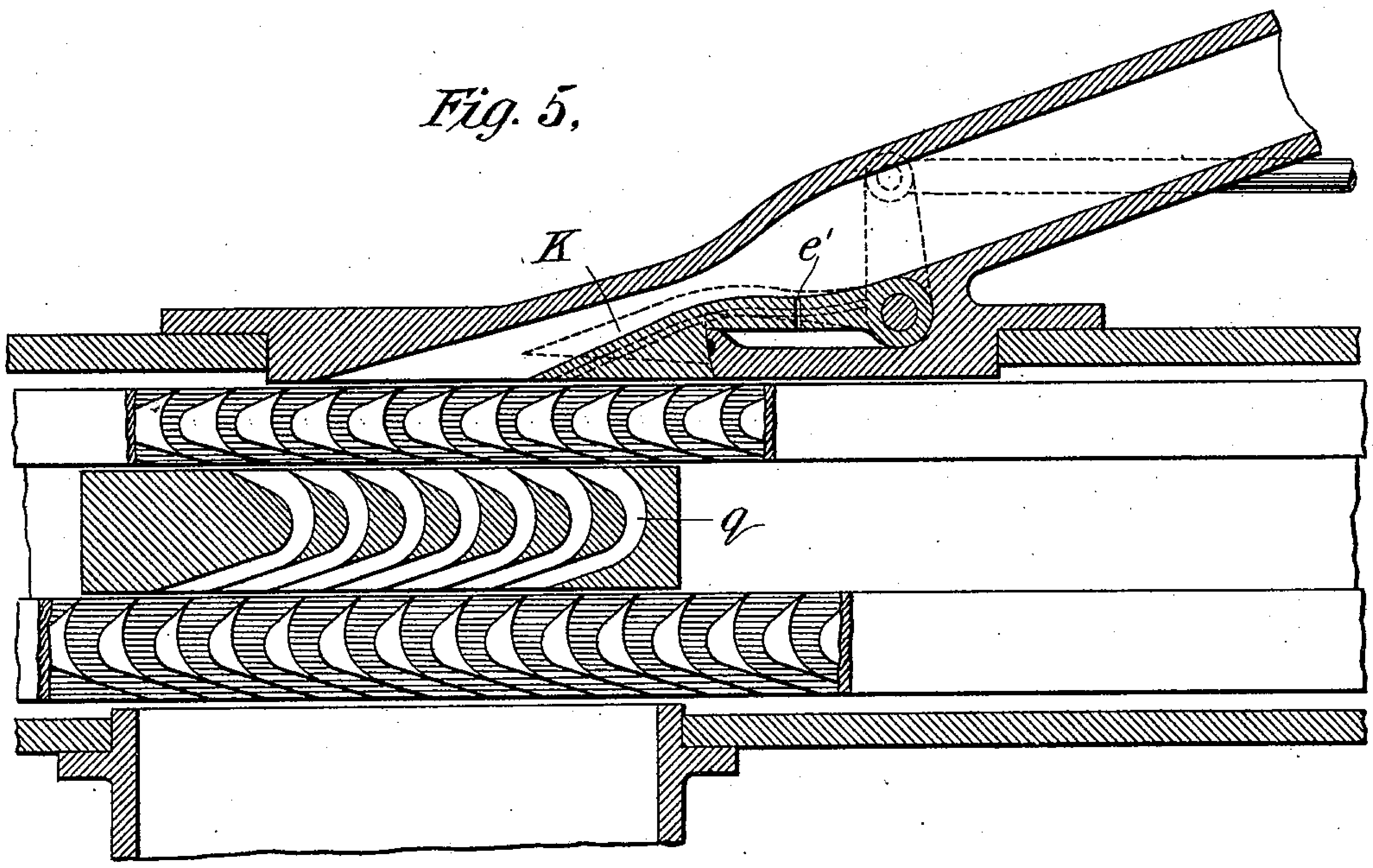
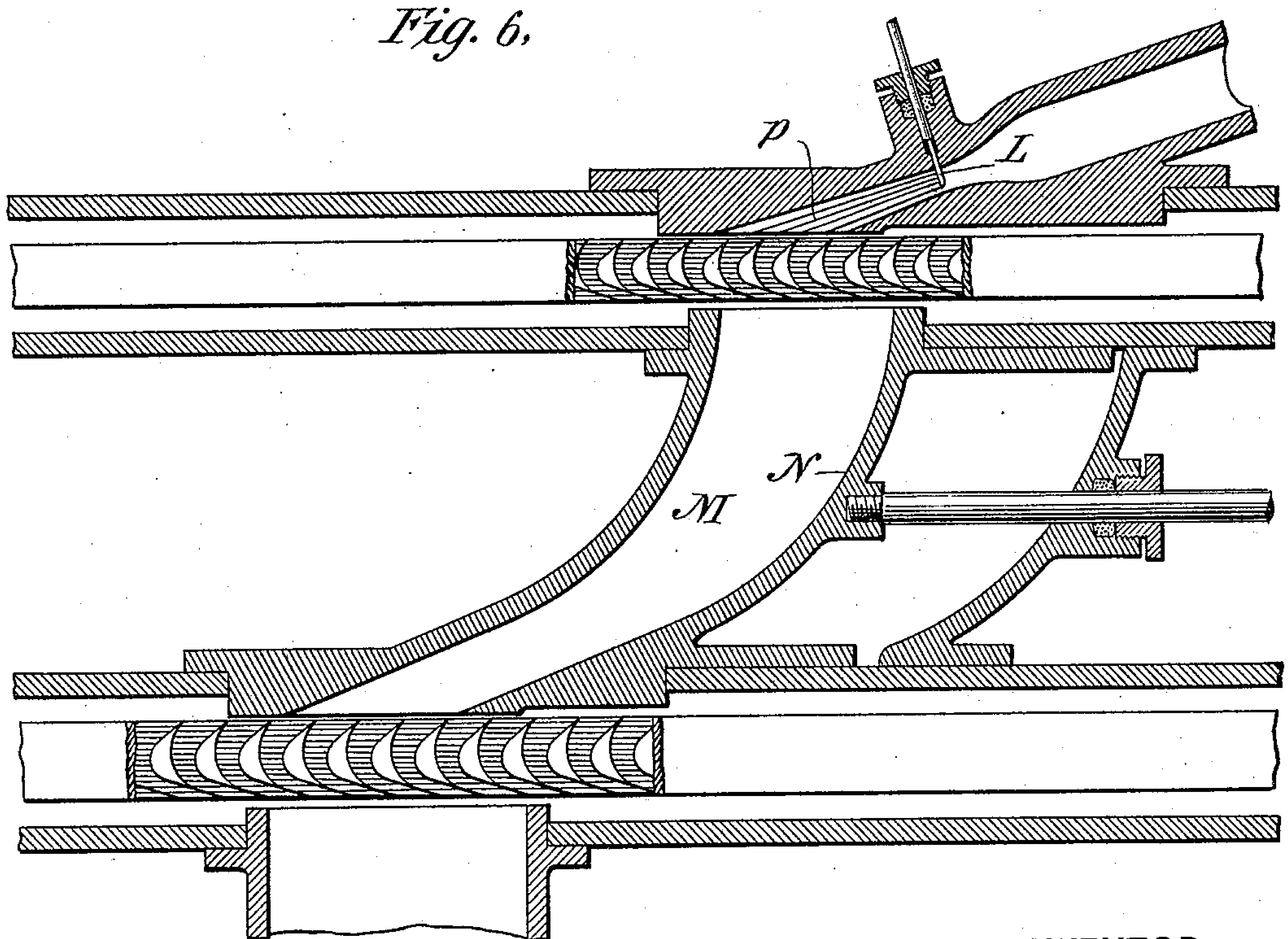


Fig. 6,



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(No Model.)

5 Sheets—Sheet 4.

C. G. CURTIS.

ELASTIC FLUID TURBINE.

No. 566,967.

Patented Sept. 1, 1896.

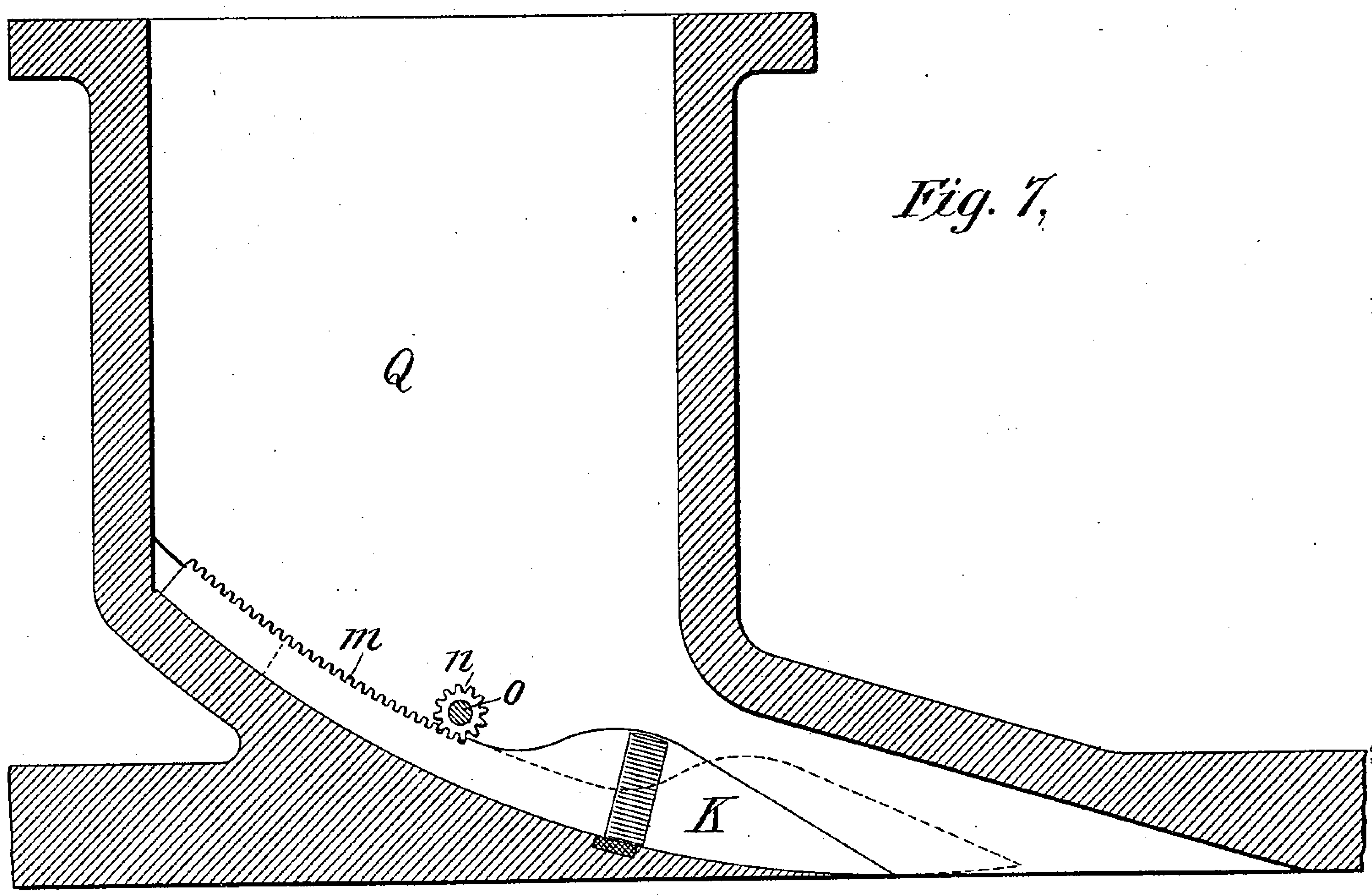
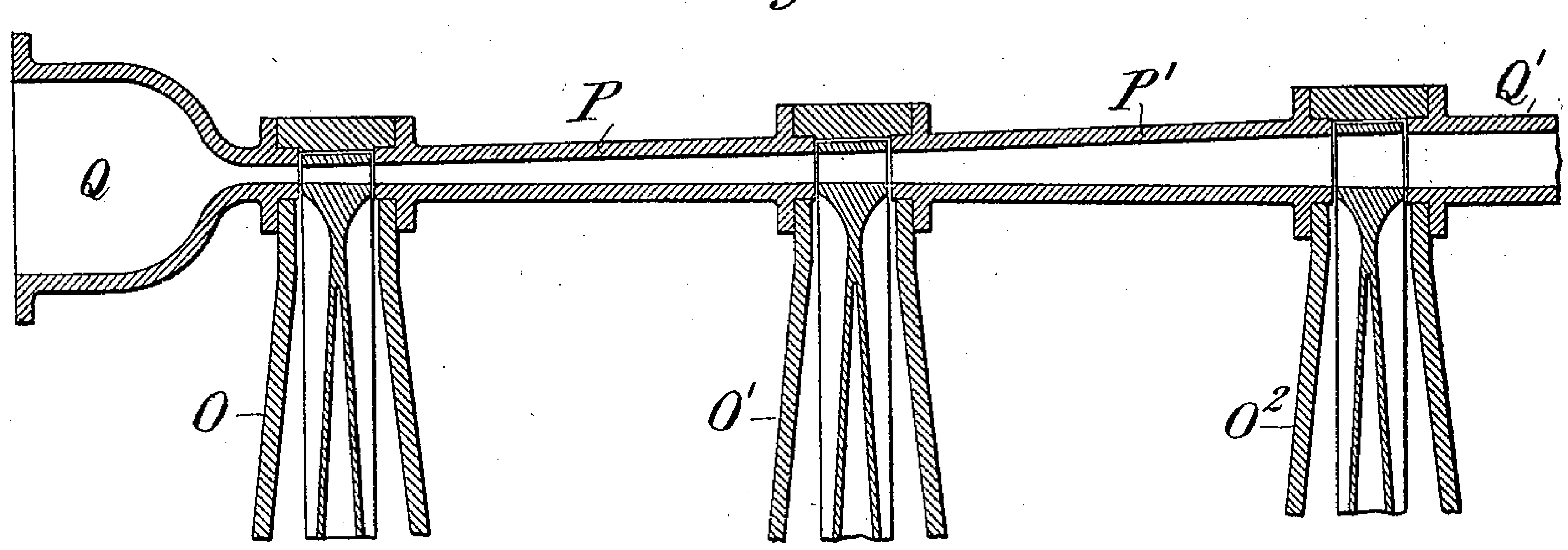


Fig. 7.

Fig. 9.



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(No Model.) 5 Sheets—Sheet 5.

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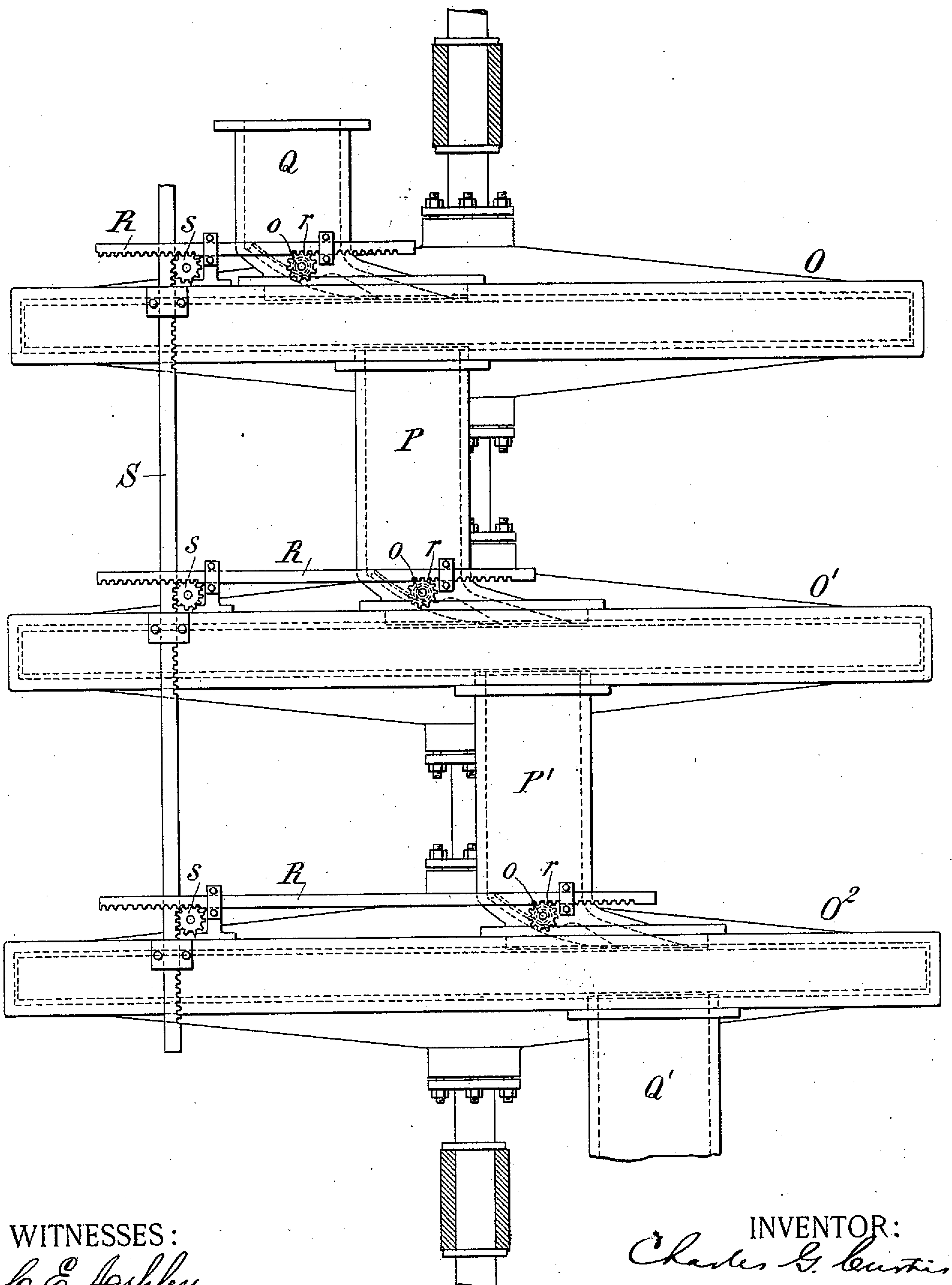
Fig. 8.



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UNITED STATES PATENT OFFICE.

CHARLES G. CURTIS, OF NEW YORK, N. Y., ASSIGNOR TO THE CURTIS COMPANY, OF SAME PLACE.

ELASTIC-FLUID TURBINE.

SPECIFICATION forming part of Letters Patent No. 566,967, dated September 1, 1896.

Application filed January 2, 1896. Serial No. 574,031. (No model.)

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.

My invention relates to apparatus for developing power from steam or other elastic fluid under pressure, wherein the energy of pressure is converted into energy of velocity or *vis viva*, and is transformed into mechanical power by being directed against a portion of the vanes of a complete circular range of rotating vanes or by being directed successively against a portion of two or more sets of such vanes. In all elastic-fluid turbines mechanical power is developed by utilizing the *vis viva* of the fluid to impart motion to the blades or vanes of the turbine. The principles underlying the successful solution of the problem of developing mechanical power by means of such turbines in an efficient, practical, and commercially-satisfactory manner have been embodied by me in methods and apparatus upon which I propose to apply for Letters Patent, Serial Nos. 575,244 and 575,679. In all successful mechanical combinations by which this result can be obtained with steam or other elastic fluid the size, form, and relative proportions of all the parts which unite to form the passage-way through which the fluid passes from the source of supply under maximum pressure to the exhaust are necessarily adapted to permit expansion of the fluid and conversion of its pressure into velocity and to convert the maximum amount of *vis viva* into rotary motion of the vanes during its passage from inlet to exhaust. Having planned and constructed such an apparatus in a manner to produce the greatest possible mechanical power when the maximum volume of fluid is admitted thereto, the problem of governing such a machine efficiently presents itself, that is to say, of insuring the same relatively high efficiency under all variations of load. This has not heretofore been accomplished. My invention has for its object the solution of this problem. For the majority of commercial purposes requiring a stationary plant an elastic-fluid turbine, like a steam-engine, must be made to maintain a practically constant speed under all variations of load. My new method of and apparatus for governing is based upon the principle that if the volume of the jet of the elastic fluid flowing through a turbine is made to vary, and at the same time the velocity of the jet remain constant, the mechanical power developed will vary as the volume of the jet varies, and therefore the efficiency of the turbine will be substantially the same at all loads. Furthermore, if the volume of the jet is made to vary substantially as the load varies, but the velocity of the jet is constant, the speed of rotation of the turbine will remain constant. On the other hand I have found that if both the velocity and volume of the jet at the point or points where it strikes the vanes of the turbine are varied the speed of rotation of the turbine will vary, or if the speed of rotation is under these conditions maintained constant a relatively larger volume of jet will be required to maintain this speed of rotation at light than at heavy loads, and in either case there will be a loss in efficiency.

In carrying out my invention I provide a governing mechanism which is so designed as to vary the volume of the jet to any desired extent without varying its velocity at the point or points where it acts upon the movable element or elements of the turbine, that is to say, where this velocity is converted into mechanical power. This I do by maintaining the same relative proportions between the parts of the expansion passage-way while varying the size of the steam-inlet, *i. e.*, the volume of the jet at its entrance to the apparatus from the source of supply. With the oldest and best-known form of expansion-nozzle, *i. e.*, one having diverging sides and gradually-enlarging cross-sections, variation of the size of the smaller end only, *i. e.*, of the volume of the jet admitted to the nozzle, will be attended with variation of the velocity of the jet at the larger end, for the velocity of the jet at the larger end will depend upon the amount of expansion that has occurred at that point, and if the nozzle is designed to permit full expansion at the larger end when the smaller end is wide open full expansion will occur before the jet reaches that point, if the smaller end is partly closed, and the consequence will be that the cross-section of the larger end will be too large to convey the reduced volume of fluid at the proper velocity and a reduced velocity at this point will follow. As the *vis viva* or energy contained in the moving fluid varies as the square of its velocity, a comparatively slight loss of velocity results in a very considerable loss of power. In order, therefore, that the degree of expansion and therefore the velocity of the jet may be constant at the larger or delivery end under variations in the size of the smaller end, it is essential that the cross-section of the larger end shall at all times bear the same proportion to the cross-section of the smaller end and the rate of cross-sectional increase between the two remain constant. Whether this or some other form of expansion-nozzle is used, or whether the expansion is allowed to take place partly in the stationary passages and partly in the movable or secondary elements of the apparatus, the essential thing is that variation in the fluid-inlet, *i. e.*, in the volume of fluid admitted from the source of supply, shall be accompanied by such variation in the controlling parts of the expansion passage-way through which the fluid-jet passes to the exhaust (*i. e.*, those parts where the fluid acts upon the movable elements of the turbine and where for that reason it is important to maintain the proper velocity or velocities) as shall maintain at all times the same proportions between the various parts and the fluid-inlet. Under these conditions the volume of the jet will vary, but its effective or virtual velocity at each point where it acts will remain substantially constant under variations in volume. The apparatus constructed by me embodying these principles of governing show the marked improvement in efficiency, economy, and commercially-satisfactory practice which is a condition precedent to any extensive use of steam or elastic-fluid turbines as prime movers.

In carrying out my invention in connection with a turbine having only one set of vanes or buckets to which motion is imparted by the *vis viva* of the fluid-jet the conversion of the pressure of the fluid into velocity should preferably precede its impact with that portion of each vane which is designed to convert such velocity into mechanical power. The means for obtaining such conversion may be either the old diverging nozzle or an improved expansion-nozzle devised by me, in which the fluid issues from a contracted inlet or nozzle into a larger passage whose cross-section may be constant and equal to the volume of the jet when the desired expansion has taken place. Describing this part of the apparatus as the "expansion" passage or nozzle, I make it adjustable, so that the cross-section of the fluid-inlet may be varied and so that every variation thereof shall be accompanied by simultaneous variations in the other parts of the expansion-passage and the proportions between them remain constant. The adjustable element may be moved by hand, but of course an automatic adjustment by means of a speed-governor or otherwise is necessary for most purposes. The adjustability may be obtained in different ways. In the case of the diverging form of nozzle one side thereof may be adjustable toward and away from the other side, or both sides may be adjustable toward and away from each other, or the single nozzle may be divided into a number of separate expanding-passages, more or fewer of which may be closed by a movable gate. In case one side of the nozzle is made adjustable, this adjustable side may be a piece having a movement in a right line, in which case the proportion between the inlet and the discharging ends will be roughly maintained, but only within narrow limits of inlet variation, unless the nozzle be made with its movable side parallel to the one opposite and the other two sides diverging, (but so that the cross-section of the nozzle shall be a parallelogram,) the increase of cross-section being thus obtained and the proportions maintained regardless of the adjusted distance between the parallel sides; or the proportion may be maintained with precision by pivoting the adjustable element of the nozzle or moving it in curved guides, so that it will have a greater rate of motion at the discharging end than at the inlet end of the nozzle, the rate of motion being proportional to the respective cross-sectional areas at these points.

In applying my invention to the case of an expansion-passage of other than the diverging form I make my expansion-passage practically of two parts, (one being a contracted inlet or nozzle and the other a larger discharge end,) and I construct these parts so that by means of movable walls or parts the cross-sectional areas of both the inlet and discharge may be caused to vary simultaneously and proportionally.

In applying my invention to a turbine having two or more sets of rotating vanes in which the *vis viva* is utilized and an inlet nozzle or passage and one or more stationary or rotating intermediate expanding-passages the principle underlying correct governing is the same. The whole passage-way through which the fluid is passing at any instant from the supply to the exhaust may be considered as made up of sections or portions in which (1) pressure is converted into *vis viva*, (2) the direction of flow of the jet is changed, as required, and (3) the *vis viva* is converted so far as possible into mechanical power. Any section may perform only one of these functions or it may combine two or more of them. With reference to governing in accordance with my invention it is necessary that all controlling cross-sections of the passage-way, considered as a whole, should vary simultaneously with every change at the inlet end and maintain at all times the same proportions to each other. With respect to any portion of the passage-way which is made up of spaces between vanes or buckets, the adjustable element of the passage-way which immediately precedes will determine the number of vanes to which the jet is admitted at any instant by the cross-section of its discharge end at that instant. Every portion of the passage-way not made up of spaces between vanes will have an adjustable side whose movement, whether on a pivot or sliding, &c., will effect the proportionate variation required, and simultaneity of variation will be obtained by connecting all the adjustable sides to appropriate mechanism, whereby all will move with every movement given to the adjustable side at the inlet, whether by an automatic speed-controlling device or otherwise. Another class of turbines may be considered, in which the passage-way through which the steam or fluid passes may be regarded as divided into a series of passage-ways each in some sense complete in itself, the first beginning at the inlet from the main steam supply and ending at an exhaust-pipe leading from the first shell to the beginning of the second passage-way, this exhaust-pipe serving as a supply-pipe to the second passage-way, and so on, the apparatus being divided up into parts, each operating under a lower initial pressure than the one before it. In this case my invention does not require any variation in the various exhaust-pipes thus described, but only that each of the series of passage-ways shall be varied throughout simultaneously and proportionally with each variation of its own inlet, and that all the inlets after the first shall vary simultaneously and proportionally with the one opening from the main steam supply. The application of my invention to this case is similar to that described above, except that what I have called the "exhaust-pipes" (regarding them now as portions or sections of the entire steam-passage) are not varied, but remain constant, the velocity of the steam or fluid being at such points trifling and unaffected by them in any way.

In the accompanying drawings, forming part hereof, Figure 1 is a side elevation of a simple or non-compounded turbine having my invention applied thereto. Fig. 2 is a sectional view of the same apparatus through the nozzle and exhaust-passage with the vanes developed in a horizontal plane and showing the well-known diverging nozzle with my invention applied thereto. Fig. 3 is a diagram indicating a new construction of expansion-nozzle or expansion intermediate stationary passage. Fig. 4 is a section similar to Fig. 2, showing a different construction of the adjustable element of the nozzle and illustrating the invention applied to a compound turbine having a divided or sectional adjustable intermediate stationary passage. Fig. 5 is a view similar to Fig. 4 and of the same character of apparatus, showing a different method of adjusting the nozzle. Fig. 6 is a sectional view similar to Fig. 5, illustrating the employment of a divided or sectional nozzle and a single or undivided adjustable intermediate stationary passage. Fig. 7 is a sectional view of an expansion-nozzle or stationary passage, showing a different method of adjustment. Fig. 8 is a side elevation illustrating the construction of Fig. 7 applied to the nozzle and intermediate passages of a compound turbine having a series of connected movable elements located in separate shells; and Fig. 9 is a radial section of the apparatus of Fig. 8, taken on a line running through the center of the steam-passages.

Referring to Figs. 1 and 2, A is a steam-tight shell, within which is mounted, upon a shaft B, a disk C, carrying on its periphery a complete circular range of curved vanes *a*. Entering one side of the shell A is the delivery-nozzle D, and from the other side of the shell leads the exhaust-opening E, which may open into the air or be connected with a condenser or other means for producing less than atmospheric pressure. Leading to the nozzle D is the pipe F from the steam-boiler or other source of elastic fluid under pressure. The nozzle D is of the well-known type having diverging sides and gradually-enlarging cross-sections between its throat or receiving end *b* and its discharging end *c*. The purpose of this nozzle is to convert the energy of pressure into energy of velocity or *vis viva*. The relation between the discharging end *c* and the receiving end *b* is determined by the conditions of velocity which it is desired to obtain at the delivery end of the nozzle. It is highly important that the velocity at which the steam is designed to be delivered to or to act upon the vanes should be maintained practically the same, whatever volume of steam is passing, because it is by means of the velocity that the machine does its work, and to do this it is necessary that the proportions between the two ends of the nozzle, whatever they are in the particular design of the machine, should be maintained substantially constant, and it is this which my invention is designed to accomplish. In order to diminish the volume or quantity of steam flowing, and at the same time obtain approximately the same efficiency in the operation of the apparatus, one of the diverging sides of the nozzle D is formed by a plate G, which slides in suitable ways *d* within the auxiliary shell *e*, an opening *e'* being made from the steam-pipe F into the space within the shell *e* to more nearly balance the pressure on the plate G. The sliding movement of the plate G is secured by means of a rod *f*, passing through a stuffing-box *g*. This rod may be connected by a link *h* with a bell-crank lever H, which lever is connected at its other end with the sliding collar *i* of a centrifugal governor located within the wheel I, so that the adjustment of the plate G will be produced automatically by a small percentage of variation in the speed of the turbine. It will be understood that by making one of the diverging sides of the nozzle adjustable from end to end of the nozzle the relations between the points *b* and *c* will be roughly maintained within narrow limits of inlet variation and the velocity of the steam as it is discharged from the nozzle will be approximately the same for all volumes of the steam-jet within a limited range of adjustment of the nozzle. If, however, the adjustable side be made parallel with the opposite side of the nozzle and the expansion is obtained by the divergence of the other two sides, (the form in cross-section being a parallelogram,) any degree of adjustment can be obtained without changing the desired relations. The nozzle, instead of having regularly-diverging walls and gradually-increasing cross-sections, as illustrated in Fig. 2, may be made in a different form, such as, for example, the construction illustrated diagrammatically in Fig. 3, in which there is a contracted inlet or nozzle *b* of proper size and a larger discharging end *c* of proper size to give the desired expansion, the walls between these points being parallel; and it should be understood that I consider such construction to be an "expansion" nozzle or an "expansion" intermediate passage within the meaning of that word as applied to such nozzles and passages in this specification. This special form of expansion-nozzle or intermediate stationary passage I propose to make the subject of a separate application for patent.

Instead of adjusting the nozzle by means of a plate moving in a right line, as in Figs 1 and 2, the end of this sliding plate may be a pivoted piece K, having a curved tailpiece *k*, held to its curved seat by a spring *l*, and balanced by a steam-opening *e'*, so that as the piece K is pushed forward it will be turned on its pivot sufficiently to preserve with precision the relations between the receiving and discharging ends of the nozzle by giving it a greater rate of movement toward the other side of the nozzle at the discharging end *c* than at the receiving end *b*, these different rates of movement being proportional to the different cross-sectional areas at those points; or, as illustrated in Fig. 5, the adjustable piece K may be pivoted at a point sufficiently removed from the nozzle to preserve the proper relation by a pivotal movement of the piece. The somewhat different construction shown in Fig. 7 I consider an excellent form. In this the movable piece K slides on a curved seat and is moved forward and backward by means of a rack *m*, with which engages a pinion *n* on a spindle *o*, extending through the side of the nozzle, or it may be moved by a sliding rod, as in other constructions shown. In Fig. 6 a construction of adjustable nozzle is shown wherein the nozzle is divided into a number of diverging sections by partitions *p*, more or less of the sections of the nozzle being closed by a sliding gate L.

In applying my invention to a compounded turbine, the stationary intermediate passage (or each of them, if the compound turbine has more than two movable elements) is divided into a number of sections by curved vanes *q*, as shown in Figs. 4 and 5. This construction secures an adjustment of the stationary passage simultaneously and proportionally with the adjustment of the nozzle, because the number of the sections of the stationary passage occupied by the steam-jet in passing from one set of movable vanes to another will depend upon the number of movable vanes from which the jet is discharged, and that number is in turn dependent upon the adjustment of the nozzle. I prefer, however, to provide a single or non-sectional intermediate passage M, and have one of its sides N adjustable toward and away from the other side throughout the length of the passage, as shown in Fig. 6, or only at the discharging end of the passage, as shown in Fig. 8. In Fig. 6 the adjustable side N of the stationary passage M is a separate piece, closing one side of the passage and moving between the parallel side walls toward and away from the other side of the passage, the movement being secured by a sliding rod which is preferably adjusted simultaneously with the adjustment of the nozzle. The construction illustrated in Figs. 8 and 9 is a compound turbine composed of three movable elements O O' O^2, contained in separate shells and connected to receive the flowing jet in succession by means of intermediate stationary passages P P', which are provided with adjustable discharging-nozzles of the character illustrated by Fig. 7.

Q is the inlet-pipe from the steam-boiler, and Q' is the exhaust-opening discharging into the air or connected with a condenser. The steam passes from the inlet Q to the vanes of the first turbine through a nozzle having an adjustable element like that illustrated in Fig. 7. The nozzle and the discharging ends of the intermediate passages are adapted to successively convert different portions of the pressure into velocity. The spindles *o*, whose inner ends carry the pinions for adjusting the movable pieces K, as illustrated in Fig. 7, have on their outer ends pinions *r*, engaging with rack-bars R, which in turn engage with pinions *s*, connected together in any suitable way, as by a single rack-bar S, whereby the adjustable elements of the expansion-nozzle and the expansion intermediate stationary passages may all be moved simultaneously and to the same extent.

What I claim is—

1. In an elastic-fluid turbine, a governing or regulating mechanism causing variations in the volume of the fluid jet unaccompanied by substantial variations in its velocity at the

point or points where it acts upon the moving parts to develop mechanical power, substantially as set forth.

2. In an elastic-fluid turbine, the combination with one or more sets of moving vanes, and a passage delivering a fluid jet to such vanes, of means for varying the volume of the fluid jet without substantial variation of its velocity at the point or points where it acts on the vanes, substantially as set forth.

3. In an elastic-fluid turbine, the combination with one or more sets of moving vanes, and an expansion-passage converting pressure into velocity and delivering a fluid jet to such vanes, of means for varying the volume of the fluid jet without substantial variation of its velocity at the point or points where it acts on the vanes, substantially as set forth.

4. In an elastic-fluid turbine, the combination with a set of rotating vanes, of an expansion-nozzle or stationary passage delivering a fluid jet to a part of the vanes and acting to convert pressure into velocity, such nozzle or passage being adjustable to vary the volume of the fluid jet while maintaining approximately the relations between its receiving and discharging ends, substantially as set forth.

5. In an elastic-fluid turbine, the combination with a set of rotating vanes, of an expansion nozzle or passage delivering a fluid jet to a part of the vanes and acting to convert pressure into velocity, and an adjustable part forming one of the sides of the expansion-nozzle at both its receiving and discharging ends, whereby the cross-sectional areas of the nozzle at its receiving and discharging ends may be varied while maintaining approximately the relation between such cross-sectional areas, substantially as set forth.

6. In an elastic-fluid turbine, an expansion delivery nozzle or passage, adjustable simultaneously at its receiving and discharging ends, substantially as set forth.

7. In an elastic-fluid turbine, an expansion delivery nozzle or passage, adjustable simultaneously at its receiving and discharging ends with a rate of variation proportional to the cross-sectional areas at such ends, substantially as set forth.

8. In an elastic-fluid turbine, the combination with a set of rotating vanes, of an expansion-nozzle or stationary passage delivering a fluid-jet to a part of the vanes and acting to convert pressure into velocity, such expansion nozzle or passage being simultaneously adjustable at its receiving and discharging ends with a rate of variation proportional to the cross-sectional areas of such ends, substantially as and for the purpose set forth.

9. In an elastic-fluid turbine, the combination with a set of rotating vanes and an expansion nozzle or passage delivering a fluid-jet to a portion of the vanes and acting to convert pressure into velocity, of an adjustable part for varying the cross-sectional areas of the expansion nozzle or passage simultaneously at the receiving and discharging ends thereof, which adjustable part has a different rate of variation at the two ends toward and away from the other side of the nozzle, such different rates of variation being proportional to the cross-sectional areas at the two ends of the expansion nozzle or passage, substantially as set forth.

10. In a compound elastic-fluid turbine, the combination with movable vanes and means for delivering the elastic fluid to the vanes two or more times in succession, of a governing or regulating mechanism causing variations in the volume of the elastic fluid unaccompanied by substantial variations in its velocity throughout the fluid-passage of the turbine, substantially as set forth.

11. In a compound elastic-fluid turbine, the combination with two or more sets of rotating vanes, of a nozzle and one or more intermediate stationary passages, whereby a fluid-jet is presented to a part only of the vanes of the sets in succession, said nozzle and intermediate passage or passages being simultaneously and proportionately adjustable in their cross-sectional areas, substantially as set forth.

12. In a compound elastic-fluid turbine, the combination with two or more sets of rotating vanes, of an expansion-nozzle delivering a fluid-jet to a part of the vanes of the first set, and one or more stationary intermediate passages conveying the fluid-jet from one set of rotating vanes to another, the area of the expansion-nozzle and of the intermediate passage or passages being simultaneously and proportionately adjustable, substantially as set forth.

13. In a compound elastic-fluid turbine, the combination of a series (two or more) of adjustable expansion nozzles or passages, receiving the fluid-jet successively and converting pressure into velocity, and two or more sets of rotating vanes to which the fluid-jet is delivered successively by such nozzles or passages, substantially as set forth.

14. In a compound elastic-fluid turbine, the combination with two or more sets of rotating vanes, of an adjustable expansion-nozzle, one or more intermediate stationary passages having adjustable expansion discharging ends, and a connection between the adjusting devices of the nozzle and intermediate passages whereby the adjustment of the nozzle and of the one or more intermediate passages will be effected simultaneously and proportionately, substantially as set forth.

15. In an elastic-fluid turbine, a governing or regulating mechanism acting to vary automatically according to changes in load or speed the volume of the fluid unaccompanied by substantial variations in its velocity at the point or points where it acts upon the mov-

ing parts to develop mechanical power, substantially as set forth.

16. In an elastic-fluid turbine, an expansion delivery nozzle or passage adjustable simultaneously at its receiving and discharging ends, in combination with speed-governing mechanism controlling the adjustable element of such nozzle or passage and effecting such adjustment automatically, substantially as set forth.

This specification signed and witnessed this 31st day of December, 1895.

CHARLES G. CURTIS.

Witnesses:
EUGENE CONRAN,
JOHN R. TAYLOR.