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L. Szilard
October 1, 1946

Figure 1 is a rotating shaft. Cylindrical tube 2 is keyed to this shaft and rotates with it. Another coaxial cylindrical tube 3 rotates freely on this shaft by virtue of the torque transferred to it through the intermediary of two liquid layers which fill the annular gap between the outer surface of cylinder 2 and the inner surface of cylinder 3. Of the two solvents the one with the smallest specific gravity* is fed in by means of pump 5 through the header 4, into the bore 8 of the shaft 1, and the solvent enters the annular gap through the tube 6. It then passes through the annular gap from left to right and leaves the gap after passing through an overflow, through the tubes 7 and 9. Similarly, the solvent with the higher specific gravity enters the shaft through header 5 and leaves the annular gap through tube 10. It passes through the annular gap from right to left and leaves the gap at the left end, after passing through an overflow, through tubes 11 and 12. While the tubes 2 and 3 rotate with approximately the same angular velocity (the angular velocity of the outer tube 3 being slightly smaller) the two solvents are separated in the annular gap by a meniscus 13, the heavier solvent forming the outer layer and the lighter solvent forming the inner layer. The angular velocity of the outer cylinder 3 is kept lower than the angular velocity of the inner cylinder 2 by applying friction to the outer rotar by means of turning the cap 14. The lighter solvent which leaves the rotor through the tubes 7 and 9 is guided by the rotating fin 15 to the right hand end of the hollow casing 16 and leaves that casing through an outlet 17. Similarly,

* What matters is strictly speaking not which of the two solvents has the smaller specific gravity but rather which of the two solutions has the smaller specific gravity.

the heavier solvent which leaves the rotating system through the tubes 11 and 12 is guided by the rotating fin 18 to the left hand end of the casing 16 and leaves it through an opening 19. 20 is a circular fin attached to the casing which prevents the two solvents from getting mixed within the casing. 21, 22, etc., are semicircular fins which are attached to the upper half of the casing and serve the purpose of preventing droplets, of the solvents, which might be sprayed against the upper part of the casing from drifting axially from one end of the casing to the other.

Figure 2 is another embodiment of serving the same purpose as the embodiment shown in Figure 1. We have again two coaxial cylinders, an inner cylinder 30 and an outer cylinder 31 which are rotating, and two solvents in the annular gap which is left free between the outer surface of the inner cylinder 30 and the inner surface of the outer cylinder 31. In this case the two cylinders however can be rotated independently. The inner rotor 30 is driven by means of the pulley 32 which is keyed to the shaft 33 and the outer cylinder can be rotated by means of the pulley 34, which is keyed to the shaft 35. The solvent having the lower specific gravity is fed in through the header 36, enters the annular gap on the left side through the tube 37, passes through the annular gap from left to right and leaves the annular gap on the right hand side through the chamber 38, through an overflow. It passes through tubes 39 and 40 and is guided by the rotating fin 41 to the right end of the casing 42 which it leaves through an outflow 43. The lighter solvent enters the shaft 33 through a header 44. It enters into the annular gap between the two rotating cylinders through the tubes 45 and 46, passes through the annular gap from right to left and leaves the annular gap through an overflow through tubes 47 and 48. It is guided by the rotating fin 49 to the left hand side of the casing 42 which it leaves through the outlet 50. A meniscus 51 separates in the annular gap the two solvents 52 and 53. 52, representing the heavier solvent, fills the outer part of the gap, whereas 53, representing the lighter solvent, fills the inner part of the gap between the rotating cylinders.

Figure 3 shows another embodiment of the same invention. Again we have two coaxial cylindrical rotors, 60 and 61. The inner cylinder 60 and the outer cylinder 61. The inner rotor is keyed to the shaft 62 which is driven by means of the pulley 63. The outer rotor 61 is supported by the bearings 64 and 65 and is driven by the pulley 66. The solvent having the lower specific gravity is fed by the pump 67 through the header 68 into the shaft 62 and enters the annular gap 69 through the tube 70 at the left hand end of the system. It leaves the annular gap through an overflow at the right hand end of the system and leaves the rotor 61 through the tubes 71 and 72. It is guided by the rotating fin 73 to the right hand corner of the casing 74 which it leaves through an outflow 75. Similarly, the heavier of the two solvents enters the shaft 62 through the header 76 and flows into the annular gap 69 through the tube 77 on the right hand side of the gap. It flows through the annular gap from right to left and leaves it through the chamber 78, by overflowing, through the tubes 79 and 80. The rotating fin 81 guides the solvent to the left hand end of the casing 74 and the solvent leaves the casing through an outflow 82. Under the action of centrifugal forces the heavier solvent 83 and the lighter solvent 84 are separated by a meniscus 85.

In all these examples shown in Figures 1, 2 and 3, the rotational speeds are so chosen that the difference in angular velocity be as large as possible but not so large as to destroy the separation of the two solvents in the annular gap. The faster the rotational speed is, the greater can this difference be made and still have the two solvents in separate layers by means of which a counter-current flow can be maintained.

There is however another consideration with respect to the turbulence set up by the differential speed of the two cylinders. While it is desirable to have as much turbulence as possible within each of the solvent layers in the tangential direction of the rotating cylinders, mixing in the axial direction due to turbulence is not desirable and the more mixing in the axial direction we have, the more we reduce what may be called the "number of theoretical plates". According to the present invention, mixing in axial direction can be kept low by subdividing the annular gap by means of rings inserted into the gap between the two rotating cylinders. This is illustrated in Figure 4 a and b. 90, 91, 92, etc., are rings which fit into the outer rotating cylinder93. Each of these rings is split, leaving a slit 94 open for the axial passage of the solvents in the annular gap which is left free between the outer rotating cylinder 93 and the inner rotating cylinder 95. The inner meniscus of the lighter of the two solvents in the gap is determined by the "overflow" for the lighter solvent. In this case it has to be so adjusted that the rings 90, 91, 92, etc., should stick out through the inner meniscus as shown in the drawing. If this condition is fulfilled, the only axial flow of the solvents during rotation will take place through the gaps 94 left free in the rings. The series of rings 96, 97, 98, etc. are slid on the cylindrical tube 95 and are rotating with it as if they formed a rigid body. These rings dip into the layer of the lighter of the two solvents but do not reach the meniscus separating the lighter from the heavier solvent. In an apparatus of this type we have a number of segments formed by the rings 90, 91, 92, etc. and within each segment we can maintain turbulent motion within each of the two layers of the heavier solvent and of the lighter solvent. This turbulent motion arises because of the difference in angular velocity between the rings 90, 91, and 92, on the one hand (which rotate ~~without a~~ with the outer cylinder 93) and the rings 96, 97, 98, etc., on the other hand (which rotate with the inner cylinder 95). There is no mixing of either solvent however between neighbouring compartments and the axial flow necessary for maintaining the counter current takes place through the slits 94 in the outer ring system.

The inner ring system may also be composed of split rings and the gaps in the split may permit the passage of the lighter solvent. This is however not absolutely necessary since the passage of the lighter solvent is in no case blocked, provided the inner rings do not pierce the meniscus that ~~split~~ separate the lighter from the heavier solvent. The Figure 4a shows on the left hand side the outflow of the heavier of the two solvents which leaves the rotating system through the tube 99. ¶ Figure 5 shows a section A, B. through Figure 1, illustrating in what manner the heavier of the two solvents leaves the rotating system through the tubes 11, 12, etc. Figure 6 shows in greater detail how the lighter of the two solvents is fed in through the header 4 into the shaft 1. And Figure 10 shows how the solvent is fed into header 4 by means of the pump 5. Figure 7a and b show an alternative method for removing the solvent from the rotating system in place of tubes 11 and 12. We have here a circular slit 100 through which the solvent ~~leaves the chamber 101.~~ may flow out radially from the chamber 101. — 101

While in the examples described in Figures 1 to 7 we had two coaxial rotating tubes and the two layers of solvents, in the annular gap, between the two tubes, were kept moving relative to each other in the tangential direction by the difference in the angular velocity of the two rotating tubes, we are now going to describe an arrangement where we have only a single rotating system and where the two layers of solvents are kept in motion relative to each other in the tangential direction by intermittently slowing and accelerating the rotation of the system.

In Figure 8, 110 is a shaft which is kept in rotation by means of the motor 111. The lighter of the two solvents is fed in through the shaft 110, through the header 112, and it enters into the rotating hollow tube 113 on the left hand side through the tube 114. This lighter of the two solvents 115 then flows from left to right through the rotating system and leaves it through the tubes 116 and 117, at the right hand end of the rotor. The rotating fin 118 guides the lighter solvent to the right hand is increased & decreased alternately

end of the hollow casing 119 and this solvent leaves the casing through the opening 120. The heavier solvent enters the shaft 110 through the header 121 and enters the rotor at its left hand end through the tube 122. The heavier solvent 123 flows through the rotating system from right to left and leaves it at the left hand end through the chamber 124 via an overflow and the tubes 125 and 126. The rotating fin 127 guides the outflowing solvent to the left hand end of the hollow casing 119, and the heavier solvent leaves this casing through the outflow 128. The circular fin 129 which is attached to the casing prevents the two solvents from mixing inside the casing 119. 130 is ~~an~~ a fly wheel. By means of the gear 131 ~~pulley 131~~ and the speed regulator 133 ~~gadget 132 and 133, the voltage energizes the starter and the excitation of the motor is intermittently changed in such a manner as to increase and to decrease the speed of the motors intermittently.~~ the speed of the motor increases and decreases intermittently in an alternating manner.

As the speed of the motor increases the mean angular velocity of the heavier solvent layer 123 which is in direct contact with the inner surface of the rotating cylinder 113, will be kept larger than the mean angular velocity of the lighter solvent layer 115 which is separated from the heavier solvent layer by a meniscus 136. Conversely, as the speed of the motor decreases, the mean angular velocity of the heavier solvent layer 123 which is adjacent to the inner surface of the rotating tube 113, will be lower than the mean angular velocity of the lighter solvent layer 115, which is separated from it by the meniscus 136. In this manner, the two liquid layers are kept tangentially in motion relative to each other and consequently a rapid transfer of the dissolved agent will take place betweenn them. The faster this transfer is, the faster we can send the two solvents through the rotating system in counter current fashion and have satisfactory performance.

In order to avoid mixing in axial direction within the two solvent layers, we may have arranged as shown in Figure 9a a number of rings, 140, 141, 142, etc., inside the rotating cylinder 113. These rings are split as can be seen from Figure 9 b, and the slit 143 permits the axial passage of the solvents from one compartment to another. At the left hand side of Figure 9a we see chamber 124 which contains an overflow through which the heavier of the two solvents leaves the rotating system. The rings 140, 141, and 142, etc., protrude through the inner meniscus of the lighter solvent 115 so that neither of the solvents can move from one compartment to ~~another~~ the next compartment except through the slits which are left free by the split rings ~~which are split~~.

L. Szilard
October 1, 1946

Figure 1 is a rotating shaft. Cylindrical tube 2 is keyed to this shaft and rotates with it. Another coaxial cylindrical tube 3 rotates freely on this shaft by virtue of the torque transferred to it through the intermediary of two liquid layers which fill the annular gap between the outer surface of cylinder 2 and the inner surface of cylinder 3. Of the two solvents the one with the smallest specific gravity is fed in by means of pump 5 through the header 4, into the bore 8 of the shaft 1, and the solvent enters the annular gap through the tube 6. It then passes through the annular gap from left to right and leaves it after passing through an overflow through the tubes 7 and 9. Similarly, the solvent with the higher specific gravity enters the shaft through header 5 and leaves the annular gap through tube 10. It passes through the annular gap from right to left and leaves it at the left end after passing through an overflow through tubes 11 and 12. While the tubes 2 and 3 rotate with approximately the same angular velocity (the angular velocity of the outer tube 3 being slightly smaller) the two solvents are separated in the annular gap by a meniscus 13, the heavier solvent forming the outer layer and the lighter solvent forming the inner layer. The angular velocity of the outer cylinder 3 is kept lower than the angular velocity of the inner cylinder 2 by applying friction to the outer rotar by means of turning the cap 14. The lighter solvent which leaves the rotar through the tubes 7 and 9 is guided by the rotating fin 15 to the right hand end of the hollow casing 16 and leaves that casing through an outlet 17. Similarly,

the heavier solvent which leaves the rotating system through the tubes 11 and 12 is guided by the rotating fin 18 to the left hand end of the casing 16 and leaves it through an opening 19. 20 is a circular fin attached to the casing which prevents the two solvents from getting mixed within the casing. 21, 22, etc., are semicircular fins which are attached to the upper half of the casing and serve the purpose of preventing droplets, of the solvents, which might be sprayed against the upper part of the casing from drifting axially from one end of the casing to the other.

Figure 2 is another embodiment of serving the same purpose as the embodiment shown in Figure 1. We have again two coaxial cylinders, an inner cylinder 30 and an outer cylinder 31 which are rotating, and two solvents in the annular gap formed between the outer surface of the inner cylinder 30 and the inner surface of the outer cylinder 31. In this case the two cylinders however can be rotated independently. The rotar 30 is driven by means of the pulley 32 which is keyed to the shaft 33 and the outer cylinder can be rotated by means of the pulley 34, which is keyed to the shaft 35. The solvent having the lower specific gravity is fed in through the header 36, enters the annular gap on the left side through the tube 37, passes through the annular gap from left to right and leaves the annular gap on the right hand side through the chamber 38, through an overflow. It passes through tubes 39 and 40 and is guided by the rotating fin 41 to the right end of the casing 42 which it leaves through an outflow 43. The lighter solvent enters the shaft 33 through a header 44. It enters into the annular gap between the two rotating cylinders through the tubes 45 and 46, passes through the annular gap from right to left and leaves the annular gap through an overflow through tubes 47 and 48. It is guided by the rotating fin 49 to the left hand side of the casing 42 which it leaves through the outlet 50. A menisous 51 separates in the annular gap the two solvents 52 and 53. 52, representing the heavier solvent, fills the outer part of the gap, whereas 53, representing the lighter solvent, fills the inner part of the gap between the rotating cylinders.

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In all these examples shown in Figures 1, 2 and 3, the rotational speeds are so chosen that the difference in angular velocity be as large as possible but not so large as to destroy the separation of the two solvents in the annular gap. The faster the rotational speed is, the greater can this difference be made and still keep the two solvents in separate layers in which a counter-current flow can be maintained. There is however another consideration with respect to the turbulence set up by the differential speed of the two cylinders. While it is desirable to have as much turbulence as possible within each of the solvent layers in the tangential direction of the rotating cylinders, mixing in the axial direction due to turbulence is not desirable and the more mixing in the axial direction we have, the more we reduce what may be called the number of theoretical plates. According to the present invention, mixing in axial direction can be kept low by subdividing the annular gap by means of rings inserted into the gap between the two rotating cylinders. This is illustrated in Figure 4 a and b. 90, 91, 92, etc., are rings which fit into the outer rotating cylinder93. Each of these rings is split, leaving a slit 94 open for the axial passage of the solvents in the annular gap left free between the outer rotating cylinder 93 and the inner rotating cylinder 95. The inner meniscus of the lighter of the two solvents in the gap is determined by the overflow for the lighter solvent. In this case it has to be so adjusted that the rings 90, 91, 92, etc., should stick out through the inner meniscus as shown in the drawing. If this condition is fulfilled, the only axial flow of the solvents during rotation will take place through the gaps 94 left free in the rings. The series of rings 96, 97, 98, etc. are slit on the cylindrical tube 95 and are rotating with it as if they formed a rigid body. These rings dip into the layer of the lighter of the two solvents but do not reach the meniscus separating the lighter from the heavier solvent. In an apparatus of this type we have a number of segments formed by the rings 90, 91, 92, etc. and within each segment we can maintain turbulent motion within each of the two layers of the heavier solvent and the lighter solvent. This turbulent motion arises because of the difference in angular velocity between the rings 90, 91, and 92, on the one hand (which rotate without a cylinder 93) and the rings 96, 97, 98, etc., on the other hand (which rotate with inner cylinder 95). There is no mixing of solvents however between compartments and the axial flow necessary for maintaining the counter current takes place through the slits 94 in the outer ring system. The inner ring system may also be composed of split rings and the gaps in the split may permit the passage of the lighter solvent. This is however not absolutely necessary since the passage of the lighter solvent is in no case blocked, provided the inner rings do not pierce the meniscus that split the lighter from the heavier solvent. The Figure 4a shows on the left hand side the outflow of the heavier of the two solents which leaves the rotating system through the tube 99. Figure 5 shows a section A, B. through Figure 1, illustrating in what manner the heavier of the two solvents leaves the rotating system through the tubes 11, 12, etc. Figure 5 shows in greater detail how the lighter of the two solvents is fed in through the header 4 into the shaft 1. And Figure 6 shows how the solvent is fed into header 4 by means of the pump 5. Figure 7a and b show an alternative method for removing the solvent from the rotating system in place of tubes 11 and 12. We have here a circular slit 100 through which the solvent leaves the chamber 101.

While in the examples described in Figures 1 to 7 we had two coaxial rotating tubes and the two layers of solvents in the annular gap, between the two tubes were kept moving relative to each other in the tangential direction by the difference in the angular velocity of the two rotating tubes, we are now going to describe an arrangement where we have only a single rotating system and where the two layers of solvents are kept in motion relative to each other in the tangential direction by intermittently slowing and accelerating the rotation of the system.

In Figure 8, 110 is a shaft which is kept in rotation by means of the motor 111. The lighter of the two solvents is fed in through the shaft 110, through the header 112, and it enters into the rotating hollow tube 113 on the left hand side through the tube 114. This lighter bf the two solvents 115 then flows from left to right through the rotating system and leaves it through the tubes 116 and 117, at the right hand end of the rotar. The rotating fin 118 guides the lighter solvent to the right hand end of the hollow casing 119 and this solvent leaves the casing through the opening 120. The heavier solvent enters the shaft 110 through the header 121 and enters the rotar at its left hand end through the tube 122. The heavier solvent 123 flows through the rotating system from right to left and leaves it at the left hand end through the chamber 124 via an overflow and the tubes 125 and 126. The rotating fin 127 guides the outflowing solvent to the left hand end of the hollow casing 119, and the solvent leaves this casing through the outflow 128. The circular fin 129 which is attached to the casing prevents the two solvents from mixing inside the casing 119. 130 is a fly wheel. By means of the pulley 131 and the gadget 132 and 133, the voltage energizes the starter and the excitation of the motor is intermittently changed in such a manner as to increase and to decrease the speed of the motors intermittently. As the speed of the motor increases the mean angular velocity of the heavier solvent layer 123 which is in direct contact with the inner surface of the rotating cylinder 113, will be kept larger than the mean angular velocity of the lighter solvent layer 115 which is separated from the heavier solvent layer by a meniscus 136. Conversely, as the speed of the motor decreases, the mean angular velocity of the heavier solvent layer 123 which is adjacent to the inner surface of the rotating tube 113, will be lower than the mean angular velocity of the lighter solvent layer 115, which is separated from it by the meniscus 136. In this manner, the two liquid layers are kept tangentially in motion relative to each other and consequently a rapid transfer of the dissolved agent will take place betweenn them. The faster this transfer is, the faster we can send the two solvents through the rotating system in counter current fashion.

In order to avoid mixing in axial direction within the two solvent layers, we may have arranged as shown in Figure 9a a number of rings, 140, 141, 142, etc., inside the rotating cylinder 113. These rings are split as can be seen from Figure 9 b, and the slit 143 permits the axial passage of the solvents from one compartment to another. At the left hand side of Figure 9a we see chamger 124 which contains an overflow through which the heavier of the two solvents leaves the rotating system. The rings 140, 141, and 142, etc., protrude through the inner meniscus of the lighter solvent 115 so that neither of the solvents can move from one compartment to another compartment except through the slits which are left free by the rings which are split.

CLAIM ONE

An apparatus for carrying out solvent extraction comprising two coaxial rotating bodies, an annular gap between said rotating bodies, means for maintaining the two bodies in rotation at different angular velocities, and means for maintaining a counter-current flow of two liquids in the axial direction through the said annular gap.

CLAIM TWO

An apparatus for carrying out solvent extraction comprising a rotating body, means for periodically increasing and dedreasing the angular velocity of the said rotating body, and means for maintaining a counter-current flow of two liquids in the axial direction through the said rotating body.

CLAIM THREE

An apparatus for carrying out solvent extraction comprising two coaxial rotating bodies, an annular gap between said rotating bodies, means for maintaining the two bodies in rotation at different angular velocities, and means for maintaining a counter-current flow of two liquids in the axial direction through the said annular gap, said means comprising an inlet adapted to admit a liquid through one of the two rotating bodies into the annular gap between the two rotating bodies and an axially displaced overflow adapted to admit the passage of a liquid from the annular gap between the two rotating bodies to the exterior of the rotating bodies, and a second inlet adapted to admit the passage of the liquid through the other of the two rotating bodies into the gap between the two rotating bodies and an axially displaced overflow adapted to permit the passage of a liquid from the periphery parts of the annular gap between the two rotating bodies to the exterior.

CLAIM FOUR

An apparatus for carrying out solvent extraction comprising a rotating body, means for periodically increasing and decreasing the angular velocity of the said rotating body, and means for maintaining a counter-current flow of two liquids in the axial direction through the said rotating body, said means comprising an inlet adapted to admit a liquid through the axial shaft of the rotating system into the interior of the rotating system and an axially displaced overflow adapted to permit the passage of a liquid from the interior of the rotating to the exterior, and a second inlet adapted to permit the entry of a second liquid through the rotating system into the interior of the rotating system and an axially displaced overflow adapted to permit the passage of a liquid from the periphery parts of the inside of the rotating body to the exterior.

CLAIM FIVE

An apparatus for carrying out solvent extraction comprising two coaxial rotating bodies, an annular gap between said rotating bodies, partitions in the said annular gap adapted to divide the said annular gap into a series of axially displaced sections, means for maintaining the two bodies in rotation at different angular velocities, and means for maintaining a counter-current flow of the two solvents in the axial direction through the said sections in the said annular gap.

CLAIM SIX

An apparatus for carrying out solvent extraction comprising a rotating body, means for periodically increasing and decreasing the angular velocity of the said rotating body, partitions within the said rotating body dividing the interior of the said rotating body into a series of axially displaced sections, and means for maintaining a counter-current flow of two liquids in the axial direction through the said rotating body.

METHOD AND APPARATUS FOR LIQUID EXTRACTION

L. Szilard

August 3, 1946

The invention herein described relates to a novel method and to apparatus suitable to carry out that method for performing liquid extraction.

In liquid extraction we have two solvents ~~of a substance~~ which are separated by a meniscus, and ~~the~~ *some* dissolved substance has to diffuse across the meniscus from one solvent into the other. This transfer ~~has been clearly~~ *can be* accelerated by keeping the two solvents in motion relative to each other. If the relative volocity of the two solvent layers is high enough, there is sufficient turbulence to insure very rapid transfer. According to the present invention, the two layers of the solvent are moved past each other in one direction rather slowly in counter current fashion, whereas perpendicular to that direction, the two layers move past each other with a substantially higher relative velocity.

The simplest embodiment of this invention would consist in two co-axial tubes leaving an annual gap between the inner surface of the outer tube and the outer surface of the inner tube.

Let us first contemplate that both of these tubes rotate with the same angular velocity around their common axis. Let the annual gap between the two tubes be filled with a certain quantity of the two solvents. Owing to the rotation of this system *and the centrifugal forces caused by the rotation*, the meniscus separating ~~the~~ two solvents will then be co-axial to the rotating tube. The two solvents can *then* be made to flow through this gap slowly, in counter current fashion. In ~~this situation,~~ these circumstances the transfer from the one solvent to the other solvent would be slow across the meniscus. In order to obtain rapid transfer, it is necessary to keep the angular velocity of the two cylinders different. If this is done, the two solvents will have different average tangential velocities and we obtain within each of the two liquid layers turbulence which will ~~clearly~~ accelerate the transfer of the dissolved substance across the meniscus from one solvent to the other. The faster the two cylinders rotate, the larger can be made the difference in the angular velocity for any given diameter of the cylinders. {explain!} The greater the difference in velocity between the two liquid layers, the faster is the transfer of the dissolved substance, and the faster we may profitably choose the counter current flow of the solvents in the axial direction. There is a limitation however on the difference in angular velocity in the two cylinders, a limitation which depends for any given diameter on the angular velocities which we use. The limitation is given by the consideration that we ~~do not want to~~ must not make the difference in angular velocity so large as to break up, by turbulence, the meniscus. We ~~wish~~ have to keep the two solvents in two separate layers, an outer and inner layer, ~~and~~ but the faster we rotate the two cylinders, the larger are the differences in their velocity ~~between the two layers~~ which can be tolerated without endangering the separation of the two solvents into two separate layers.

Figures I and II show a schematic drawing of an apparatus which is suitable for carrying out the above described method. Figure I is a transfer section through the machine. Figure II is a plan view of the machine.

Insert I comes in here.

The general principle of this invention can be carried out also in a different manner. Again, we have a rotating tube and inside the rotating tube, the two solvents forming two cylindrical layers, separated by a meniscus which is co-axial with a rotating cylinder. Again, we can maintain a counter current flow, either at a constant velocity or at a velocity which we may wish intermittently to vary and again, we wish to maintain a comparatively high relative velocity in the tangential direction between the two layers. But this time we contemplate bringing about these different tangential velocities between the two layers by periodically increasing and again decreasing the angular velocity of the rotating cylinder.

During the period when the cylinder increases its angular velocity, the outer solvent layer which is closer to the cylinder, will have a higher average tangential velocity than the inner solvent layer and vice versa.

During the period when the angular velocity of the cylinder decreases, the inner solvent layer will have a higher tangential velocity than the solvent layer. The counter current flow, which is in the axial direction, need not be kept constant but we may wish to have this flow faster when the velocity difference between the two layers is high and have the flow slow when the differences of tangential velocity between the two layers is small.

An apparatus suitable for carrying out the above described method is sketched in III and IV.

Insert II comes in here.

For the efficiency of the above described methods, it is desirable to have as little mixing as possible in the axial direction within any one of the two layers of the solvent. Axial mixing can be prevented by a series of transversal walls which prevent an axial flow, provided that some suitable orifice permits it to maintain the axial flow which is required for maintaining the counter current in the solvent extraction. ~~This is illustrated in Figures V and VI.~~

METHOD AND APPARATUS FOR LIQUID EXTRACTION

L. Szilard

August 3, 1946

The invention herein described relates to a novel method and to apparatus suitable to carry out that method for performing liquid extraction.

In liquid extraction we have two solvents of a substance which are separated by a meniscus, and the dissolved substance has to diffuse across the meniscus from one solvent into the other. This transfer has been clearly accelerated by keeping the two solvents in motion relative to each other. If the relative volocity of the two solvent layers is high enough, there is sufficient turbulence to insure very rapid transfer. According to the present invention, the two layers of the solvent are moved past each other in one direction rather slowly in counter current fashion, whereas perpendicular to that direction, the two layers move past each other with a substantially higher relative velocity. The simplest embodiment of this invention would consist in two co-axial tubes leaving an annual gap between the inner surface of the outer tube and the outer surface of the inner tube.

Let us first contemplate that both of these tubes rotate with the same angular velocity around their common axis. Let the annual gap between the two tubes be filled with a certain quantity of the two solvents. Owing to the rotation of this system, the meniscus separating the two solvents will then be co-axial to the rotating tube. The two solvents can be made to flow through this gap slowly, in counter current fashion. In this situation, the transfer from the one solvent to the other solvent would be slow across the meniscus. In order to obtain rapid transfer, it is necessary to keep the angular velocity of the two cylinders different. If this is done, the two solvents will have different average tangential velocities and we obtain turbulence which will clearly accelerate the transfer of the dissolved substance from one solvent to the other. The faster the two cylinders rotate, the larger can be made the difference in the angular velocity for any given diameter of the cylinders. The greater the difference in velocity between the two liquid layers, the faster the transfer of the dissolved substance, and the faster we may profitably choose the counter current flow of the solvents in the axial direction. There is a limitation however on the difference in angular velocity in the two cylinders, a limitation which depends for any given diameter on the angular velocities which we use. The limitation is given by the consideration that we do not want to make the difference in angular velocity so large as to break up, by turbulence, the meniscus. We wish to keep the two solvents in two separate layers, an outer and inner layer, and the faster we rotate the cylinders, the larger differences in velocity between the two layers can be tolerated without endangering the separation of the two solvents.

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During the period when the cylinder increases its angular velocity, the outer solvent layer which is closer to the cylinder, will have a higher average tangential velocity than the inner solvent layer and vice versa.

During the period when the angular velocity of the cylinder decreases, the inner solvent layer will have a higher tangential velocity than the solvent layer. The counter current flow, which is in the axial direction, need not be kept constant but we may wish to have this flow faster when the velocity difference between the two layers is high and have the flow slow when the differences of tangential velocity between the two layers is small.

An apparatus suitable for carrying out the above described method is sketched in III and IV.

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For the efficiency of the above described methods, it is desirable to have as little mixing as possible in the axial direction within any one of the two layers of the solvent. Axial mixing can be prevented by a series of transversal walls which prevent an axial flow, provided that some suitable orifice permits it to maintain the axial flow which is required for maintaining the counter current in the solvent extraction. This is illustrated in Figures V and VI.

CLAIM

I claim apparatus adapted for carrying out solvent extraction consisting in two co-axially rotating bodies, an annual gap between the said two bodies, means for maintaining a difference in the angular velocity of the two bodies, two solvents in the said annual gap, and means for maintaining a counter current flow in the axial direction through the said annual gap.

CLAIM

I claim apparatus adapted for carrying out solvent extraction consisting in a hollow rotating body, two solvents inside the said rotating body, means for intermittently increasing and decreasing the angular velocity of the rotation of the said angular body, means for maintaining a counter current flow in the axial direction through the said rotating body.

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Dr Szilard

Please find enclosed the specification and claims regarding your invention.

The statute explicitly does not permit more than four (4) embodiments in anyone invention. Your present invention contains substantially six. I would not suggest any more embodiments; since the acceptance of the present amount is up to the Patent office's discretion.

L. Bernat

This invention relates to a novel method and apparatus for performing liquid extraction.

In a liquid extraction the dissolved substance diffuses across a meniscus separating one solvent from the other, and it is a primary object of the present invention to accelerate this diffusion by maintaining the two solvents in relative motion.

Another object of the invention is to afford turbulence between the two solvents, thereby facilitating diffusion of the dissolved substance therebetween.

Still another object of the invention is to move the two solvents in one direction relatively slowly in counter-current manner and at the same time to move the two solvents at a relatively high velocity approximately perpendicular to the direction of counter-current.

The above-mentioned objects of the invention are accomplished by flowing the two solvents in counter-current so that the solvents define radially inner and outer cylindrical layers which are rotated in the same direction by the different rotational velocities to afford turbulence between the layers, thereby accelerating transfer of the dissolved substance or solute from one solvent to the other. In order to maintain separation between the layers one of the layers has a relatively greater specific gravity than the other solvent.

The foregoing and other objects of the invention will become apparent from consideration of the following specifications and the accompanying drawings, wherein:

Fig. 1 is a central longitudinal sectional view partly in elevation of the novel apparatus for carrying out the invention;

Fig. 2 is a fragmentary top plan view of the apparatus shown in Fig. 1;

Fig. 3 is an end view taken from the right, as seen in Figs. 1 and 2;

Fig. 4 is a sectional view taken on the line 4-4 of Fig. 1;

Fig. 5 is a sectional view taken on the line 5-5 of Fig. 1;

Fig. 6 is a fragmentary longitudinal sectional view comparable to that of Fig. 1 but illustrating a modification of the apparatus;

Fig. 6a is a sectional view taken on the line 7-7 of Fig. 6;

Fig. 7 is a central longitudinal sectional view partly in elevation of another modification of the apparatus;

Fig. 8 is a sectional view comparable to Fig. 1 but illustrating another modification of the invention;

Fig. 9 is a longitudinal sectional view comparable to Fig. 8 but illustrating another embodiment of the invention;

Fig. 10 is a sectional view taken on the line 10-10 of Fig. 9;

Fig. 11 is a central longitudinal sectional view partly in elevation of still another embodiment of the novel apparatus , in ~~comparison~~ combination with a wiring diagram illustrating the means for actuating the apparatus;

Fig. 12 is a fragmentary longitudinal sectional view comparable to Fig. 11, but illustrating a modification of the apparatus shown therein; and

Fig. 13 is a crosssectional view taken in the planes indicated by the line 13-13 of Fig. 12.

Describing the invention in detail and referring first to the embodiment thereof shown in Figs. 1 to 5 inclusive, the novel apparatus comprises a rotatable shaft 1 and a cylindrical tube 2 keyed to the shaft for rotation therewith. Another coaxial cylindrical tube 3 is generated on the shaft 2 and rotated freely thereon by means of a torque transferred to the tube 3 as hereinafter described. It will be understood that the tubes 2 and 3 define an annular or cylindrical gap through which the solvents pass axially in counter-current. The solvent with the smaller specific gravity is forced by means of a pump 23 through a coupling 4 into a bore 8 of the shaft 1, and this solvent enters the annular gap between the tubes 2 and 3 through a passage 6 in an end wall of the tube 2. This solvent then passes axially through the annular gap from left to right as seen in Fig. 1, and flows from the right end of the gap through the passages 7 and 9 into an outlet port 17, an annular cone-shaped baffle or fin being provided to direct the flow of the solvent into the port 17.

The solvent with the relatively high specific gravity is pumped into a coupling 5 by means of a pump 5a (Fig. 3). This solvent flows from the coupling 5 through a passage 10 into the annular gap between the tubes 2 and 3 and passes from the annular gap at the left end thereof through passages 11 and 12 and thence into an outlet port 19, an annular baffle or fin 18 being provided to direct the flow of this solvent into the port 19.

It may be noted in this connection that it is not necessary that one solvent per se have a greater specific gravity than the other, provided that one solution including the material dissolved in the solvent has a relatively great specific gravity.

It may be noted that the shaft 1 is rotated in a convenient manner such as a pulley 1a, which is connected in conventional manner to an associated motor (not shown), thus rotating the tubes 2 and 3 at approximately the same rotational velocities, the rotational velocity of the outer tube 3 being slightly less than that of the inner tube 2.

The two solvents are separated by an interface or a meniscus 13, the heavier solvent forming a radially outer layer and the lighter solvent forming a radially inner layer. The rotational velocity of the outer cylinder 3 is maintained at a lower rate than that of the inner cylinder 2 by an adjustable friction device 14, thus affording turbulence between the two solvents to facilitate the transfer of the dissolved substance therebetween.

The tubes 2 and 3 are disposed within a casing 20 comprising an annular radial web or fin 20a which prevents the two solvents from co-mingling within the casing, and the casing is also provided with a plurality of semicircular radial fins 21 attached to the upper half of the casing for the purpose of preventing droplets of the solvents which may be spilled against the upper part of the casing from drifting axially from one end thereof to the other.

Referring now to Fig. 6 and 6a, a modified form of the apparatus is shown wherein the passages 11 and 12 of Fig. 1 are replaced by an annular passage 100 (Fig. 6) which communicates with ports 100a through the tube 3 so that the heavier solvent flows from the ports 100a into the outlet port 19.

Referring now to Fig. 7, another modification of the novel apparatus is shown, wherein two coaxial cylindrical tubes 30 and 31 define an annular gap therebetween. This modification differs from the embodiment of Fig. 1 in that the tubes 30 and 31 may be independently rotated. The inner cylinder 30 is driven by means of a pulley 32 keyed to a shaft 33, which is in turn keyed to the tube 30. The outer tube 31 is rotated by means of a pulley 34, which is keyed to a shaft 35 connected to the tube 31. The solvent having the lower specific gravity is admitted to the apparatus through the coupling 36 and flows through a passage 37 into the annular gap between the tubes 30 and 31 and axially therealong to the right-hand end thereof into the chamber 38. This solvent then flows through passages 39 and 40 and is guided by the conical baffle 41 into the outlet port 43. The heavier solvent is admitted to the apparatus through the coupling 44 and passes through an axial passage 45 into the shaft 33 and thence into a radial passage 46 into the annular gap between the tubes 30 and 31, and axially therethrough toward the left end thereof into passages 47 and 48. The solvent flows from these passages and is guided by the conical baffle 49 into the outlet port 50. A meniscus 51 separates the solvents 52 and 53 in the annular gap between the tubes 30 and 31. The heavier solvent illustrated at 52 is disposed in the radially outer portion of the gap, and the lighter solvent indicated at 53 is disposed in the radially inner portion of the gap. Thus it will be understood that in the modification of Fig. 7 the tubes 30 and 31 might be driven at any desired relative rotational velocities to regulate the turbulence between the solvents at the meniscus 51.

Referring now to Fig. 8 another modification of the invention is shown wherein two coaxial cylindrical tubes 60 and 61 are adapted for independent rotation. The inner tube 60 is keyed to a shaft 62 which is driven by a pulley 63. The outer shaft 64a is supported at one end by a bearing 64 and at the opposite end by a bearing 65 and driven by a pulley 66. The solvent having the lower specific gravity is urged by a pump 67 through a coupling 68 into an axial bore 68a in the shaft 62. This solvent flows from the bore 68a into a radial passage 70 in an end wall of the tube 60 into the annular gap between the tubes and axially along said gap into tubes 71 and 72. An annular conical baffle 73 is provided for directing the solvent from the tubes 71 and 72 into the outlet port 75. The heavier of the two solvents is pumped into the shaft 62 through a coupling 76 and passes through a radial passage 77 in an end wall of the tube 60 into an annular gap between the tubes. This solvent flows through the annular gap toward the left, as seen in Fig. 8 and passes into an outlet chamber 78. The heavier solvent is conveyed from the chamber 78 through tubes 79 and 80 and is guided by the conical baffle 81 into the outlet port 82. The two solvents are separated by a meniscus 85 at which point turbulence between the solvents is afforded by varying the relative rotational velocities of the tubes 60 and 61, as in the previously discussed embodiment.

It may be noted that in the above-discussed embodiments of the invention the rotational speeds of the rotor tubes may be of any desired velocity, as, for example, two thousand r.p.m., the rotational speeds selected so that the difference in rotational velocities between the inner and outer tubes is as large as possible but not sufficiently large to destroy the separation of the two solvents in the annular gap. It will be understood that this difference in rotational velocities may be greater where the rotational speeds of both solvents are increased, without disrupting the inner and outer layers of the respective solvents. It will be understood that the maintenance of the two layers is necessary to achieve the above-discussed countercurrent flow between the respective solvents. While it is desirable to accommodate as much turbulence as possible within the respective solvent layers in the tangential direction of the rotating cylinders, mixing of the solvents in the axial direction is undesirable inasmuch as this type of mixing tends to reduce what may be called the "number of theoretical plates of laminae".

Figs. 9 and 10 illustrate a modification of the novel apparatus wherein mixing of the solvents in the axial direction is minimized by providing means for subdividing the annular gap between the inner and outer rotor tubes. This is accomplished by providing a plurality of rings 90 which are press-fitted into the outer rotor tube 93 for rotation as a unit therewith. Each of the rings 90 is split, affording a passage 94 to accommodate axial flow of the solvents in the annular gap between the outer rotor tube 93 and the inner rotor tube 95. The inner meniscus of the lighter of the two solvents in the annular gap is determined by the overflow from the lighter solvent, and this overflow is adjusted in the embodiment of Figs. 9 and 10 so that the rings 90 project radially inwardly through the meniscus as shown in the drawings. Thus the only axial flow of the solvents due to rotation of the tubes 93 and 95 takes place through the passages 95 in the rings. A plurality of rings 96 are press-fitted on the inner tube 95 for rotation as a unit therewith. The rings 96 project into the layer of the lighter of the two solvents but do not project into the meniscus separating the solvents. Thus in the modification in Figs. 9 and 10 the rings 90 and 96 define a plurality of axially spaced segments or compartments within the annular gap between the rotor tubes 93 and 95. Turbulence is maintained between the solvents within each compartment. However, there is no mixing of the solvents between the compartments, and the axial flow of the solvents as they pass through the tubes in counter-current takes place through the passages 94. If desired, the rings 96 may be provided with similar passages 94; however, this is not absolutely necessary inasmuch as the lighter solvent may pass through the annular gap radially outwardly of the rings 96.

Referring now to Fig. 11 another embodiment of the novel apparatus is illustrated wherein the layers formed by the respective solvents are rotated by a single tube, relative motion between the two layers being achieved by intermittently slowing and accelerating rotation of the two. In this modification of the invention a shaft 110 is rotated by a motor 111. The lighter of the two solvents is pumped into the apparatus through a coupling 112, thence through a passage 114 in the shaft 110 into a rotating hollow tube 113 which is keyed to the shaft 110. This solvent then flows toward the right, as seen in Fig. 8, into passages 116 and 117 of the rotor tube. The solvent flows from the passages 116 and 117 along the conical baffle 118 into an outlet port 120. The heavier solvent is pumped into the apparatus through a coupling 121 and flows through a passage 122 in the shaft 110 into the tube 113. The heavier solvent flows toward the left, as seen in Fig. 11, through tubes 125 and 126 along the conical baffle 127 into an outlet port 128. A circular fin 129 inside the casing 119 prevents the two solvents from mixing therewithin.

A flywheel 130 is interposed between the motor 111 and the shaft 110, and the shaft 110 is connected by a gear ~~chain~~ drive 131 to a gear box 132 which is operatively connected to an arm 134 linked to the movable contact 135 of a conventional rheostat 133. Thus as the shaft 110 rotates the arm 134 moves according to a predetermined program determined by the gear box 132 to vary the resistance through the series-wound motor 111. By means of this arrangement the speed of the motor is alternately incfeased and decreased , thus alternately increasing and decreasing the rotational speed of the tube 113. As the speed of the motor 111 increased, the rotational velocity of the heavier solvent 123, which is in direct contact with the inner surface of the radial tube 113, is increased with respect to the rotational velocity of the lighter solvent 115, which is separated from the heavier solvent by a meniscus 136.

Conversely as the speed of the motor decreases, the rotational velocity of the heavier solvent is decreased more rapidly than that of the lighter solvent 115. Thus the two solvent layers are rotated relative to each other, accommodating turbulence therebetween, thereby facilitating rapid transfer of the dissolved substance between the two solvents.

Referring now to Figs. 12 and 13, a modification of the apparatus of Fig. 11 is shown wherein the rotating cylinder 113 is provided with a plurality of radially ascending rings 140 press-fitted therewithin for rotation as a unit therewith. These rings are split, as previously seen in Fig. 13, to provide passages 143 accommodating axial flow of the solvents along the tube of cylinder 113. The rings 140 project through the meniscus between the solvents so that neither solvent will move axially along the cylinder 113 except through the passages 143. This prevents turbulence due to the axial flow between the liquids and accommodates turbulence due to the relative rotational movement therebetween for the purposes heretofore discussed in connection with the embodiment of Figs. 9 and 10.

It will be understood that the above-discussed embodiments of the invention are merely by way of illustration, inasmuch as various and other modifications of the invention will be readily apparent to those skilled in the art without departing from the spirit of the invention or the scope of the appended drawings. What is claimed is:

1.

An apparatus for carrying out solvent extraction comprising two co-axial rotating bodies, an annular gap therebetween, means for maintaining the two bodies in rotation at different rotational velocities, two solvents in said annular gap, and means for maintaining a counter-current flow of the two solvents in the axial direcion through said annular gap.

2.

A device for carrying out solvent extraction comprising an annular chamber, two solvents, one of said solvents being heavier than the other, means for rotating said solvents in the same direction at different rotational velocities to separate said solvents into axially disposed layers, and means for providing a counter-current flow of said solvents through the respective layers.

3.

An apparatus for carrying out solvent extraction comprising an annular chamber, means for flowing a relatively heavy solvent and a relatively light solvent in an opposite direction axially of said chamber, and means for rotating said solvents in the same direction at different rotational velocities.

4.

A method of solvent extraction comprising flowing a relatively light solvent and a relatively heavy solvent in opposite directions through an annular chamber while rotating the two solvents in the same direction at different rotational velocities, to afford turbulence at the meniscus between said solvents.

5.

5.

An apparatus adapted for carrying out solvent extraction, comprising a hollow rotating body, two solvents inside the said rotating body, means for intermittently increasing and decreasing the angular velocity of the rotation of the said rotating body, and means for maintaining the two solvents in a counter-current flow in the axial direction through the said rotating body.

6. A method of solvent extraction comprising the step of forcing two solvents of different specific gravities in opposite directions axially through a hollow member while rotating the latter on its axis to separate the solvents into radially inner and outer layers.

7 A method of solvent extraction comprising the step of rotating a cylinder containing two solvents one of which contains a substance dissolved therein and is of a different specific gravity than the other, thereby causing said solvents to separate into radially innner and outer solvent layers with a meniscus therebetween at which the substance may be dissolved in said other solvent, and forcing said solvents through the respective layers in opposite directions along the rotational axis of said cylinder

8 A method of solvent extraction comprising rotating radially inner and outer solvent layers of different specific gravity with a meniscus therebetween, one of said solvent layers containing a substance dissolved therein to be dissolved by the other at said meniscus, and forcing respective layers to flow in opposite directions axially of the rotational axis of said layers.

9 A method according to claim 8, ~~(previous claim number)~~, wherein the respective layers are rotated at different rotational velocities to cause turbulence along said meniscus.

10 An apparatus comprising a cylinder containing two solvents of different specific gravities one of the solvents containing a dissolved substance to be dissolved in the other, means for rotating said cylinder to force the respective solvents into radially inner and outer layers, and means for flowing respective solvents through said cykinder in opposite directions along the rotational axis of said cylinder.

METHOD AND APPARATUS FOR LIQUID EXTRACTION

L. Szilard

August 3, 1946

The invention herein described relates to a novel method and to apparatus suitable to carry out that method for performing liquid extraction.

In liquid extraction we have two solvents ~~for a substance~~ which are separated by a meniscus, and ~~the~~ same dissolved substance has to diffuse across the meniscus from one solvent into the other. This transfer ~~has been clearly~~ can be accelerated by keeping the two solvents in motion relative to each other. If the relative volocity of the two solvent layers is high enough, there is sufficient turbulence to insure very rapid transfer. According to the present invention, the two layers of the solvent are moved past each other in one direction rather slowly in counter current fashion, whereas perpendicular to that direction, the two layers move past each other with a substantially higher relative velocity.

The simplest embodiment of this invention would consist in two co-axial tubes leaving an annual gap between the inner surface of the outer tube and the outer surface of the inner tube.

Let us first contemplate that both of these tubes rotate with the same angular velocity around their common axis. Let the annual gap between the two tubes be filled with a certain quantity of the two solvents. Owing to the rotation of this system, and the centrifugal forces caused by the rotation the meniscus separating the two solvents will then be co-axial to the rotating tube. The two solvents can then be

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made to flow through this gap slowly, in counter current fashion. In ~~this situation,~~ these circumstances, the transfer from the one solvent to the other solvent would be slow across the meniscus. In order to obtain rapid transfer, it is necessary to keep the angular velocity of the two cylinders different. If this is done, the two solvents will have different average tangential velocities and we obtain within each of the two liquid layers turbulence which will ~~clearly~~ accelerate the transfer of the dissolved substance across the meniscus from one solvent to the other. The faster the two cylinders rotate, the larger can be made the difference in the angular velocity for any given diameter of the cylinders. { explain! The greater the difference in velocity between the two liquid layers, the faster is the transfer of the dissolved substance, and the faster we may profitably choose the counter current flow of the solvents in the axial direction. There is a limitation however on the difference in angular velocity in the two cylinders, a limitation which depends for any given diameter on the angular velocities which we use. The limitation is given by the consideration that we ~~do not want to~~ must not make the difference in angular velocity so large as to break up, by turbulence, the meniscus. We ~~wish~~ have to keep the two solvents in two separate layers, an outer and inner layer, ~~and~~ but the faster we rotate the two cylinders, the larger are the differences in their velocity ~~between the two layers~~ which can be tolerated without endangering the separation of the two solvents into two separate layers.-

Figures I and II show a schematic drawing of an apparatus which is suitable for carrying out the above described method. Figure I is a transfer section through the machine. Figure II is a plan view of the machine.

Insert I comes in here.

The general principle of this invention can be carried out also in a different manner. Again, we have a rotating tube and inside the rotating tube, the two solvents forming two cylindrical layers, separated by a meniscus which is co-axial with a rotating cylinder. Again, we can maintain a counter current flow, either at a constant velocity or at a velocity which we may wish intermittently to vary and again, we wish to maintain a comparatively high relative velocity in the tangential direction between the two layers. But this time we contemplate bringing about these different tangential velocities between the two layers by periodically increasing and again decreasing the angular velocity of the rotating cylinder.

During the period when the cylinder increases its angular velocity, the outer solvent layer which is closer to the cylinder, will have a higher average tangential velocity than the inner solvent layer and vice versa.

During the period when the angular velocity of the cylinder decreases, the inner solvent layer will have a higher tangential velocity than the solvent layer. The counter current flow, which is in the axial direction, need not be kept constant but we may wish to have this flow faster when the velocity difference between the two layers is high and have the flow slow when the differences of tangential velocity between the two layers is small.

An apparatus suitable for carrying out the above described method is sketched in III and IV.

Insert II comes in here.

For the efficiency of the above described methods, it is desirable to have as little mixing as possible in the axial direction within any one of the two layers of the solvent. Axial mixing can be prevented by a series of transversal walls which prevent an axial flow, provided that some suitable orifice permits it to maintain the axial flow which is required for maintaining the counter current in the solvent extraction. ~~This is illustrated in Figures V and VI.~~

L. Szilard
October 1, 1946

Figure 1 is a rotating shaft. Cylindrical tube 2 is keyed to this shaft and rotates with it. Another coaxial cylindrical tube 3 rotates freely on this shaft by virtue of the torque transferred to it through the intermediary of two liquid layers which fill the annular gap between the outer surface of cylinder 2 and the inner surface of cylinder 3. Of the two solvents the one with the smaller specific gravity* is fed in by means of pump 5 through the header 4, into the bore 8 of the shaft 1, and the solvent enters the annular gap through the tube 6. It then passes through the annular gap from left to right and leaves the gap, after passing through an overflow, through the tubes 7 and 9. Similarly, the solvent with the higher specific gravity enters the shaft through header 5 and leaves the annular gap through tube 10. It passes through the annular gap from right to left and leaves the gap at the left end, after passing through an overflow, through tubes 11 and 12. While the tubes 2 and 3 rotate with approximately the same angular velocity (the angular velocity of the outer tube 3 being slightly smaller) the two solvents are separated in the annular gap by a meniscus 13, the heavier solvent forming the outer layer and the lighter solvent forming the inner layer. The angular velocity of the outer cylinder 3 is kept lower than the angular velocity of the inner cylinder 2 by applying friction to the outer rotar by means of turning the cap 14. The lighter solvent which leaves the rotor through the tubes 7 and 9 is guided by the rotating fin 15 to the right hand end of the hollow casing 16 and leaves that casing through an outlet 17. Similarly,

* What matters is strictly speaking not which of the two solvents has the smaller specific gravity but rather which of the two solutions has the smaller specific gravity.

the heavier solvent which leaves the rotating system through the tubes 11 and 12 is guided by the rotating fin 18 to the left hand end of the casing 16 and leaves it through an opening 19. 20 is a circular fin attached to the casing which prevents the two solvents from getting mixed within the casing. 21, 22, etc., are semicircular fins which are attached to the upper half of the casing and serve the purpose of preventing droplets, of the solvents, which might be sprayed against the upper part of the casing from drifting axially from one end of the casing to the other.

Figure 2 is another embodiment of serving the same purpose as the embodiment shown in Figure 1. We have again two coaxial cylinders, an inner cylinder 30 and an outer cylinder 31 which are rotating, and two solvents in the annular gap which is left free ~~formed~~ between the outer surface of the inner cylinder 30 and the inner surface of the outer cylinder 31. In this case the two cylinders however can be rotated independently. The inner rotor ~~rotor~~ 30 is driven by means of the pulley 32 which is keyed to the shaft 33 and the outer cylinder can be rotated by means of the pulley 34, which is keyed to the shaft 35. The solvent having the lower specific gravity is fed in through the header 36, enters the annular gap on the left side through the tube 37, passes through the annular gap from left to right and leaves the annular gap on the right hand side through the chamber 38, through an overflow. It passes through tubes 39 and 40 and is guided by the rotating fin 41 to the right end of the casing 42 which it leaves through an outflow 43. The lighter solvent enters the shaft 33 through a header 44. It enters into the annular gap between the two rotating cylinders through the tubes 45 and 46, passes through the annular gap from right to left and leaves the annular gap through an overflow through tubes 47 and 48. It is guided by the rotating fin 49 to the left hand side of the casing 42 which it leaves through the outlet 50. A meniscus 51 separates in the annular gap the two solvents 52 and 53. 52, representing the heavier solvent, fills the outer part of the gap, whereas 53, representing the lighter solvent, fills the inner part of the gap between the rotating cylinders.

Figure 3 shows another embodiment of the same invention. Again we have two coaxial cylindrical rotors, 60 and 61. The inner cylinder 60 and the outer cylinder 61. The inner rotor is keyed to the shaft 62 which is driven by means of the pulley 63. The outer rotor 61 is supported by the bearings 64 and 65 and is driven by the pulley 66. The solvent having the lower specific gravity is fed by the pump 67 through the header 68 into the shaft 62 and enters the annular gap 69 through the tube 70 at the left hand end of the system. It leaves the annular gap through an overflow at the right hand end of the system and leaves the rotor 61 through the tubes 71 and 72. It is guided by the rotating fin 73 to the right hand corner of the casing 74 which it leaves through an outflow 75. Similarly, the heavier of the two solvents enters the shaft 62 through the header 76 and flows into the annular gap 69 through the tube 77 on the right hand side of the gap. It flows through the annular gap from right to left and leaves it through the chamber 78, by overflowing, through the tubes 79 and 80. The rotating fin 81 guides the solvent to the left hand end of the casing 74 and the solvent leaves the casing through an outflow 82. Under the action of centrifugal forces the heavier solvent 83 and the lighter solvent 84 are separated by a meniscus 85.

In all these examples shown in Figures 1, 2 and 3, the rotational speeds are so chosen that the difference in angular velocity be as large as possible but not so large as to destroy the separation of the two solvents in the annular gap. The faster the rotational speed is, the greater can this difference be made and still have the two solvents in separate layers by means of which a counter-current flow can be maintained.

There is however another consideration with respect to the turbulence set up by the differential speed of the two cylinders. While it is desirable to have as much turbulence as possible within each of the solvent layers in the tangential direction of the rotating cylinders, mixing in the axial direction due to turbulence is not desirable and the more mixing in the axial direction we have, the more we reduce what may be called the "number of theoretical plates." According to the present invention, mixing in axial direction can be kept low by subdividing the annular gap by means of rings inserted into the gap between the two rotating cylinders. This is illustrated in Figure 4 a and b. 90, 91, 92, etc., are rings which fit into the outer rotating cylinder93. Each of these rings is split, leaving a slit 94 open for the axial passage of the solvents in the annular gap which is left free between the outer rotating cylinder 93 and the inner rotating cylinder 95. The inner meniscus of the lighter of the two solvents in the gap is determined by the "overflow" for the lighter solvent. In this case it has to be so adjusted that the rings 90, 91, 92, etc., should stick out through the inner meniscus as shown in the drawing. If this condition is fulfilled, the only axial flow of the solvents during rotation will take place through the gaps 94 left free in the rings. The series of rings 96, 97, 98, etc. are slid on the cylindrical tube 95 and are rotating with it as if they formed a rigid body. These rings dip into the layer of the lighter of the two solvents but do not reach the meniscus separating the lighter from the heavier solvent. In an apparatus of this type we have a number of segments formed by the rings 90, 91, 92, etc. and within each segment we can maintain turbulent motion within each of the two layers of the heavier solvent and of the lighter solvent. This turbulent motion arises because of the difference in angular velocity between the rings 90, 91, and 92, on the one hand (which rotate with the outer cylinder 93) and the rings 96, 97, 98, etc., on the other hand (which rotate with the inner cylinder 95). There is no mixing of either solvents however between neighbouring compartments and the axial flow necessary for maintaining the counter current takes place through the slits 94 in the outer ring system.

The inner ring system may also be composed of split rings and the gaps in the split may permit the passage of the lighter solvent. This is however not absolutely necessary since the passage of the lighter solvent is in no case blocked, provided the inner rings do not pierce the meniscus that ~~split~~ separate the lighter from the heavier solvent. The Figure 4a shows on the left hand side the outflow of the heavier of the two solvents which leaves the rotating system through the tube 99. ¶ Figure 5 shows a section A, B. through Figure 1, illustrating in what manner the heavier of the two solvents leaves the rotating system through the tubes 11, 12, etc. Figure 6 shows in greater detail how the lighter of the two solvents is fed in through the header 4 into the shaft 1. And Figure 10 shows how the solvent is fed into header 4 by means of the pump 5. Figure 7a and b show an alternative method for removing the solvent from the rotating system in place of tubes 11 and 12. We have here a circular slit 100 through which the solvent ~~leaves the chamber 101.~~ may flow out radially from the chamber 101. —

While in the examples described in Figures 1 to 7 we had two coaxial rotating tubes and the two layers of solvents, in the annular gap between the two tubes, were kept moving relative to each other in the tangential direction by the difference in the angular velocity of the two rotating tubes, we are now going to describe an arrangement where we have only a single rotating system and where the two layers of solvents are kept in motion relative to each other in the tangential direction by intermittently slowing and accelerating the rotation of the system.

In Figure 8, 110 is a shaft which is kept in rotation by means of the motor 111. The lighter of the two solvents is fed in through the shaft 110, through the header 112, and it enters into the rotating hollow tube 113 on the left hand side through the tube 114. This lighter of the two solvents 115 then flows from left to right through the rotating system and leaves it through the tubes 116 and 117, at the right hand end of the rotor. The rotating fin 118 guides the lighter solvent to the right hand end of the hollow casing 119 and this solvent leaves the casing through the opening 120. The heavier solvent enters the shaft 110 through the header 121 and enters the rotor at its left hand end through the tube 122. The heavier solvent 123 flows through the rotating system from right to left and leaves it at the left hand end through the chamber 124 via an overflow and the tubes 125 and 126. The rotating fin 127 guides the outflowing solvent to the left hand end of the hollow casing 119, and the heavier solvent leaves this casing through the outflow 128. The circular fin 129 which is attached to the casing prevents the two solvents from mixing inside the casing 119. 130 is a~~n~~ fly wheel. By means of the gear 131 ~~pulley 131~~ and the speed regulator 133 ~~gadget 132 and 133, the voltage energizes the starter~~ the speed of the motor increases and decreases ~~intermittently~~ in an alternating manner ~~and the excitation of the motor is intermittently changed in such a manner as to increase and to decrease the speed of the motors intermittently.~~

As the speed of the motor increases the mean angular velocity of the heavier solvent layer 123 which is in direct contact with the inner surface of the rotating cylinder 113, will be kept larger than the mean angular velocity of the lighter solvent layer 115 which is separated from the heavier solvent layer by a meniscus 136. Conversely, as the speed of the motor decreases, the mean angular velocity of the heavier solvent layer 123 which is adjacent to the inner surface of the rotating tube 113, will be lower than the mean angular velocity of the lighter solvent layer 115, which is separated from it by the meniscus 136. In this manner, the two liquid layers are kept tangentially in motion relative to each other and consequently a rapid transfer of the dissolved agent will take place betwenn them. The faster this transfer is, the faster we can send the two solvents through the rotating system in counter current fashion and have satisfactory performance. —

In order to avoid mixing in axial direction within the two solvent layers, we may have arranged as shown in Figure 9a a number of rings, 140, 141, 142, etc., inside the rotating cylinder 113. These rings are split as can be seen from Figure 9 b, and the slit 143 permits the axial passage of the solvents from one compartment to another. At the left hand side of Figure 9a we see chamber 124 which contains an overflow through which the heavier of the two solvents leaves the rotating system. The rings 140, 141, and 142, etc., protrude through the inner meniscus of the lighter solvent 115 so that neither of the solvents can move from one compartment to ~~another~~ the next compartment except through the slits which are left free by the split rings ~~which are split~~.

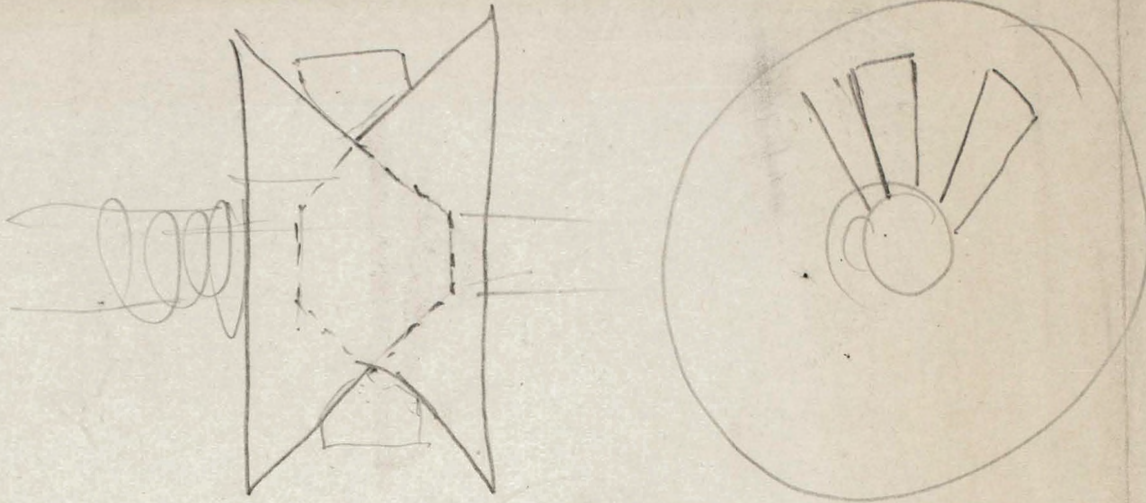
CLAIM ONE

I claim an apparatus adapted for carrying out solvent extraction, consisting of two coaxial rotating bodies, an annular gap between the said two bodies, means of maintaining the said two bodies in rotation at a divergent angular velocity to the solvents in the said annular gap, and means for maintaining a counter-current flow of the two solvents in an axial direction through the said annular gap.

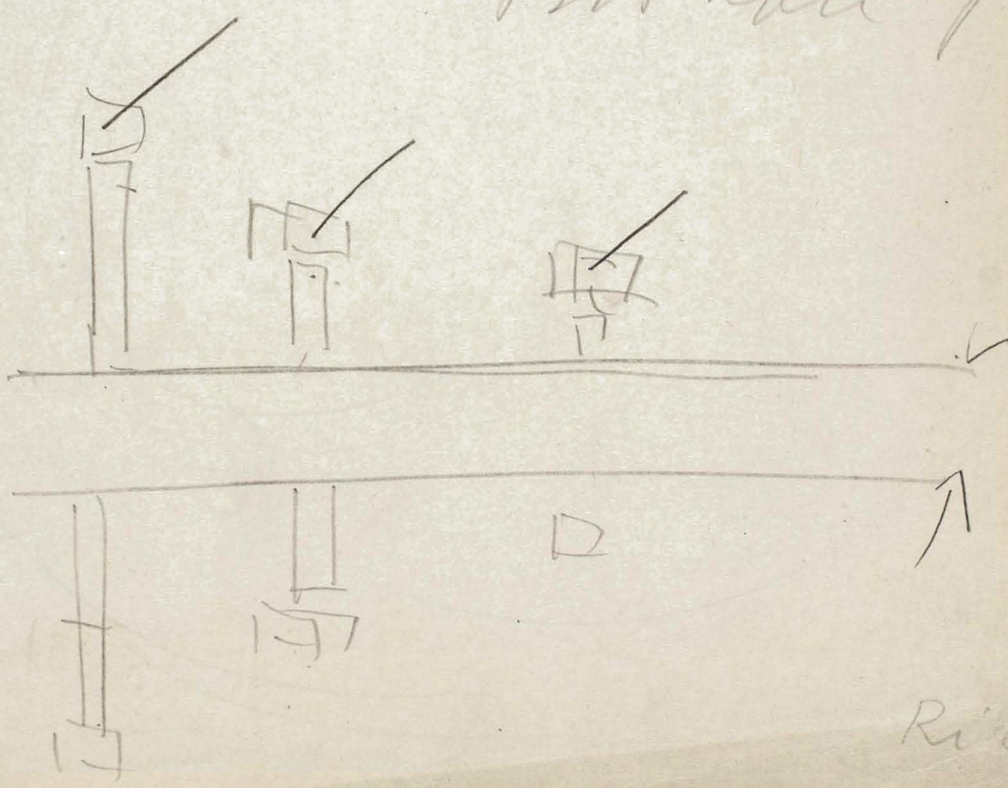
CLAIM TWO

I claim an apparatus adapted for carrying out solvent extraction, consisting in a hollow rotating body, two solvents inside the said rotating body, means for intermittently increasing and decreasing the angular velocity of the rotation of the said rotating body, means for maintaining the two solvents in a couhter-current flow in an axial direcion through the said rotating body.

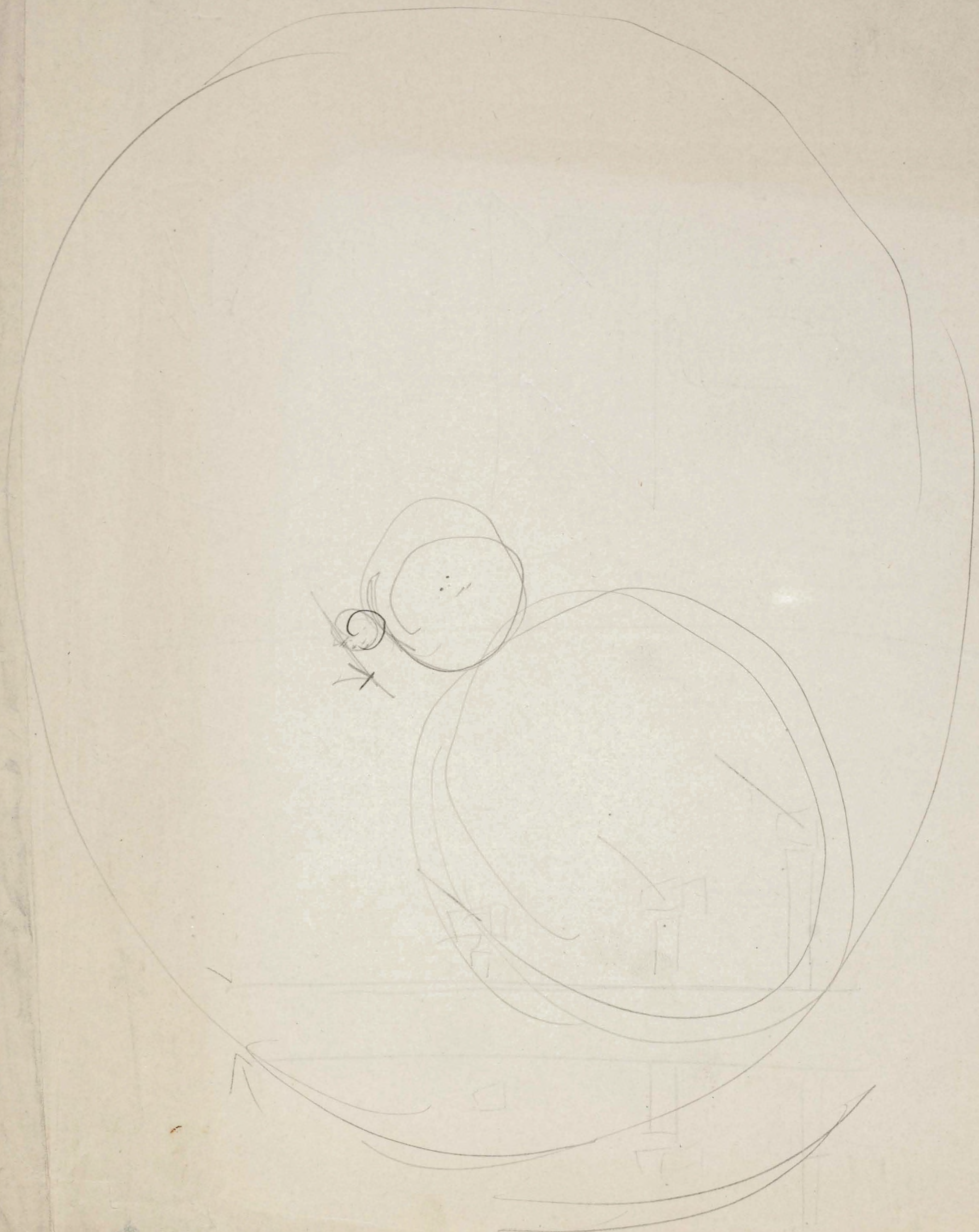
DO ALL Pully



Planetary gear
Boston Gear Co



Rice



Sexund anbringe i række antflaw
af hvader lagmidl. –

Udlade I med II

Fig 5

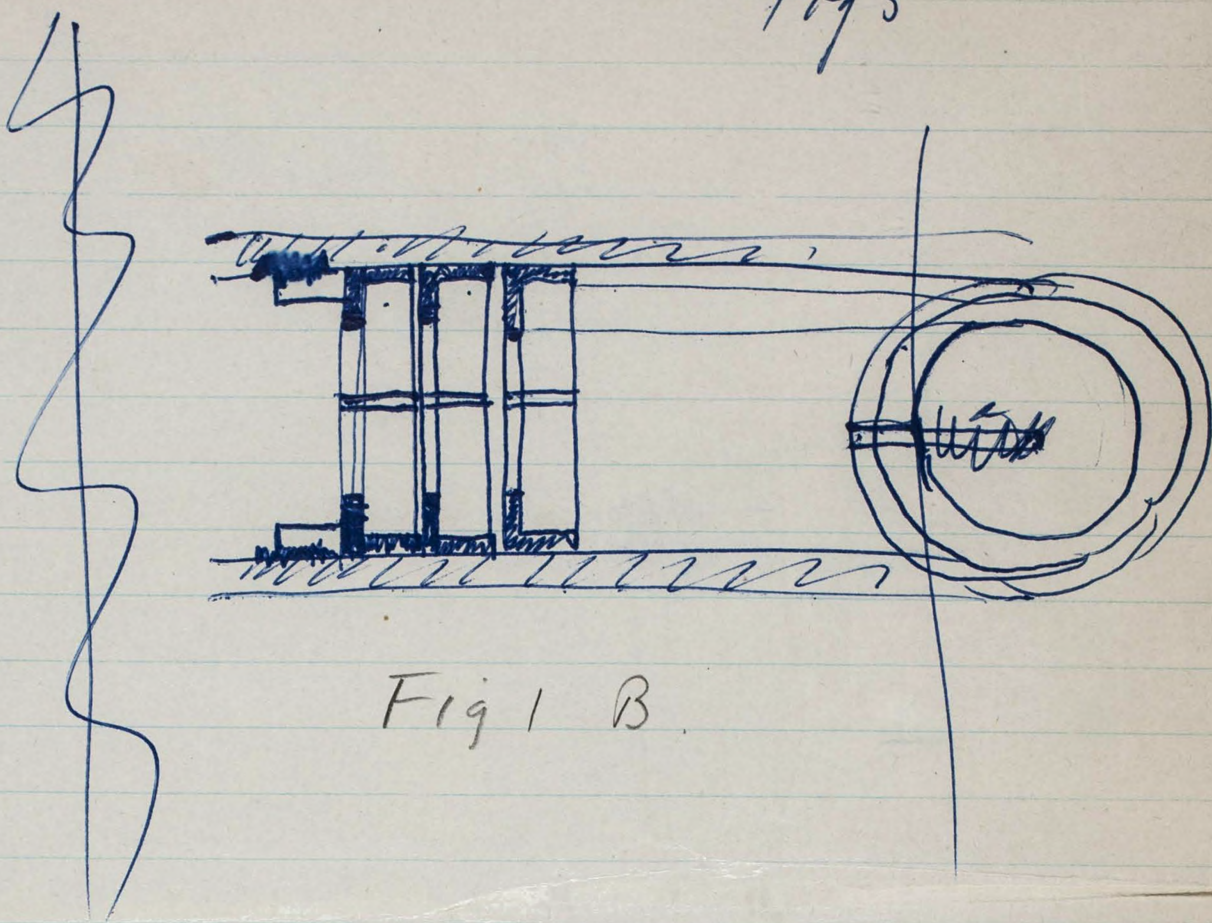


Fig 1 B

Udlade V

Fig 6

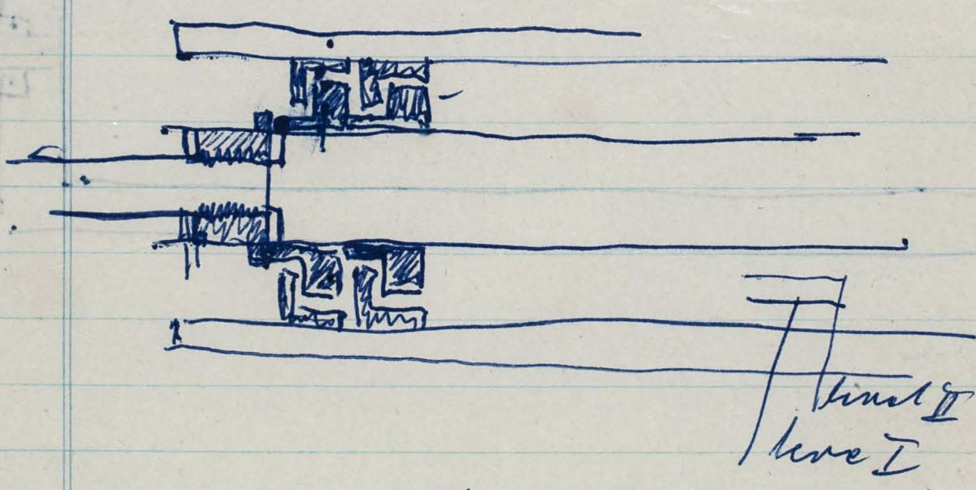
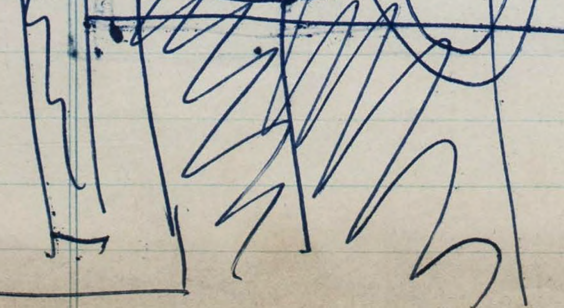
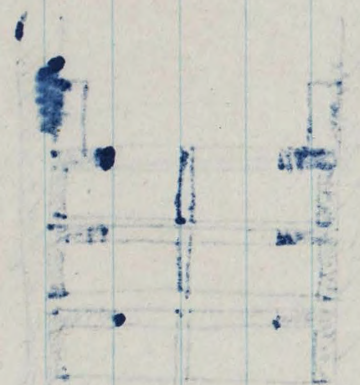
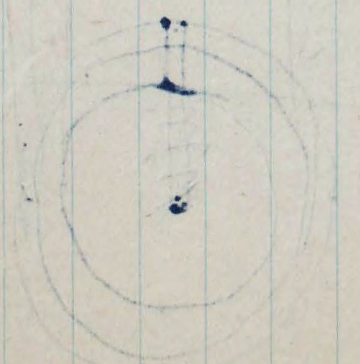
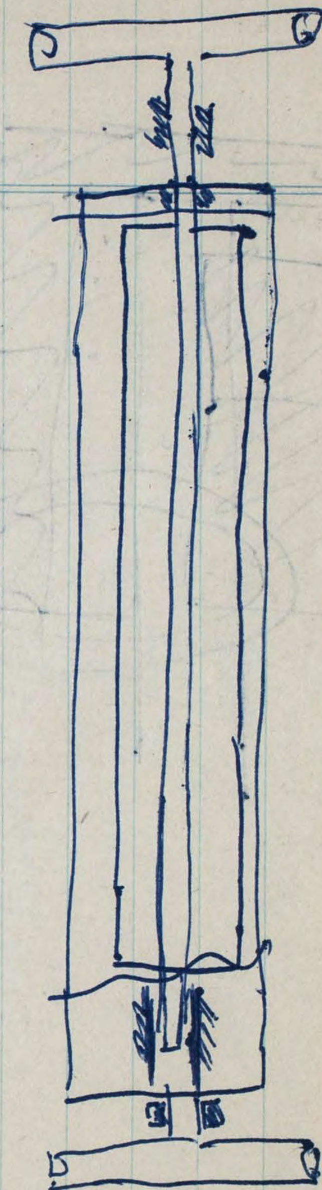
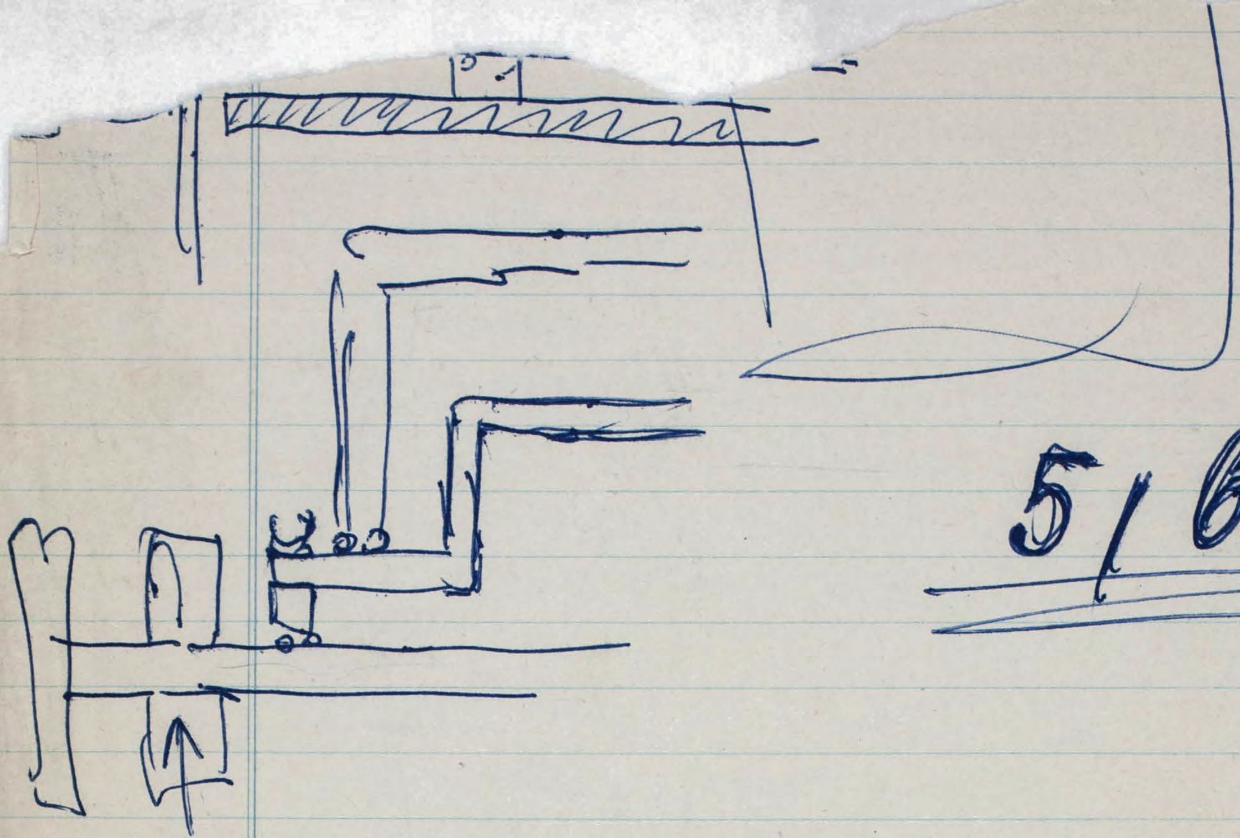


Fig 1 A

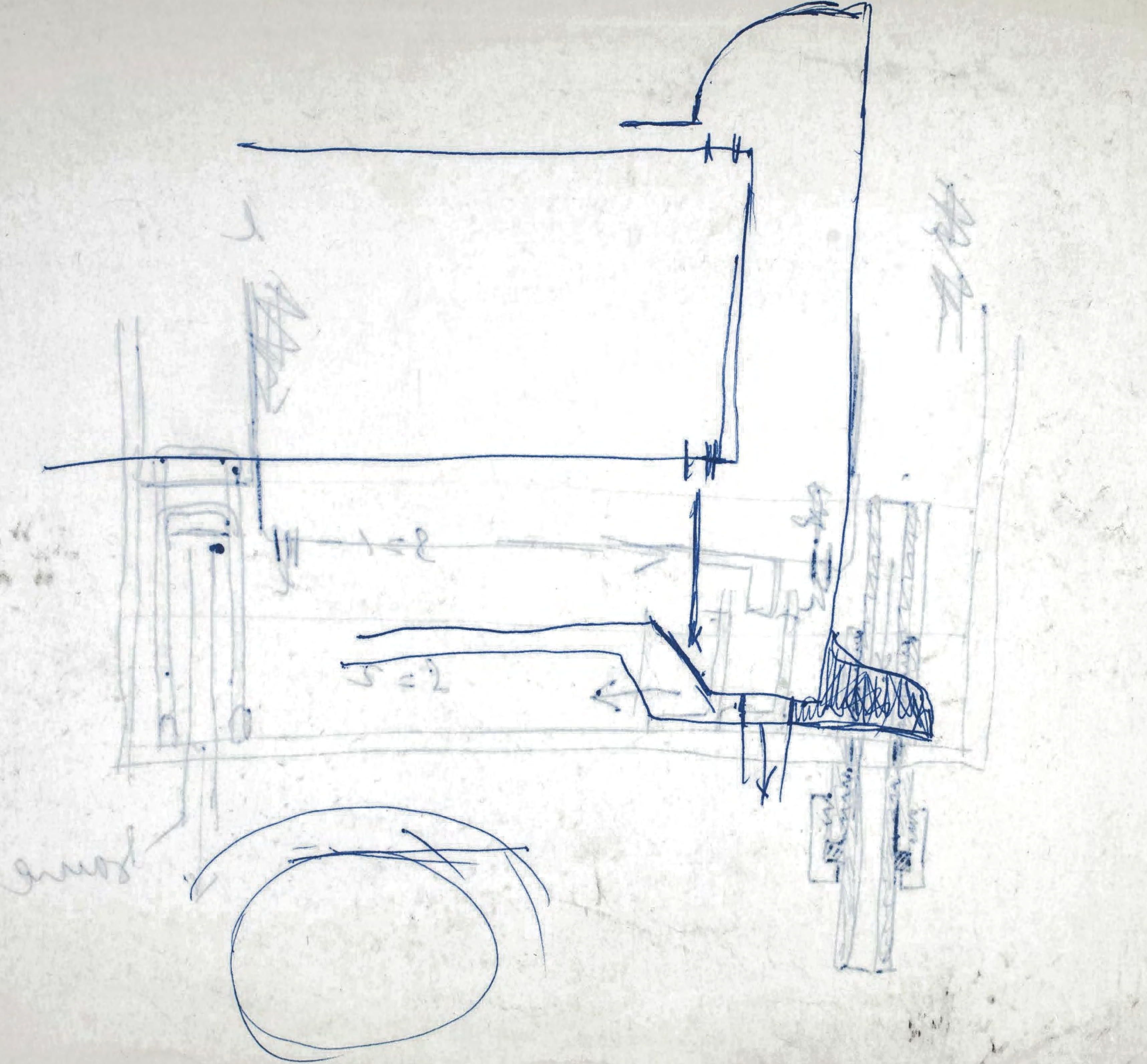


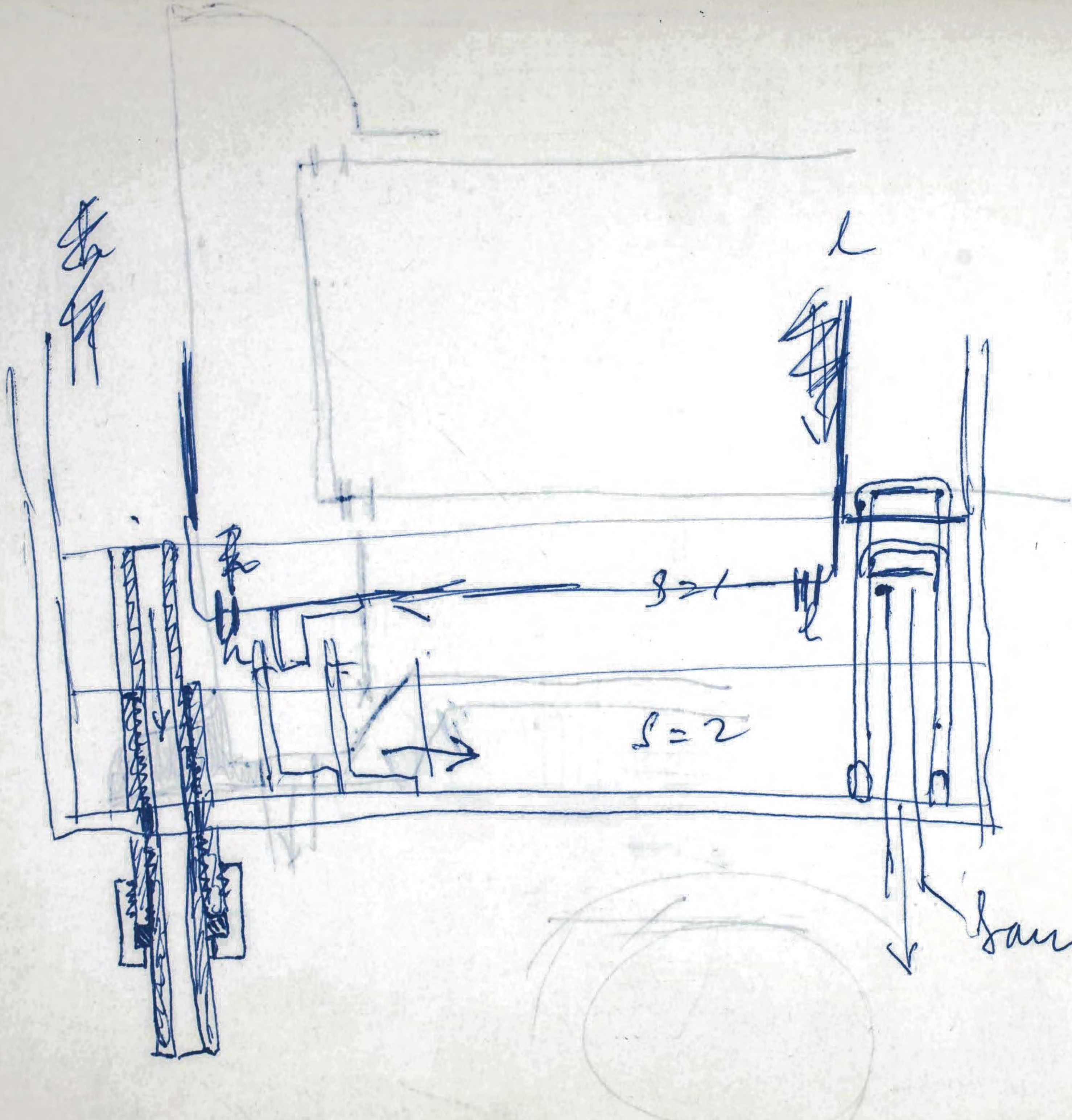



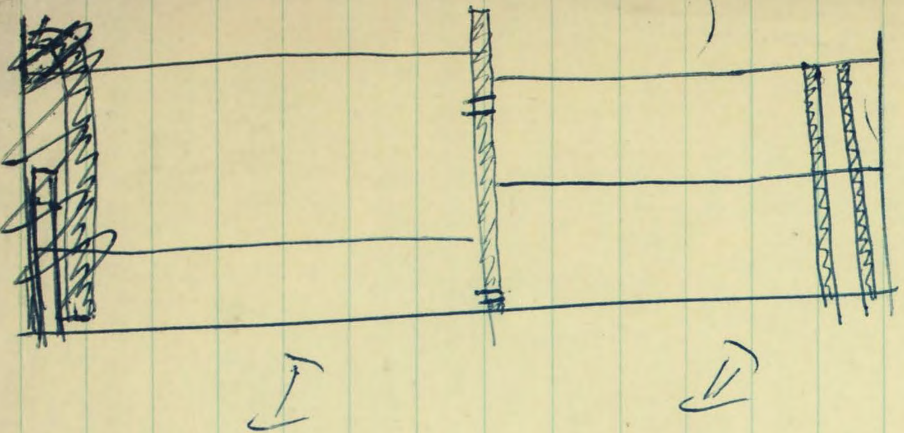




5/6




s = 2
same

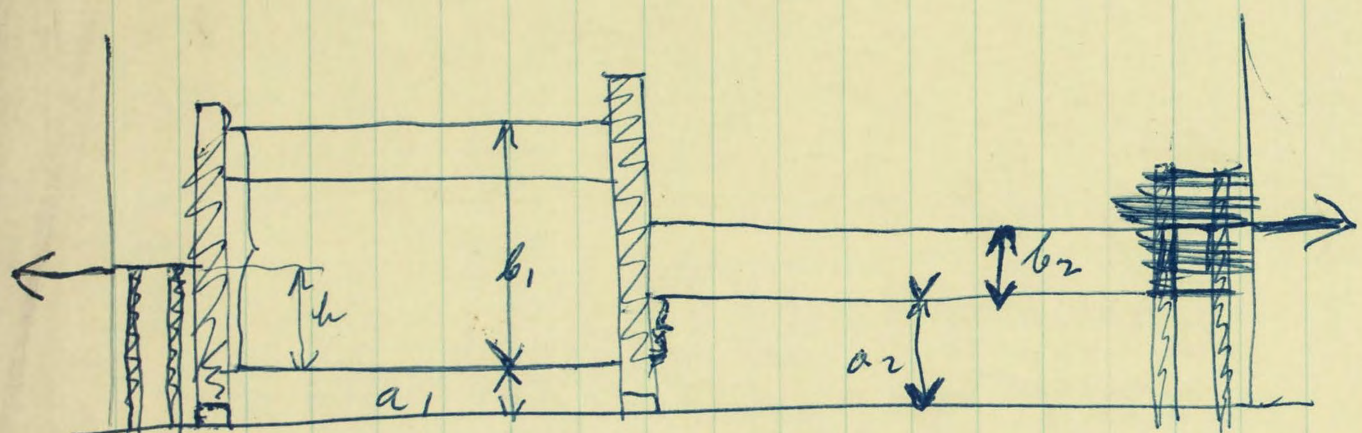


speed of flow in axial direction determines level in I. Figure assumes ratio of densities of light 2:1

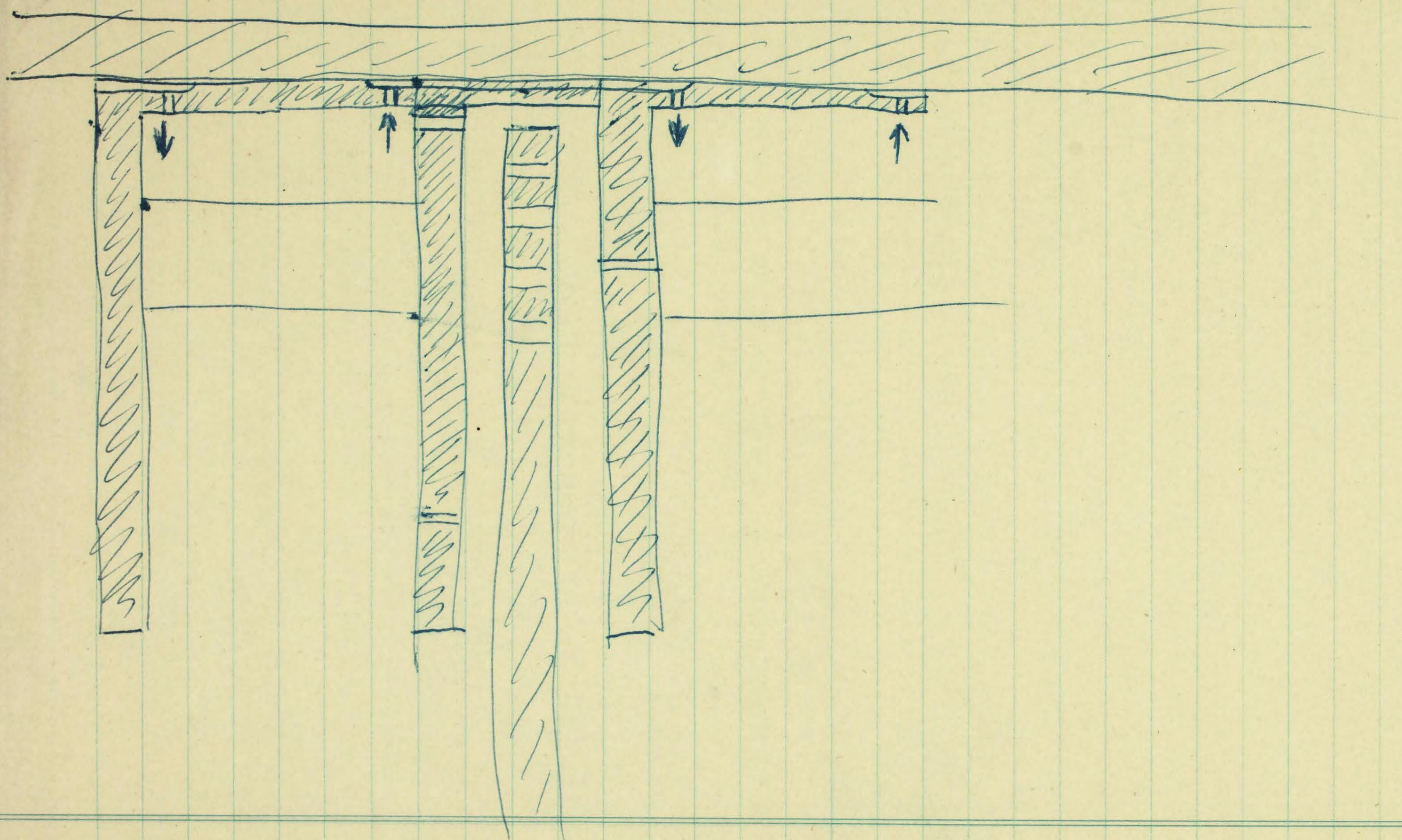
$s = 2$

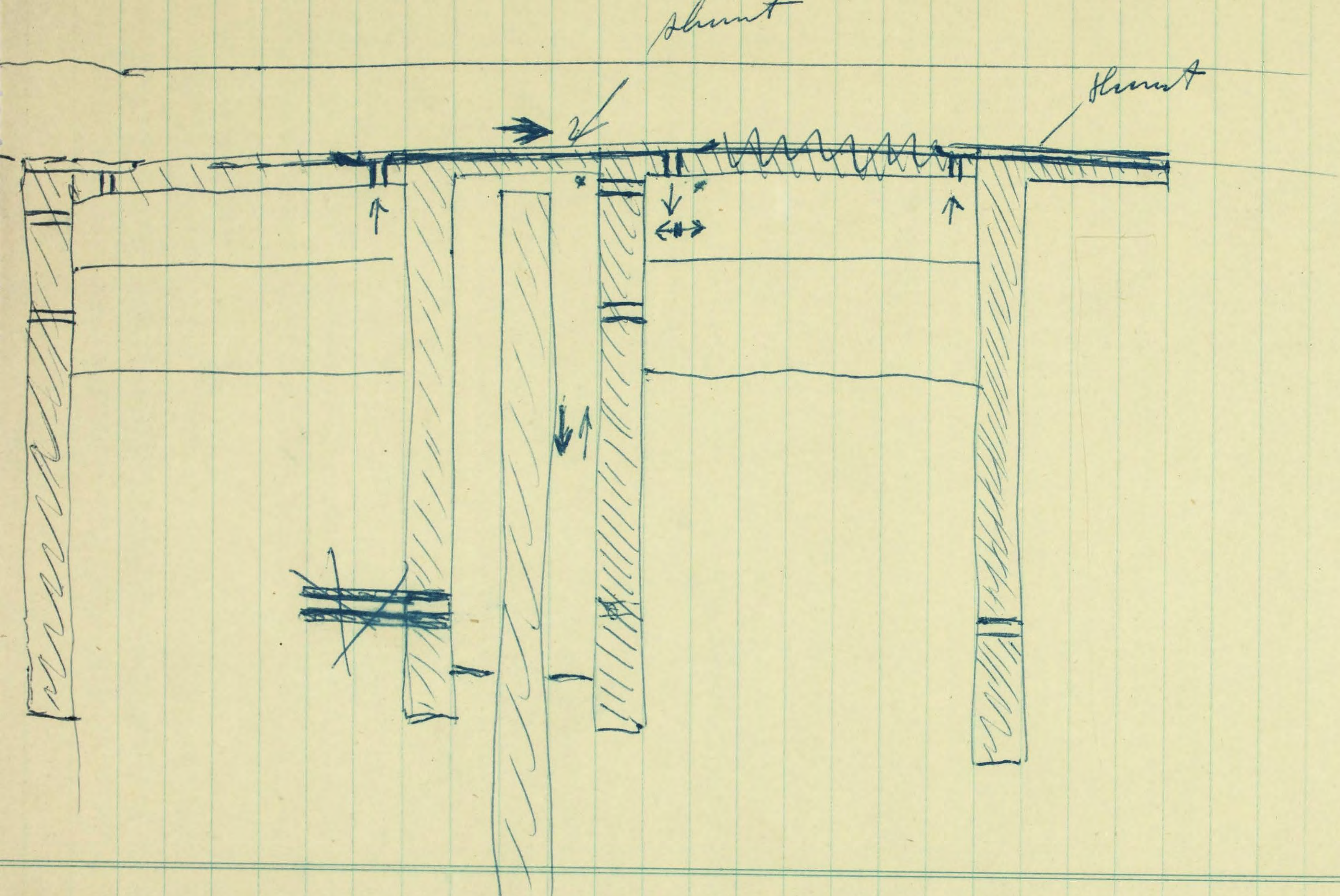
$$b_1 - b_2 = s(a_2 - a_1)$$

$$h = \frac{b_1}{s}$$



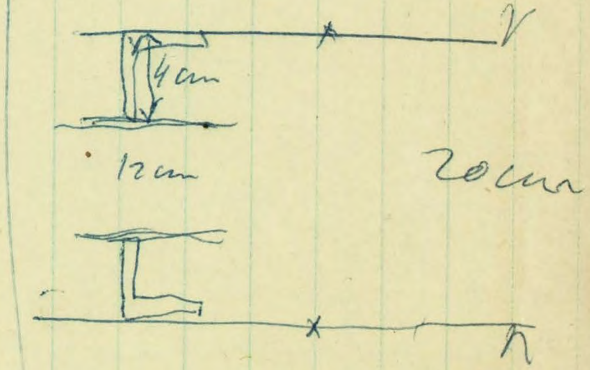
Or (no bolts)

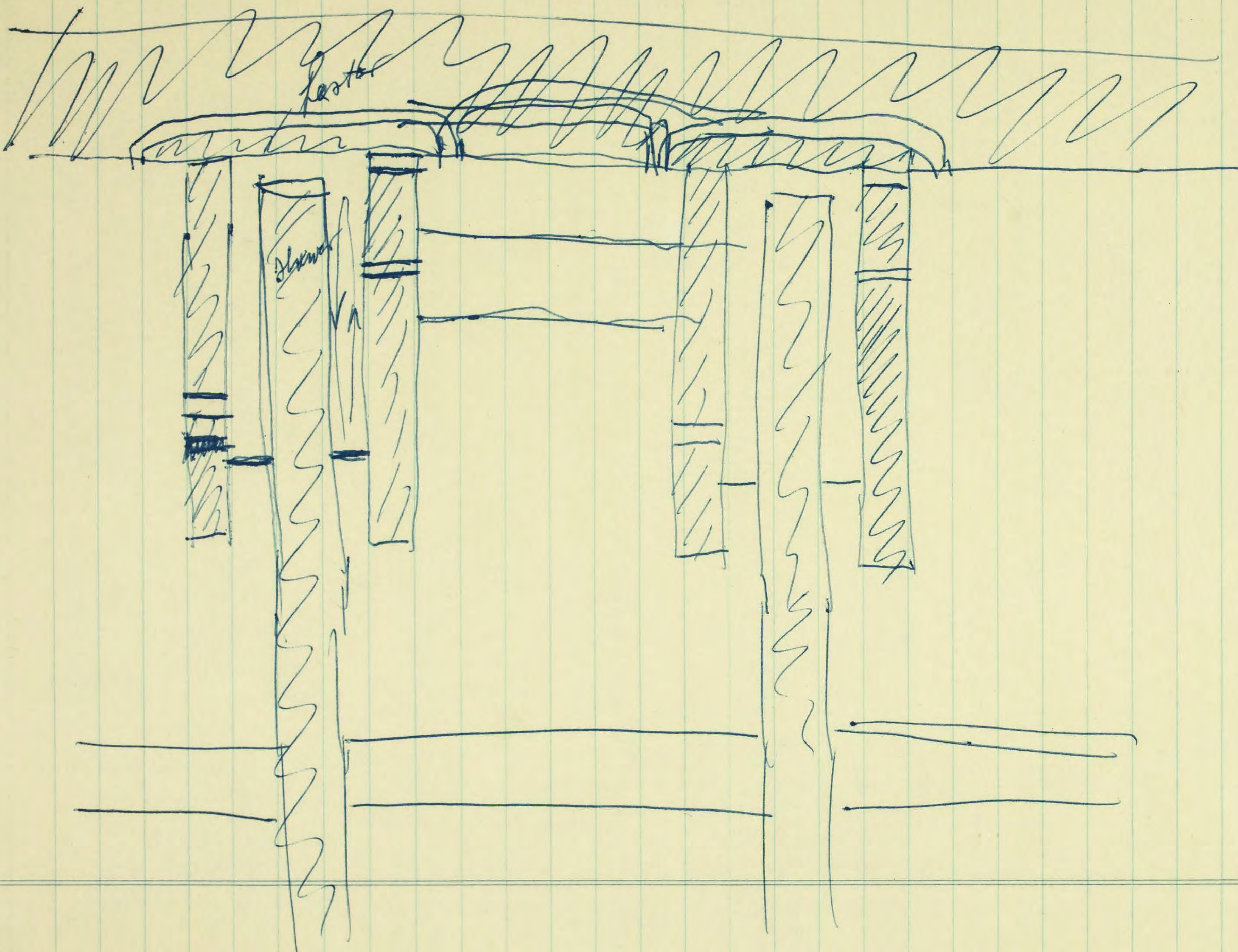




1500 rpm

60cm 15 meter
25 per sec



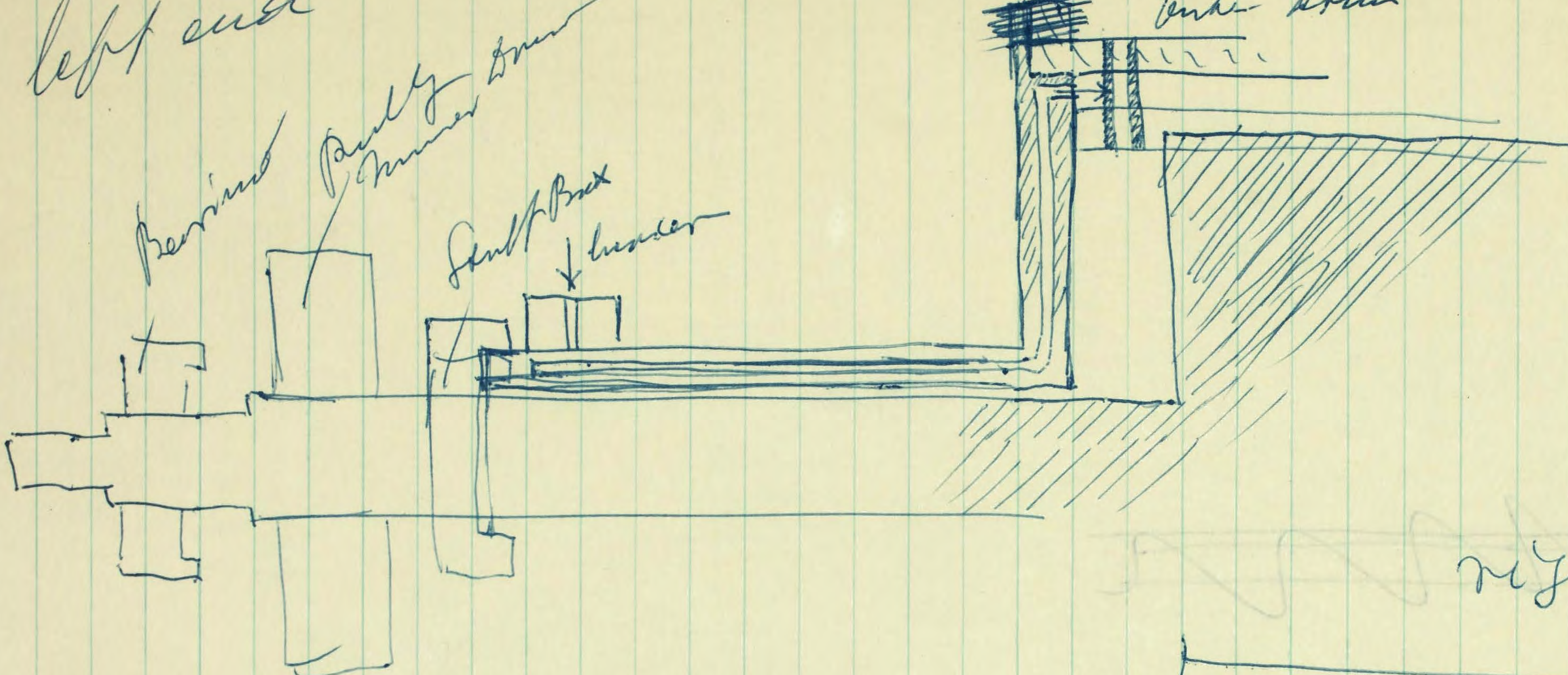


Top

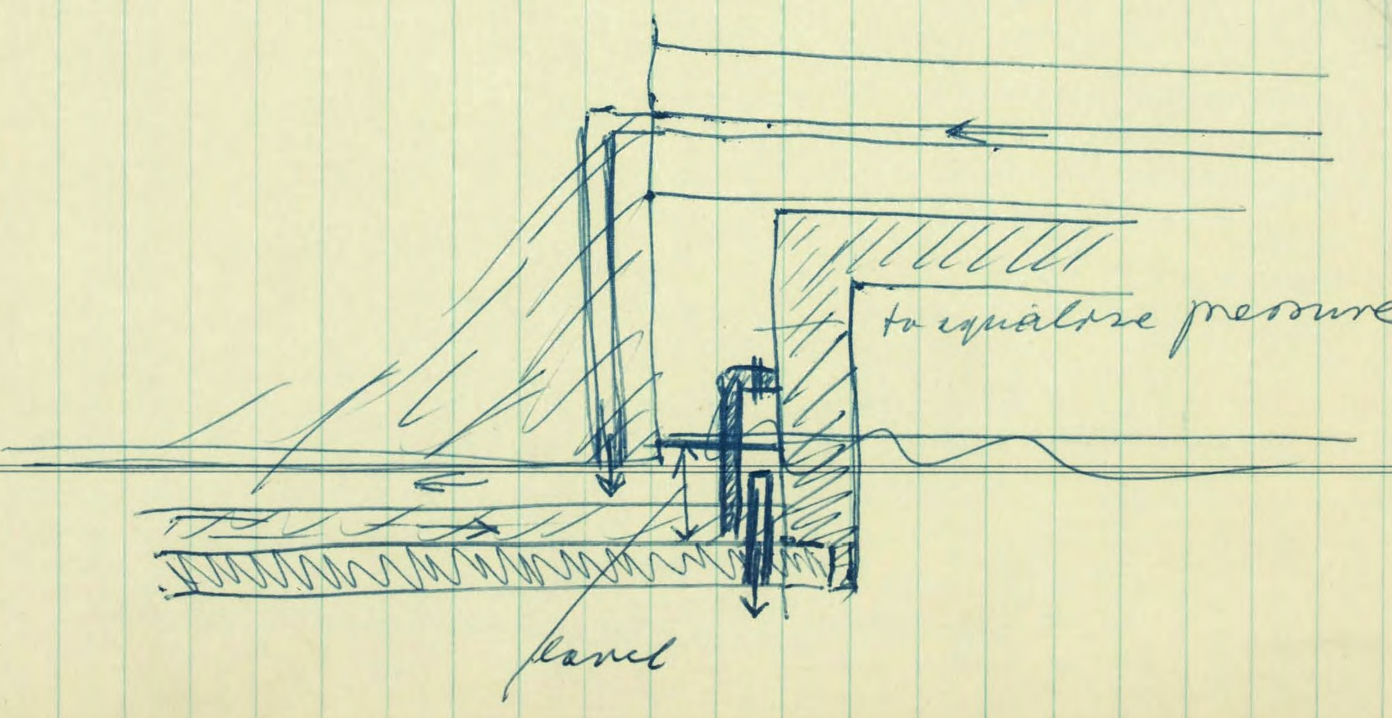
Final alternative

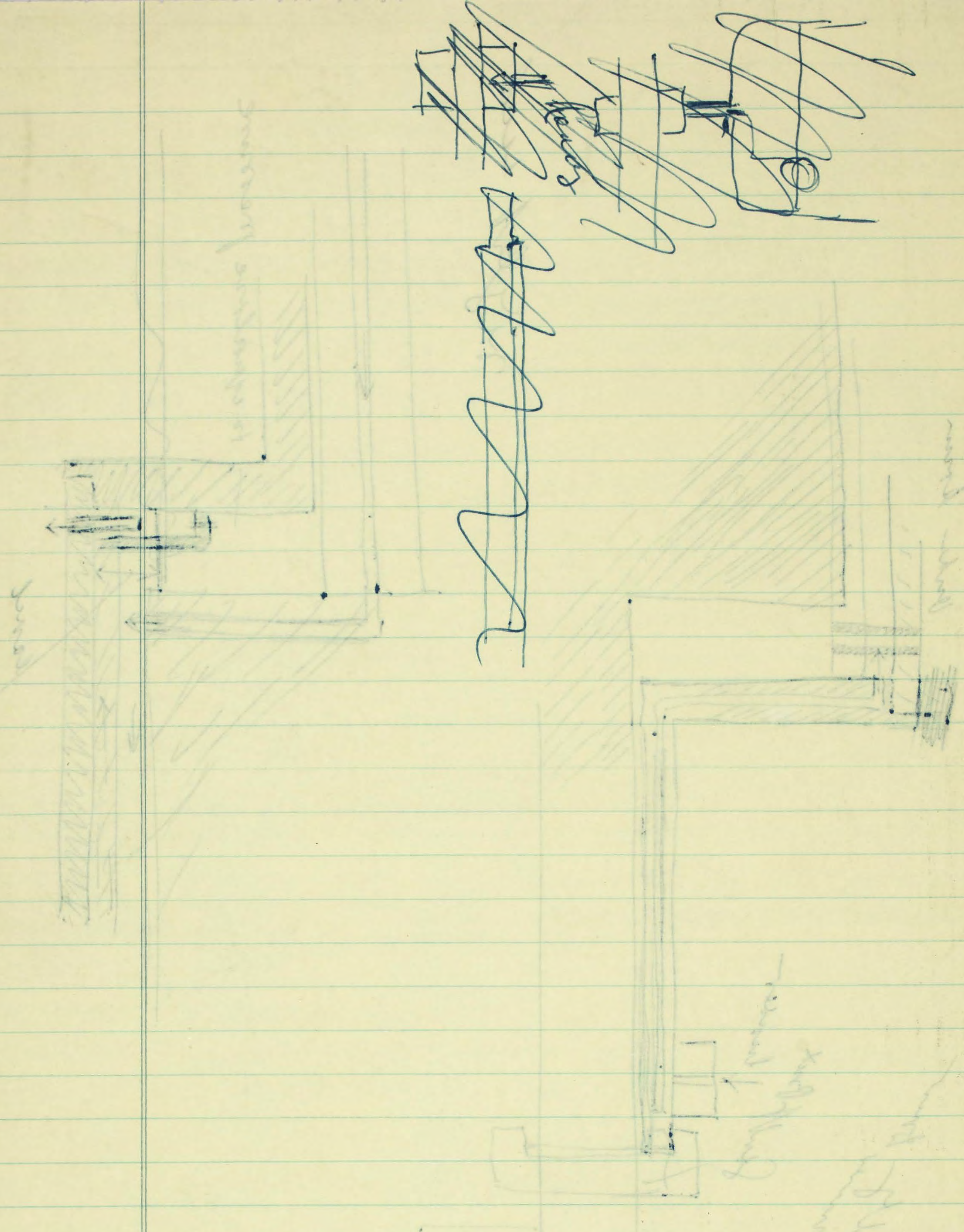
II

left end

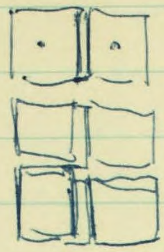


right end





f.



~~[illegible]~~ f cal/sec degree

1/2 ~~[illegible]~~/sec if layer 1 cm thick

KW/m²

~~[illegible]~~ 1400 Watt

1/10 Watt/cm²

$\frac{1}{40}$ cal/cm²

or [illegible] by 40 of layer 1 cm thick

~~[illegible]~~ for 2 meter = v 1°C | $\frac{4,870}{15 \times 25}$ kW/m²

$\frac{200}{15} = \frac{40}{3} = 13$

~~[illegible]~~ $\frac{13}{40}$

or to transmit 1 cal it takes $\frac{40}{13}$ sec

half value $\frac{1}{2}$ 3 second or 1.5 sec

for 1 cm thick layer. —

Now for diffusion take $\sqrt{t}$ of constants

0.0013

$\frac{1.3}{10^3}$

$\frac{13}{10^4}$

$\sqrt{\ } = \frac{3.5}{100}$

diff $= \frac{1}{3600 \times 24}$

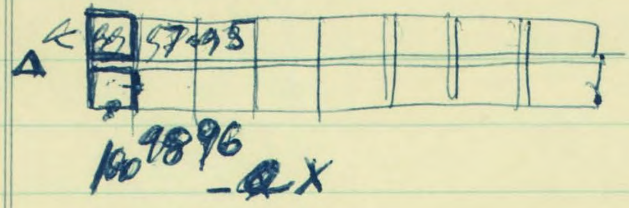
$= \frac{1}{9} \times \frac{1}{100} \frac{1}{100}$

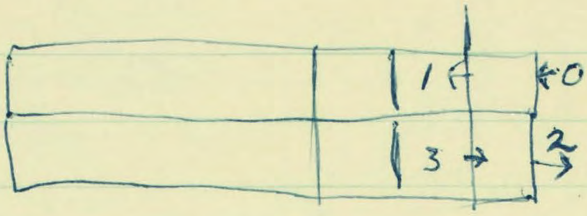
$= \frac{1}{10} \frac{1}{10^4}$

factor 10 worse

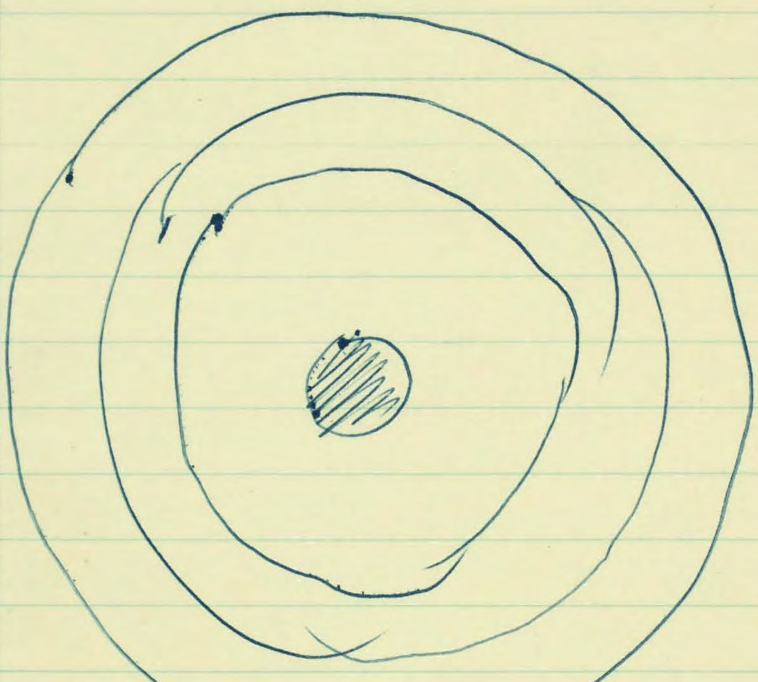
so it would move from 1 section to next for 1 cm thick layer in 1.5 sec (1/2 value) or speed of each section is 1 cm long almost .5 cm/sec

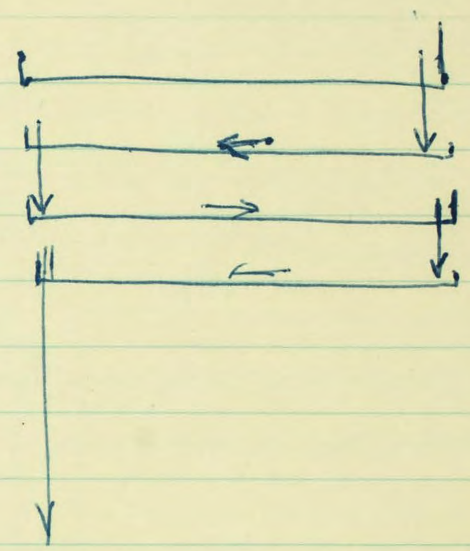
A 10 cm ~~diameter~~ [1 meter long], will therefore treat ~~15~~300 ~~...~~ 4.5 cc/sec or 280 cc/min with 100 theoretical plates.
or with 25 theor plates = 1 liter/min

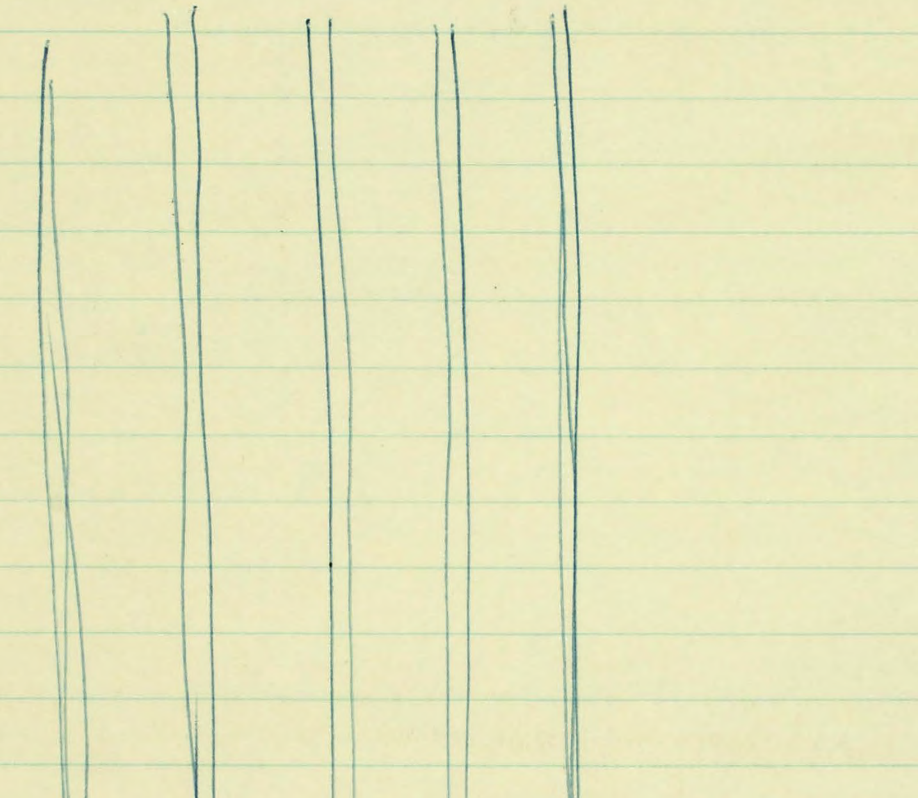




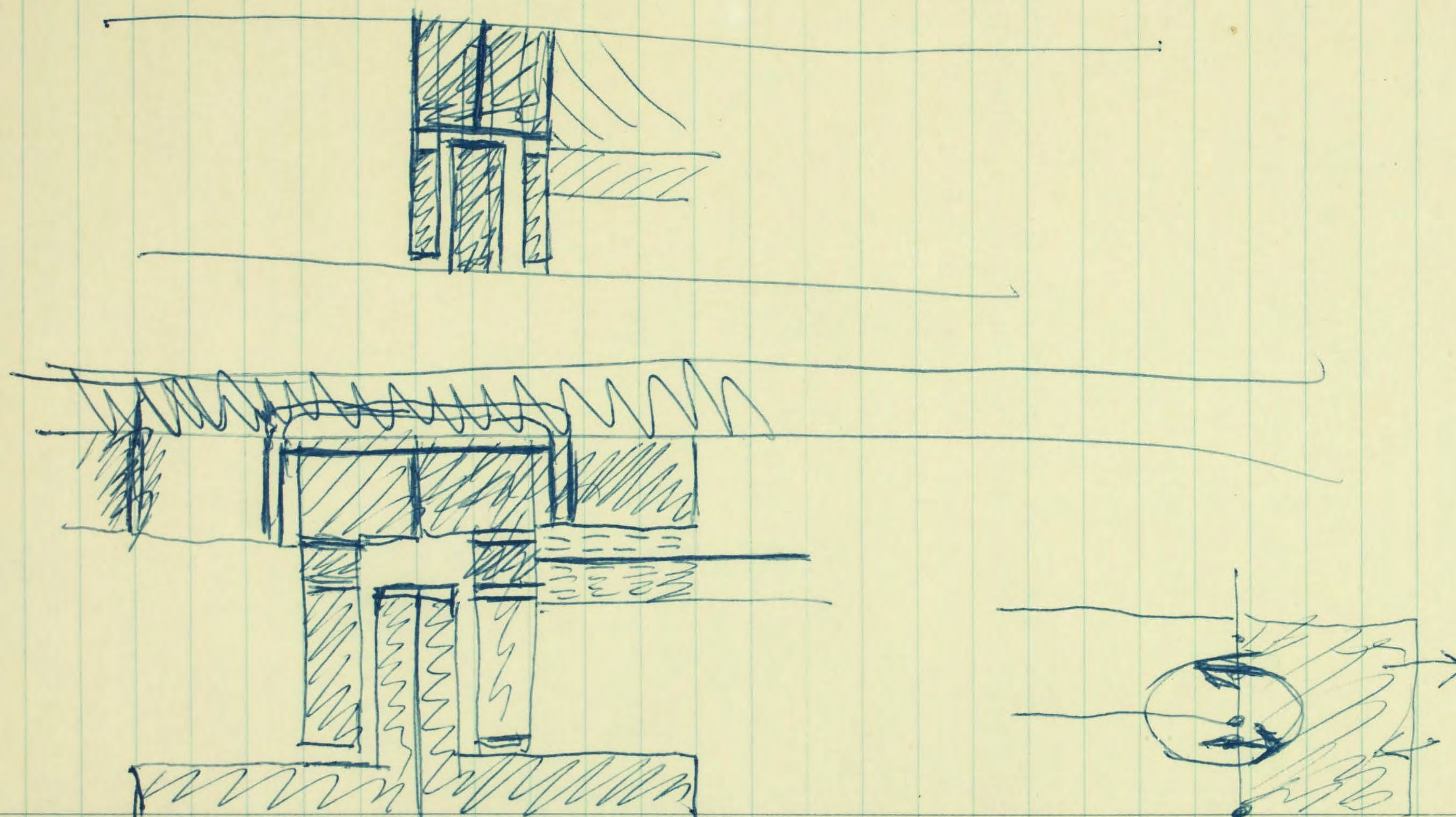
Multiple Unit

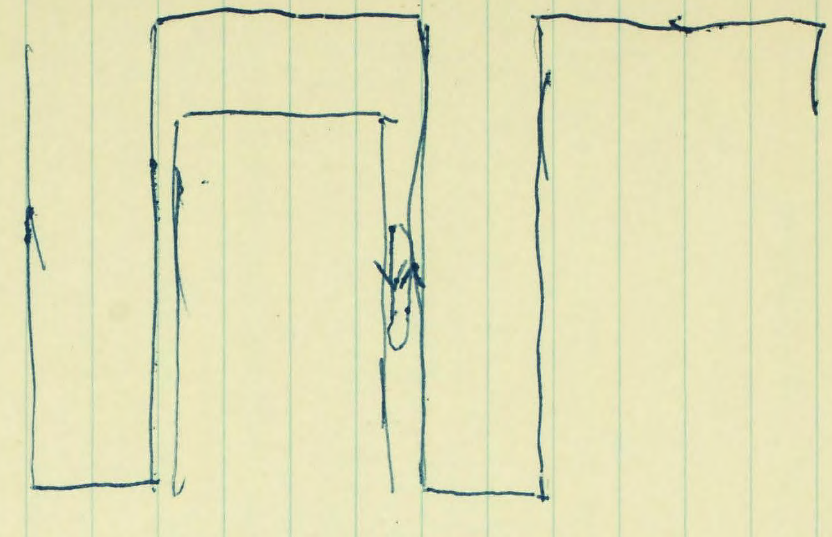


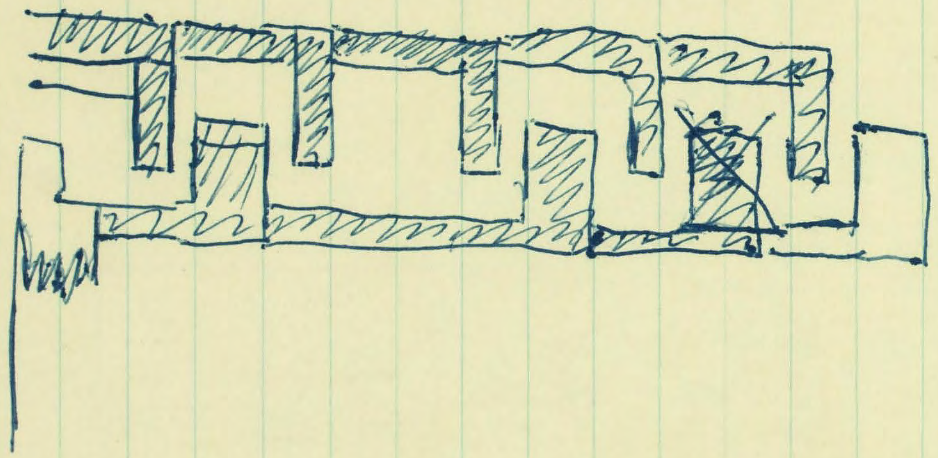




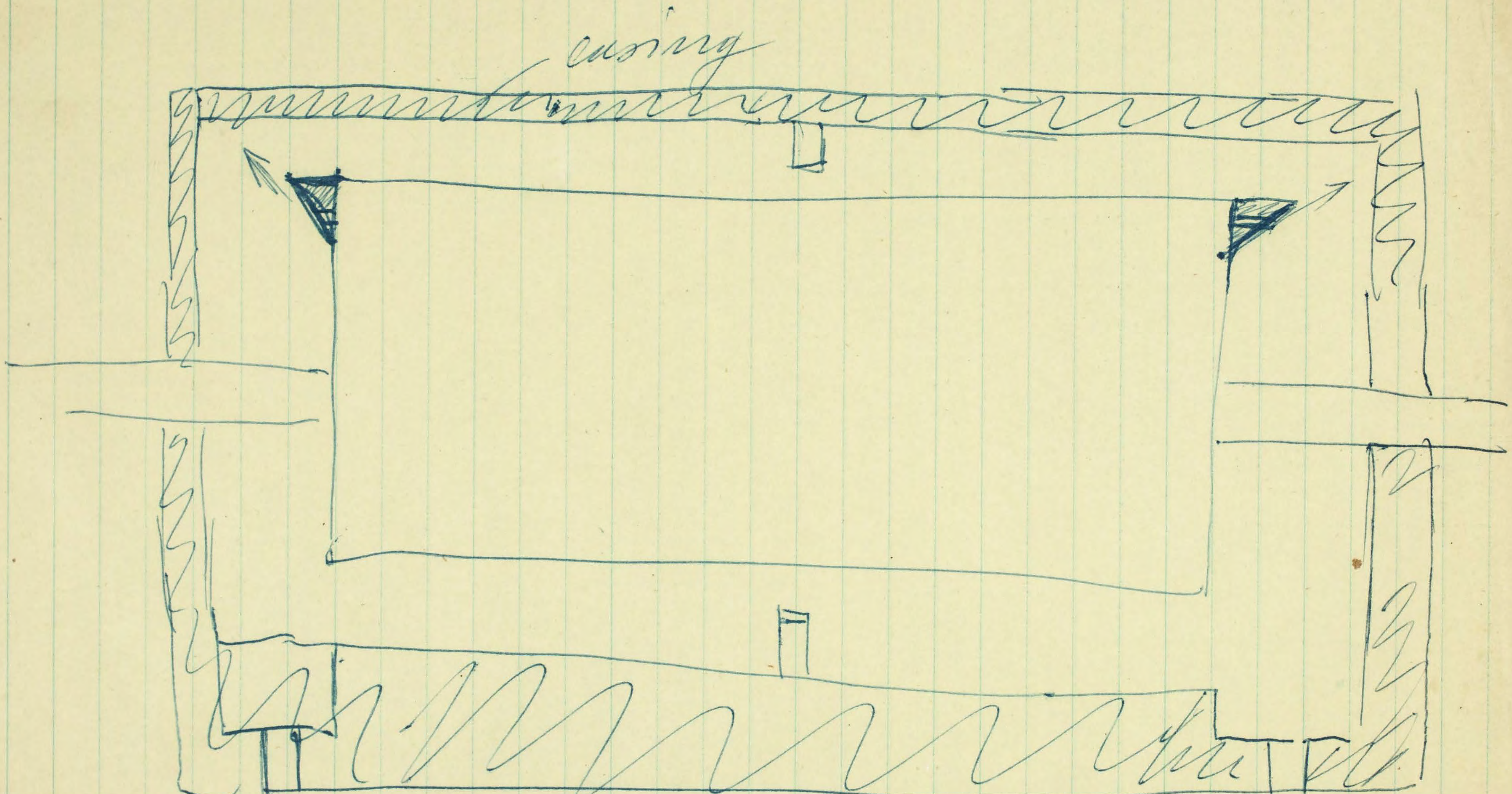
28





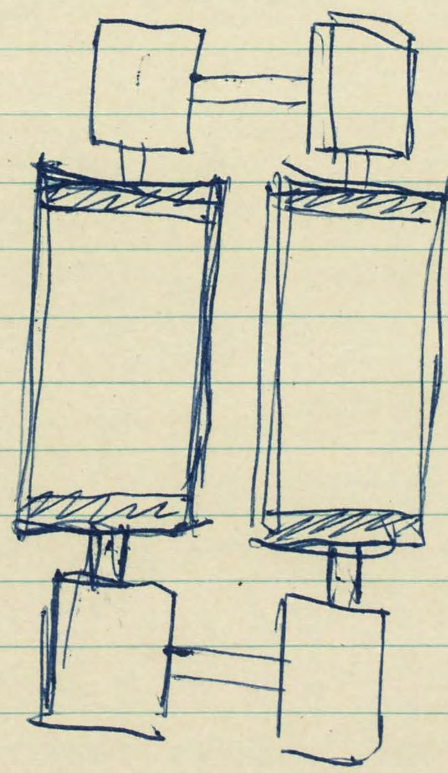


Modification of 4a

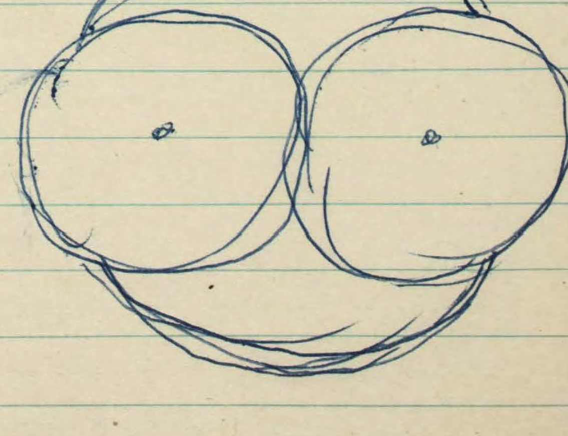

casing

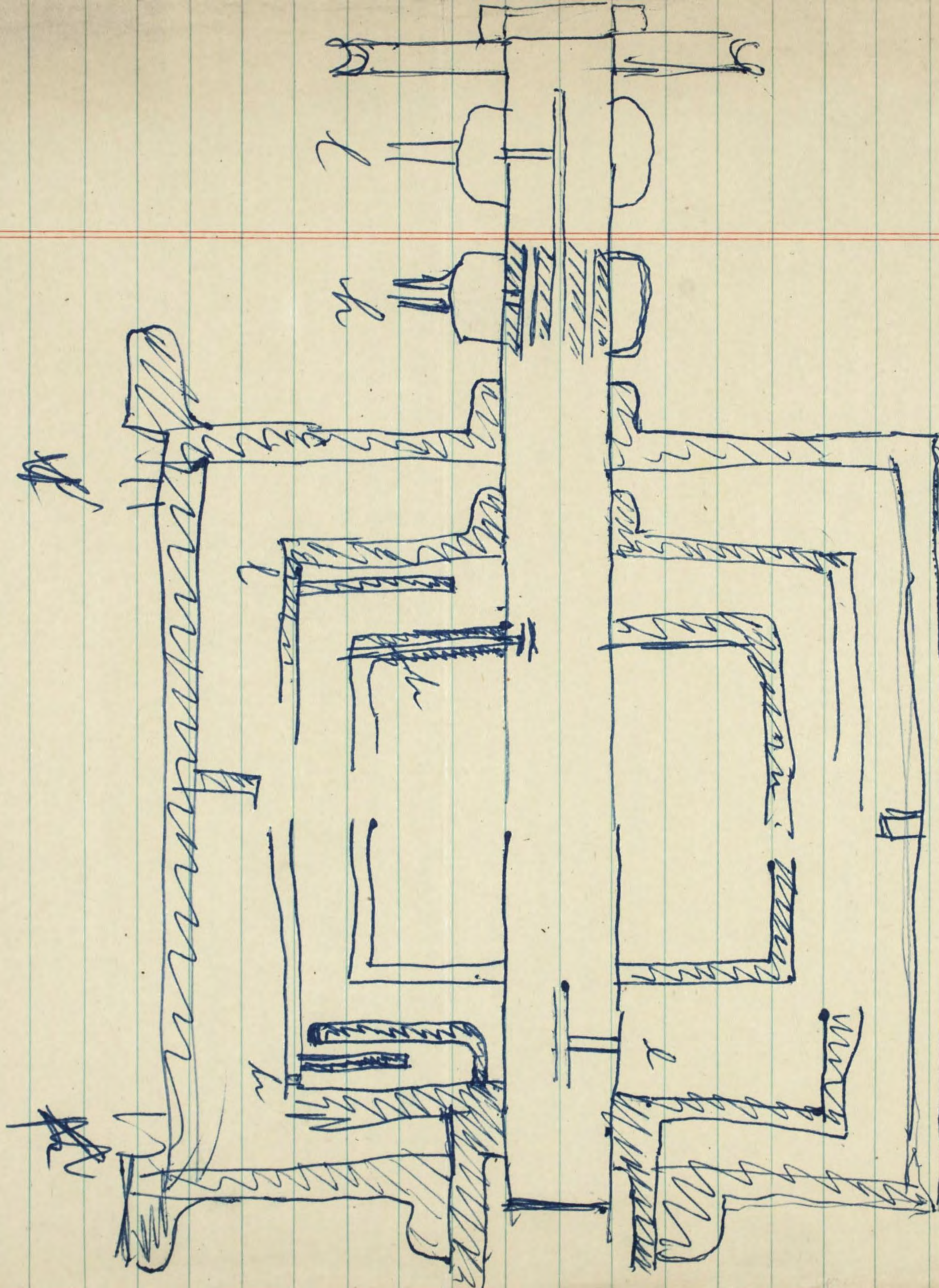
T S R R

4M



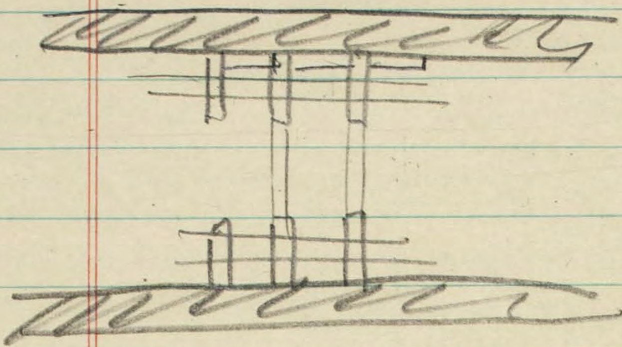
4H

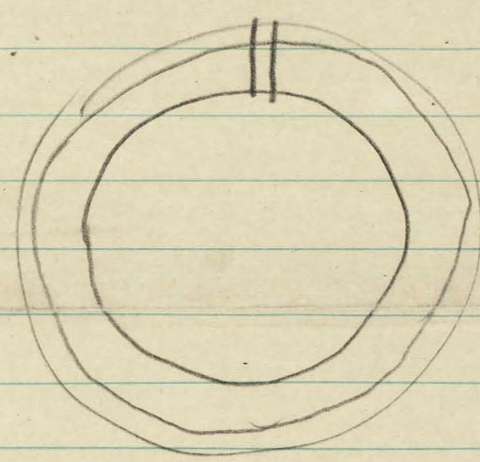


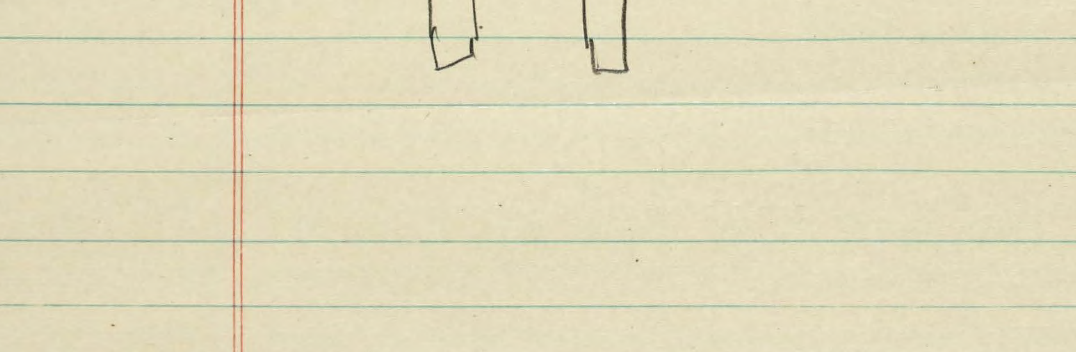


alternator
2

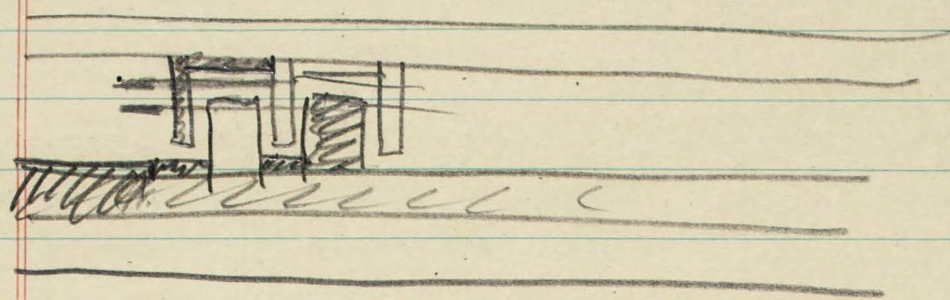
to variable
speed

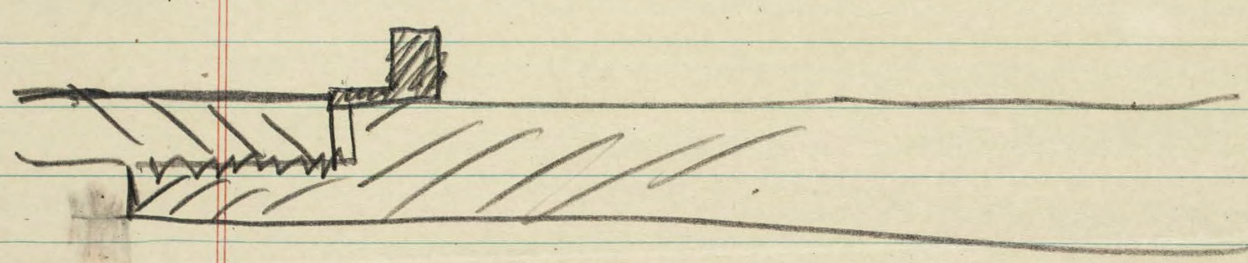




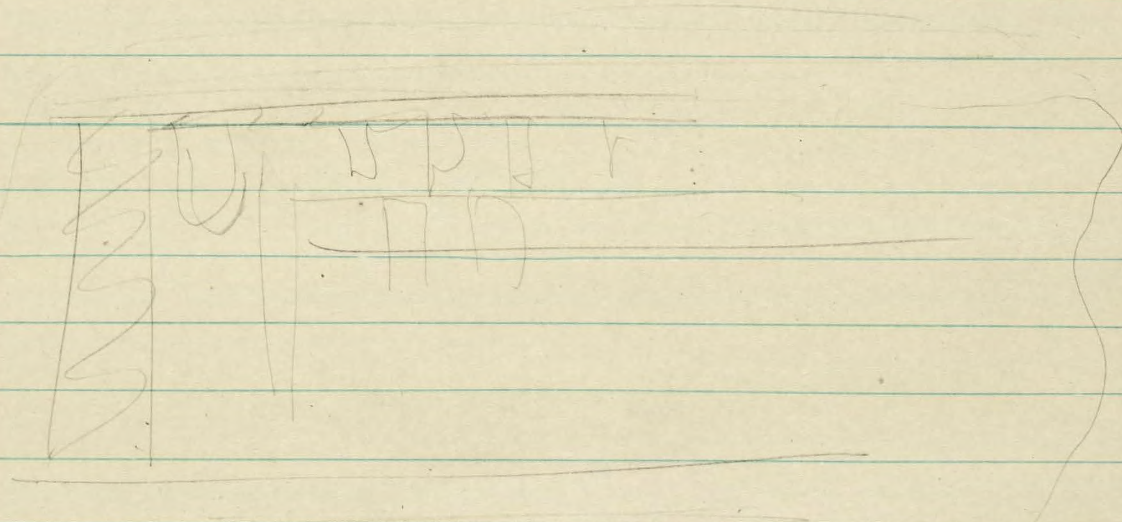


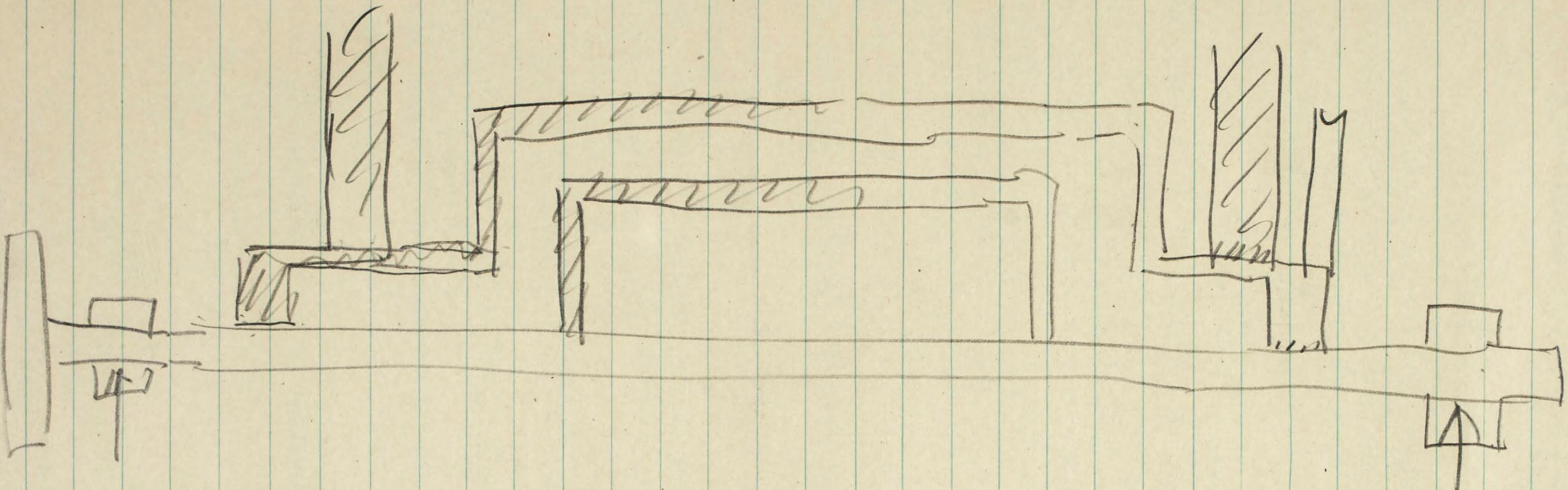
double rotor type





Show enlargement of
1 end



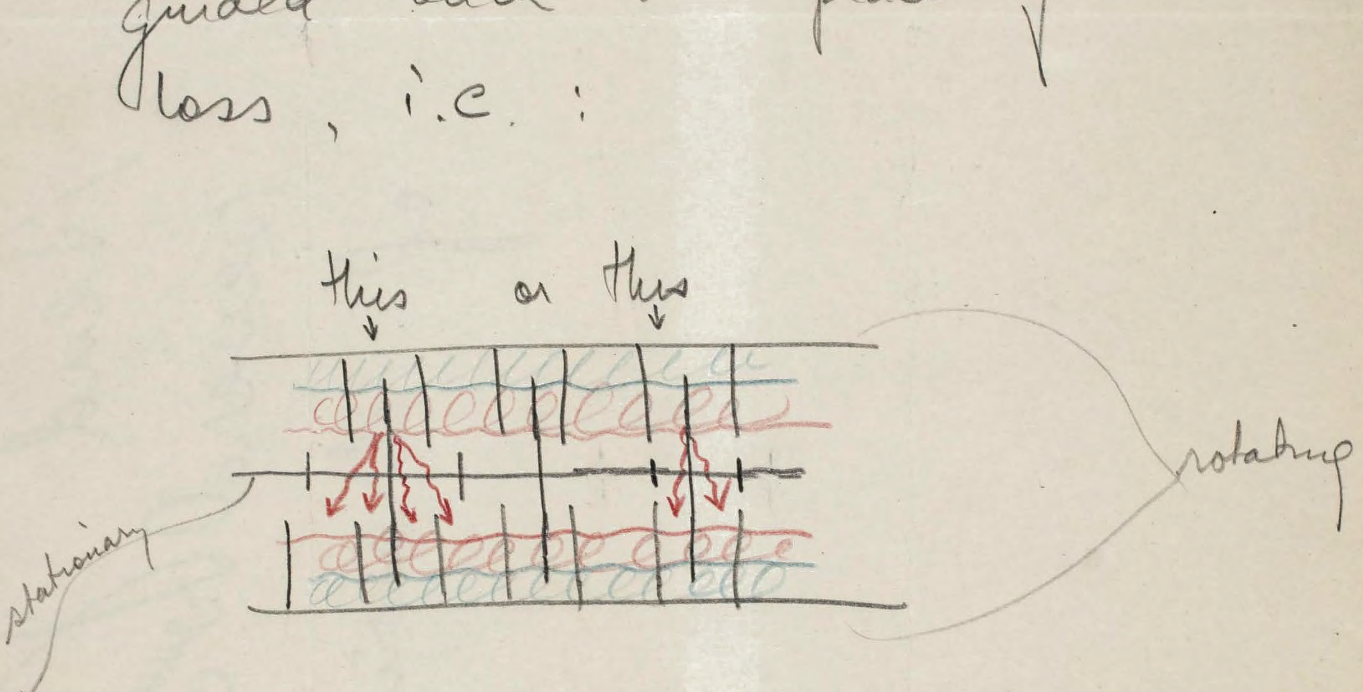


Alternator 3

Szilard's Gadget

then cant separately vary stirring + centrifugal fields, but cover it in riteup anyhow — (if any)

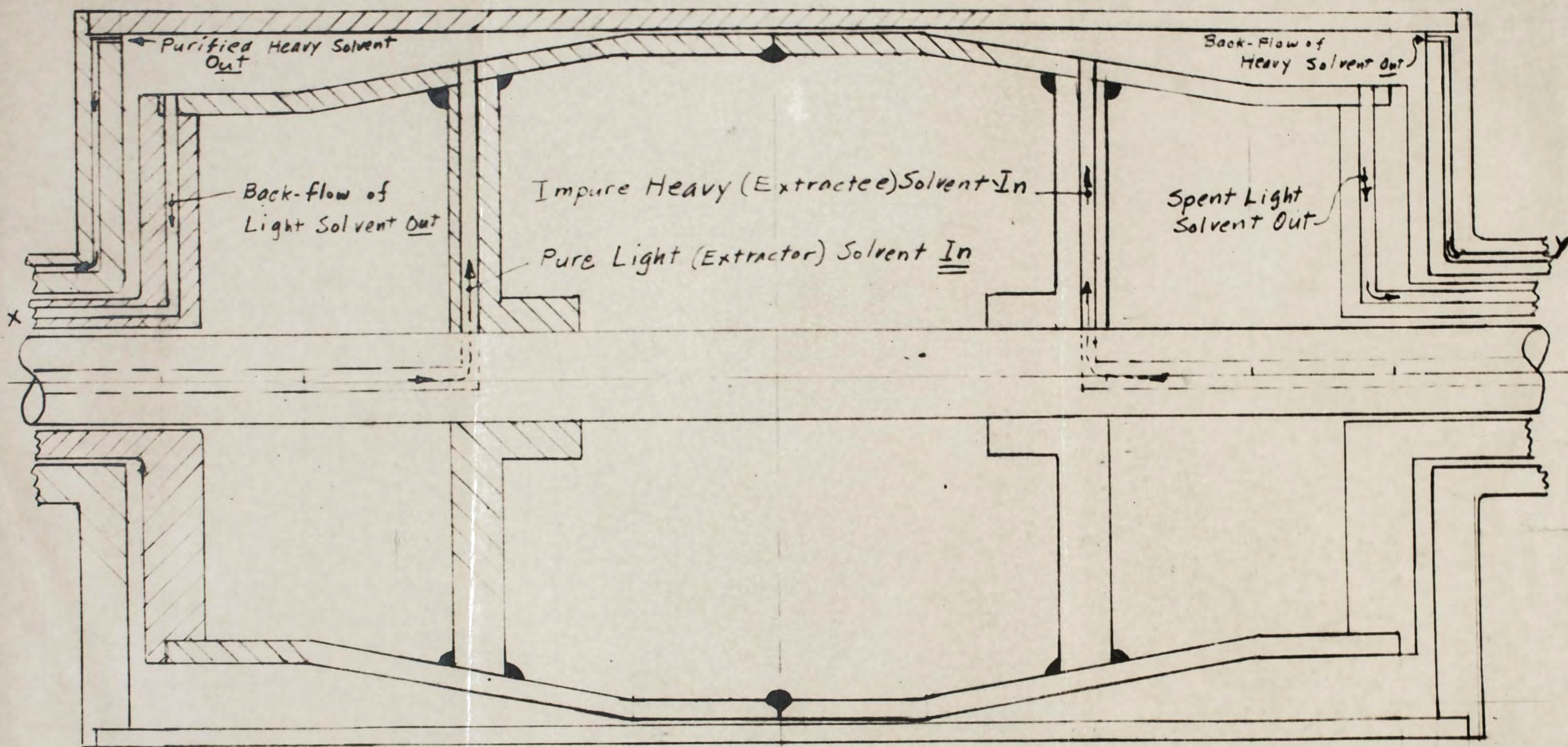
Inner member needn't turn — even if fluid dribbles down off mixer discs (stationary) it can be guided back to a place of no loss, i.e.:



This may be a substantial simplificat of mechanics and probably this alternat should be included in patent

Send JRM several complete sets copies of drawings

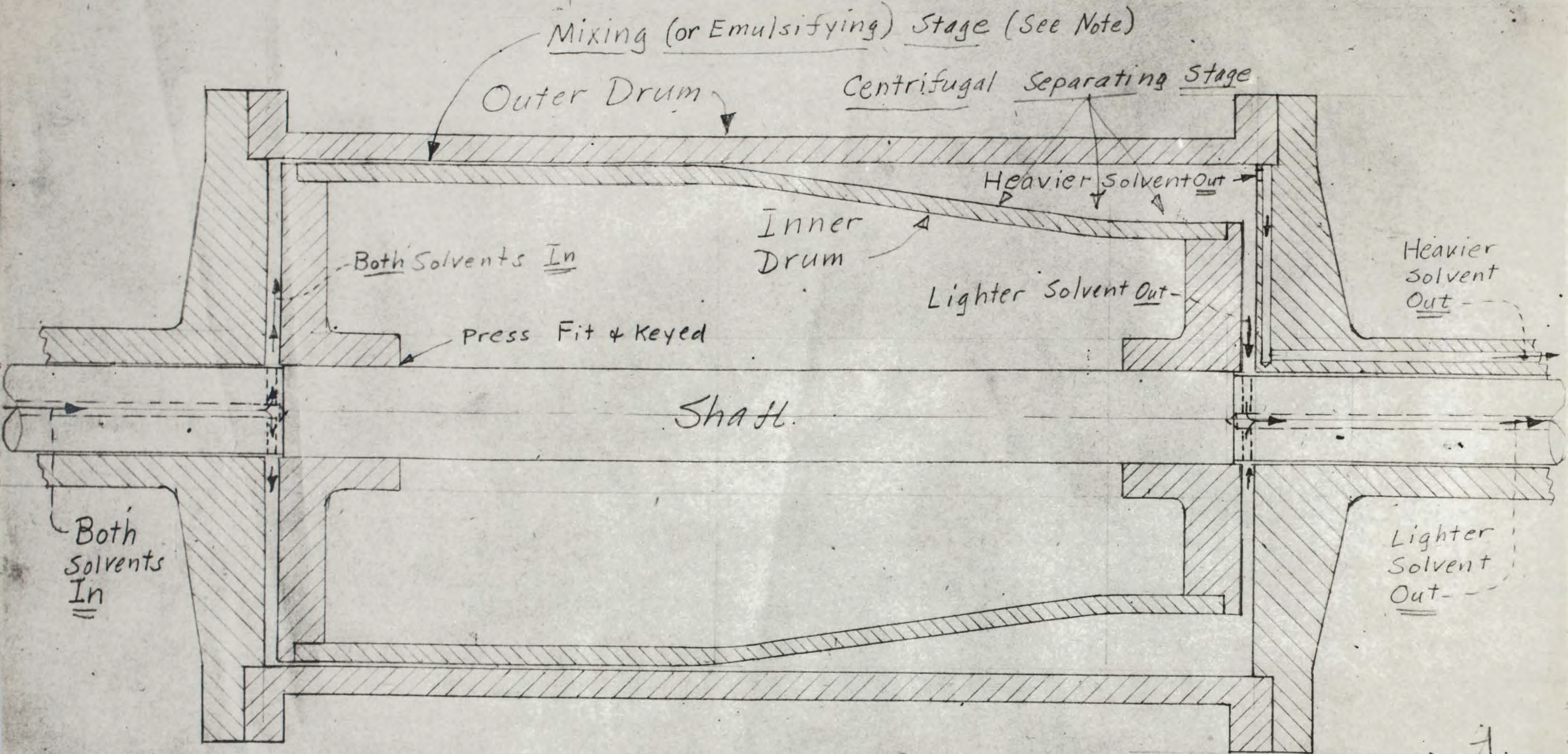
Fig. 5. Combination of Mixing and Counter-Flow.



x and y are valves which are normally closed and opened only intermittently to remove back-flow, or else are left open continuously but just "cracked".

B Leibowitz
350 Fifth Ave
N.Y.
Oct. 21, 1946

Fig. 2 - Mixing (or Emulsifying) and Separating Centrifuge.
Inner drum tapered.

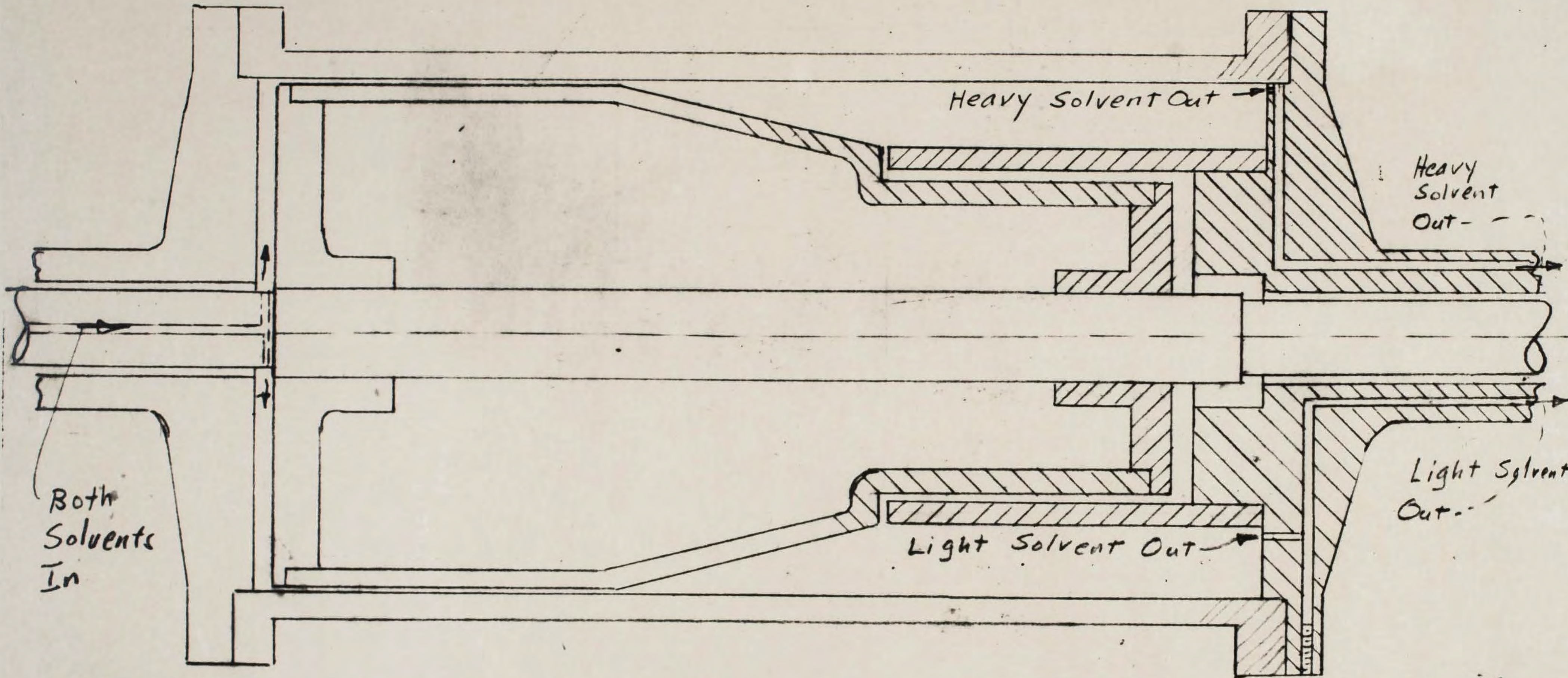


Note: Clearance between drums in Mixing or Emulsifying Stage to be very small, e.g. a few thousandths to a few hundredths of an inch. Surfaces of Annulus in Mixing Stage to be roughned (as by sand-blasting) or fluted parallel to axis

For End Structures See Fig. 1.

350 Fifth Ave
New York.
Oct. 12, 1946

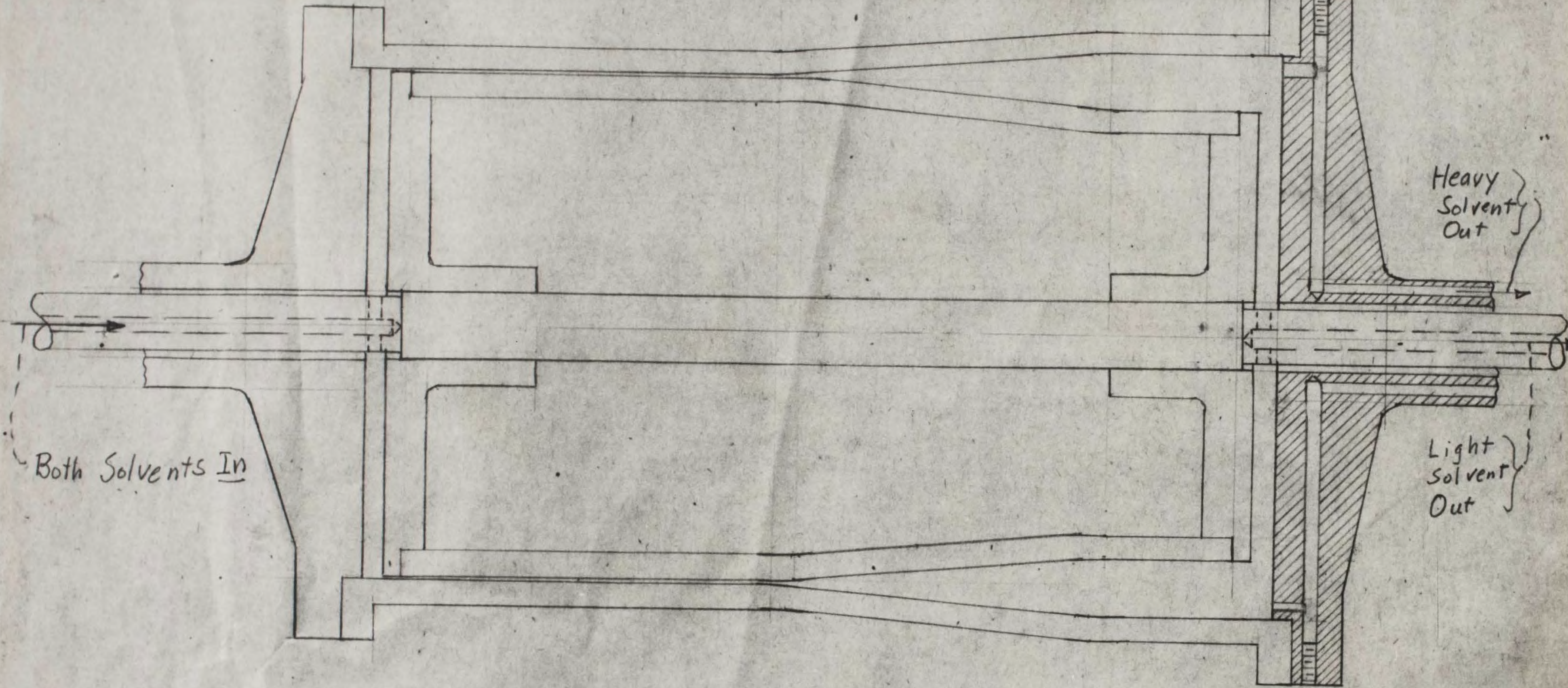
Fig. 2A - Mixing + Separating Centrifuge
with No Differential Speed in Separating Stage.



Benjamin Liebowitz
350 Fifth Ave.
New York
Oct 14, 1946

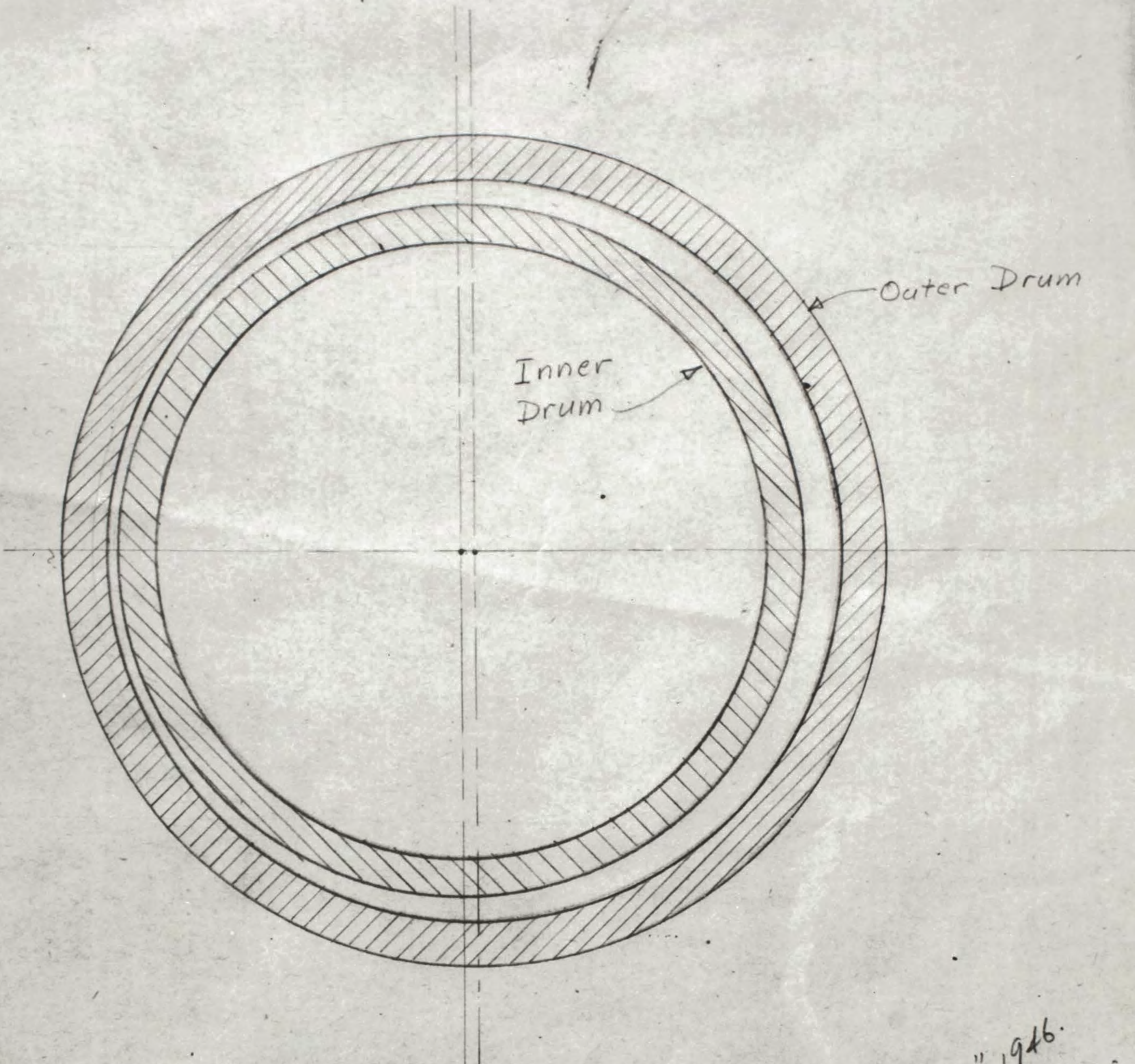
Fig. 3 - Mixing (or Emulsifying) and Separating Centrifuge

With inner and outer drums both tapered



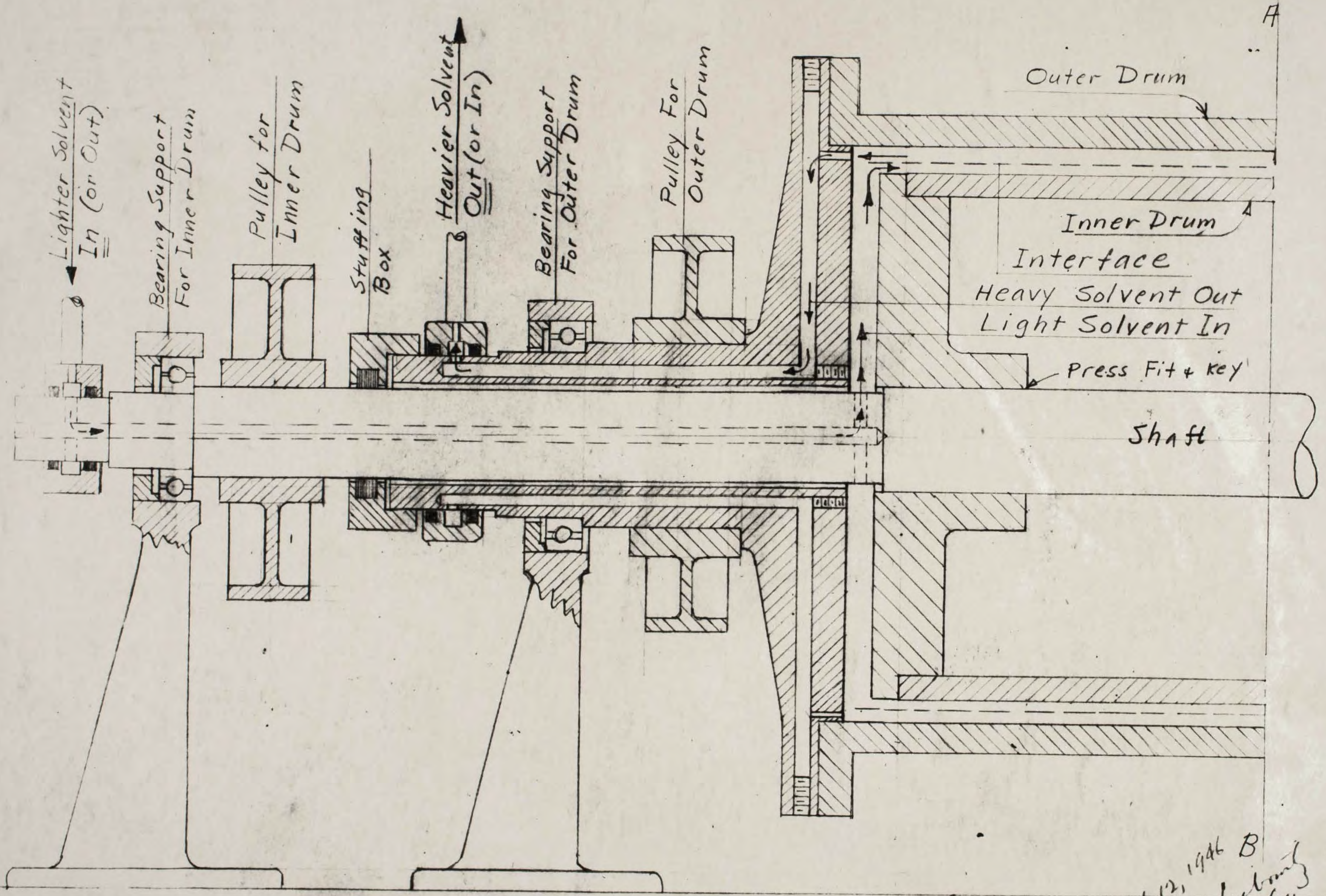
B. Liebowitz
350 Fifth Av.
N.Y.
Oct. 12, 1946.

Fig. 4 - Showing Eccentricity (exaggerated) between Inner and Outer Drums



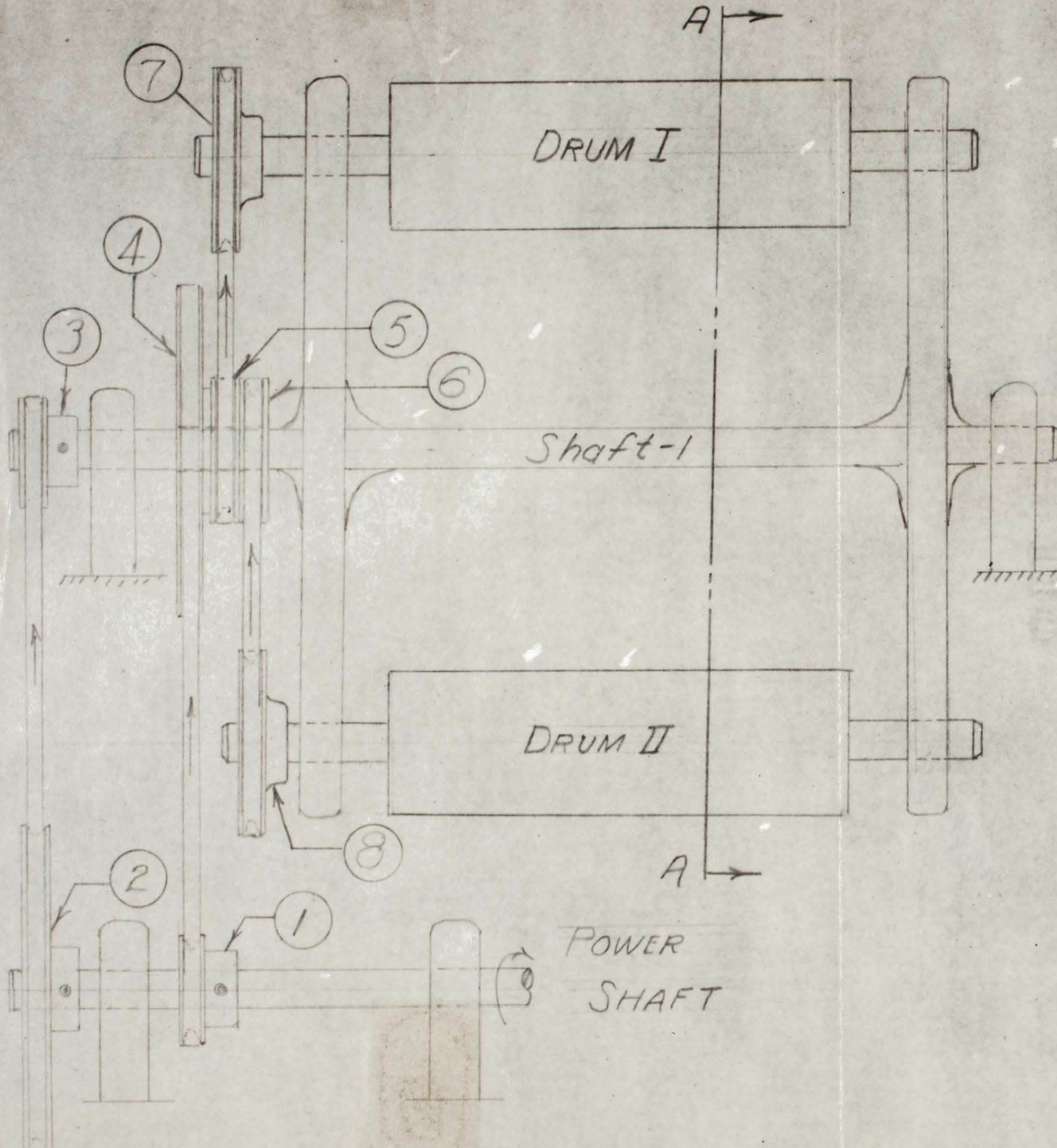
Oct. 12", 1946.
[illegible]
350 Fifth Ave.
N.Y.

Fig. 1. Szilard System as Modified.



Except for Pullies, Structure is Symmetrical about a Line AB

Oct. 12, 1946 Lubrom? 350 Fifth Ave. N.Y.



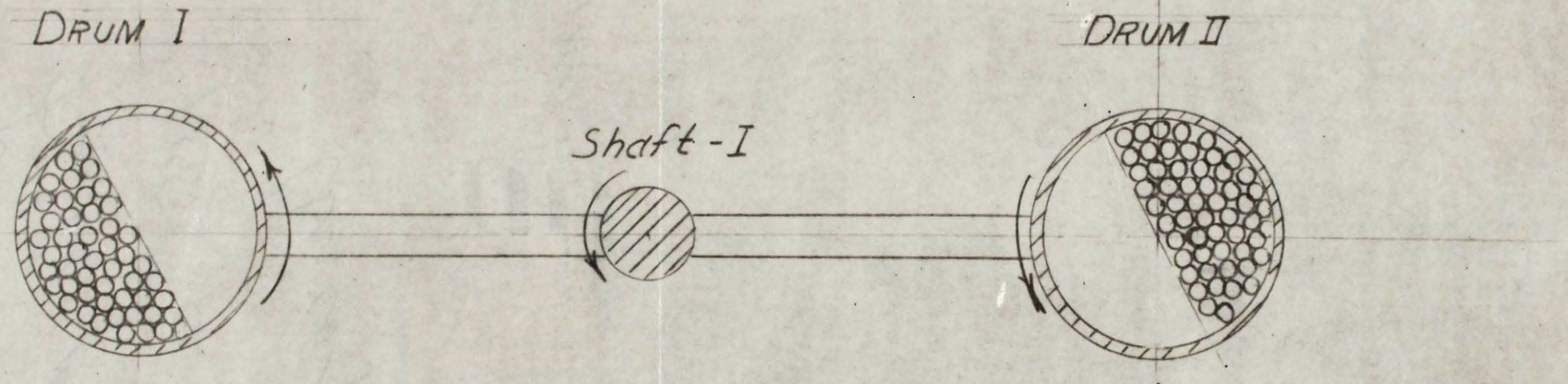
Pulleys 4, 5, & 6 are integral
Ratio dia. ① to dia. ④ is 1:3
Ratio dia. ② to dia. ③ is 3:1
Ratio dia. ⑤ to dia. ⑦ is 4:5
Ratio dia. ⑥ to dia. ⑧ is 4:5
(Tripple pulleys, 4, 5, & 6, floating on shaft-1)

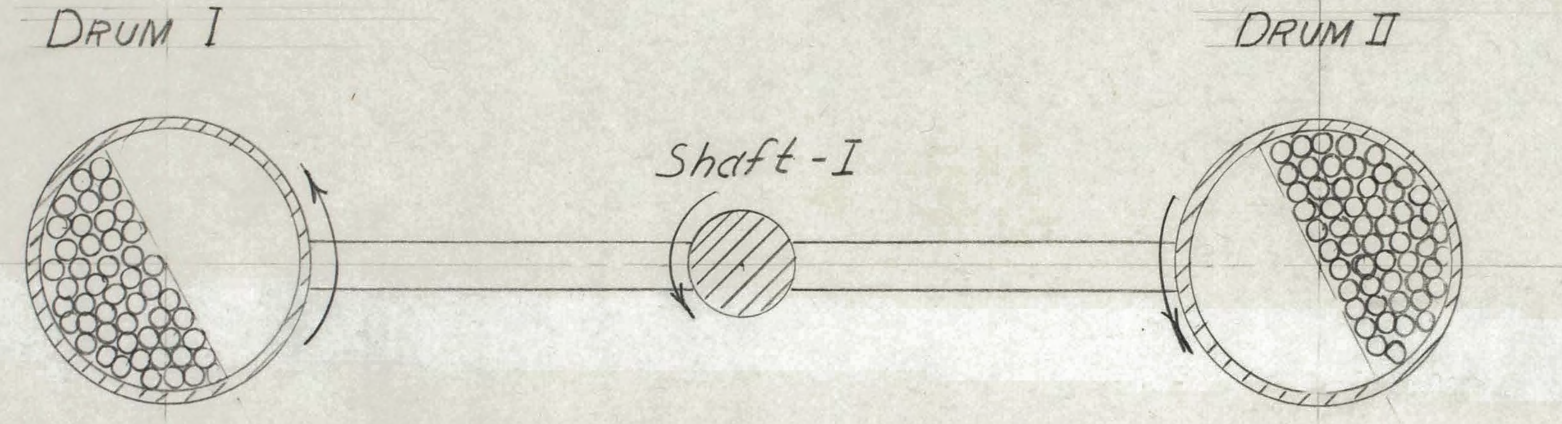
Final speed ratio of shaft-1 to Drums I & II is approximately 10 to 1.
All mountings on ball-bearings

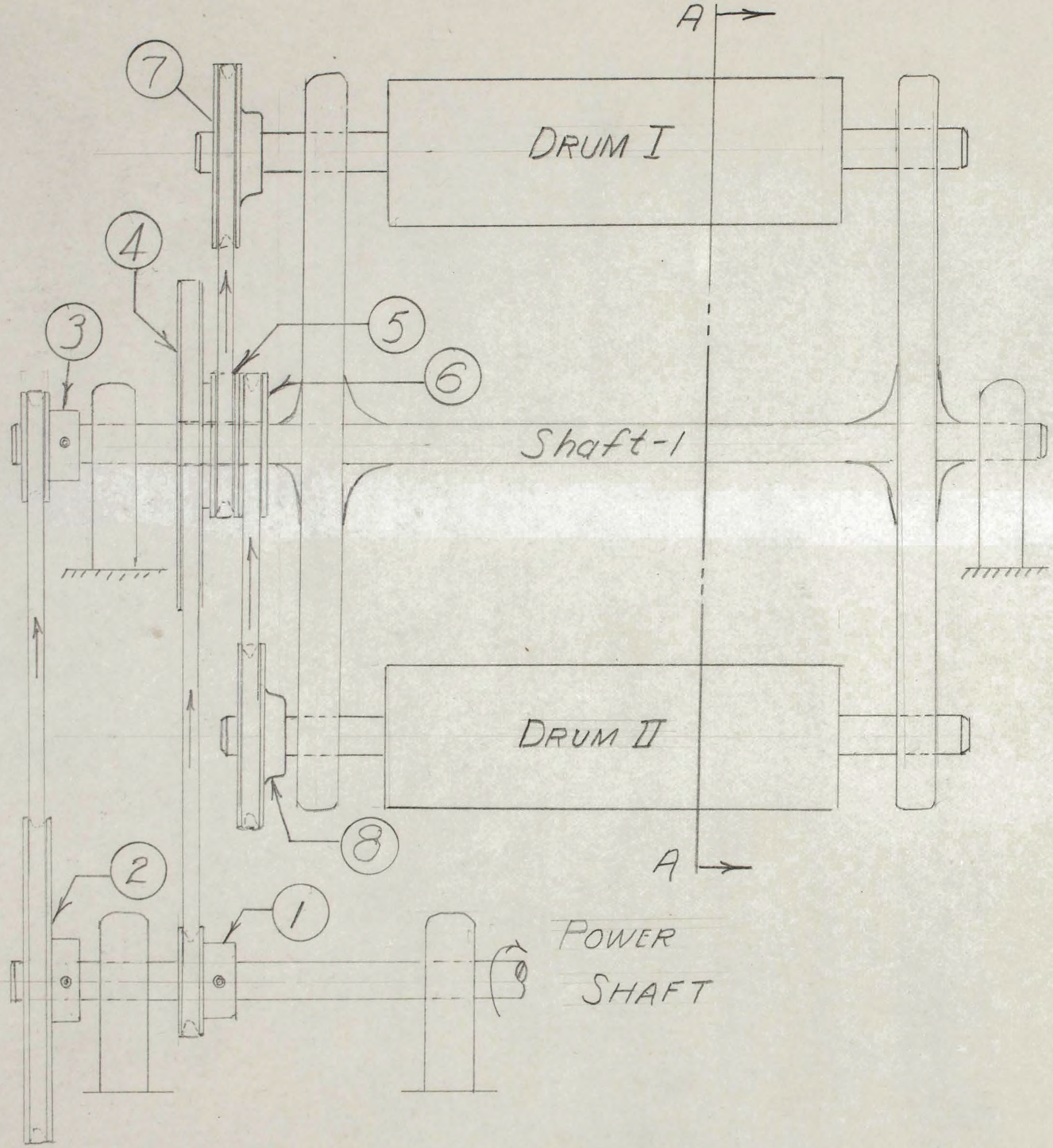
DENVER
APR
16
5 PM
19[illegible]
COLO

Leo Szilard
1155 E 57th Str.
Chicago 37 Ill

From L. Szilard
1155 E 57th Str.
Chicago 37 Ill


DRUM I
Shaft - I
DRUM II


DRUM I
Shaft - I
DRUM II



Pulleys 4, 5, & 6 are integral
Ratio dia. (1) to dia. (4) is 1:3
Ratio dia. (2) to dia. (3) is 3:1
Ratio dia. (5) to dia. (7) is 4:5
Ratio dia. (6) to dia. (8) is 4:5
(Tripple pulleys, 4, 5, & 6, floating on shaft-1)

Final speed ratio of shaft-1 to Drums I & II is approximately 10 to 1.
All mountings on ball-bearings

Fig. 8

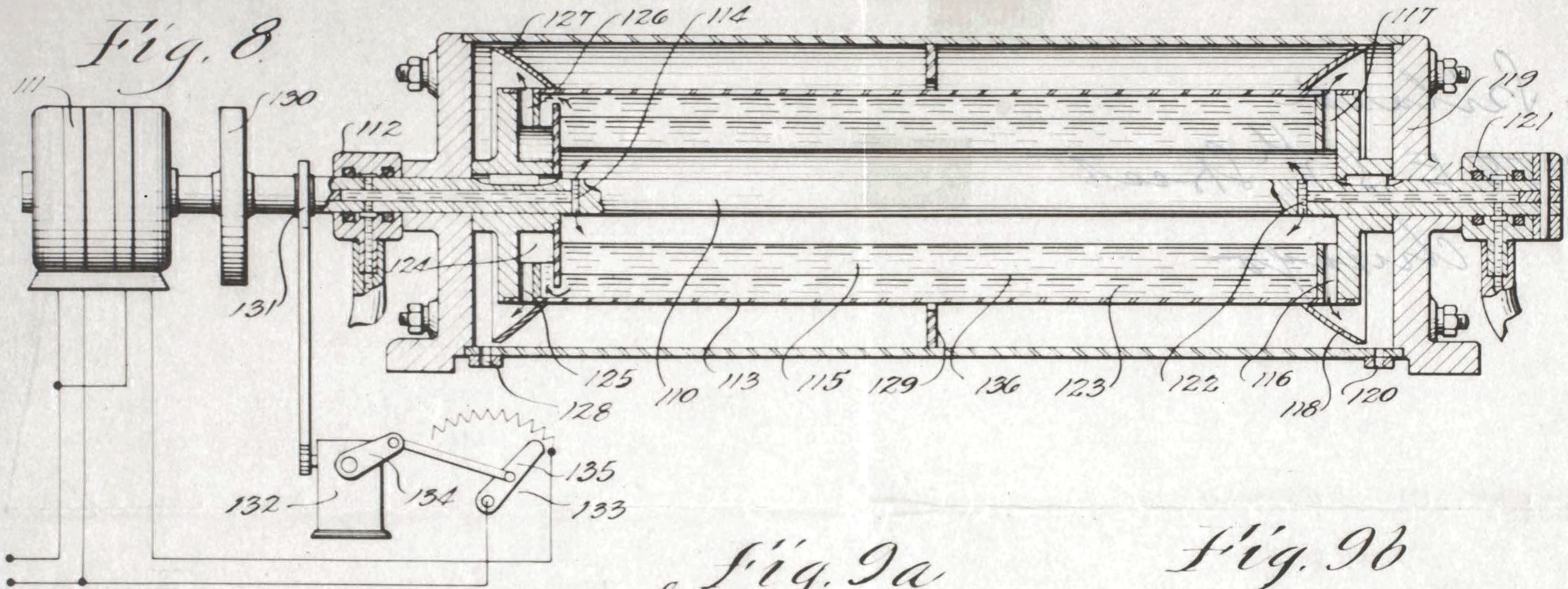


Fig. 9a

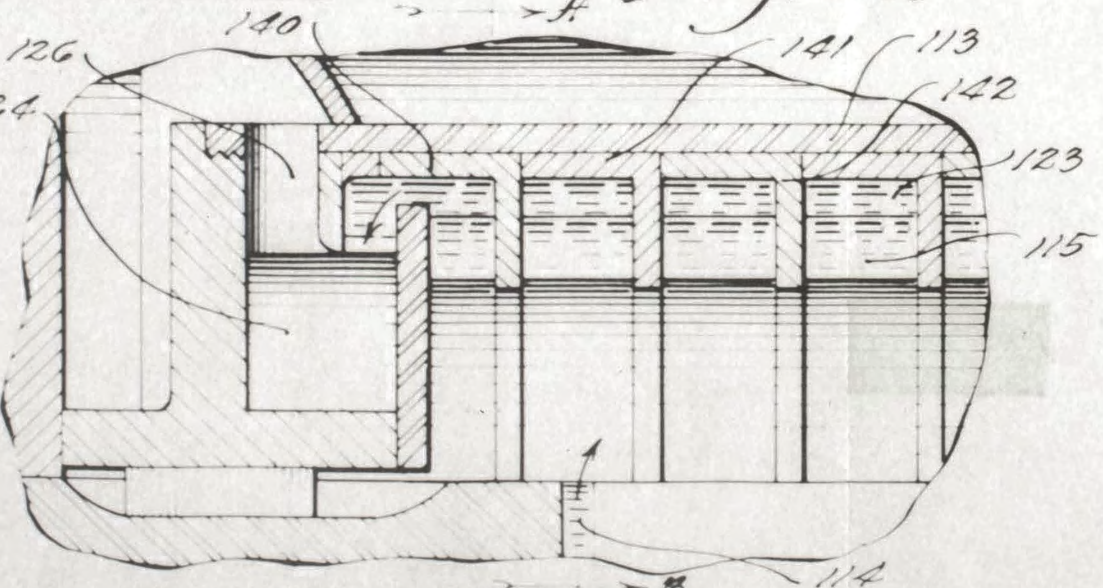
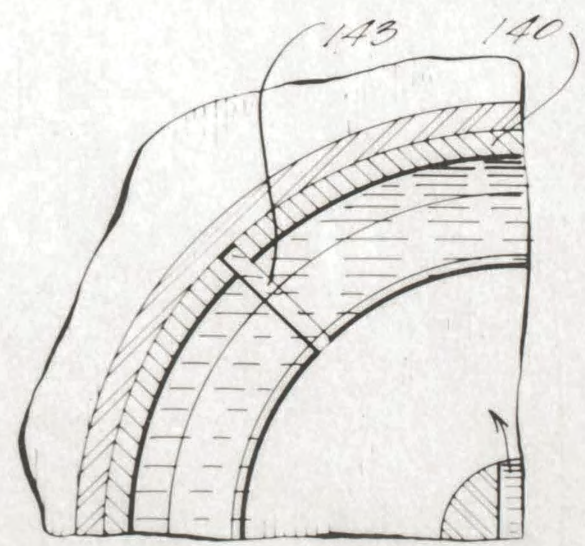


Fig. 9b



Inventor
Attorney

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Chicago

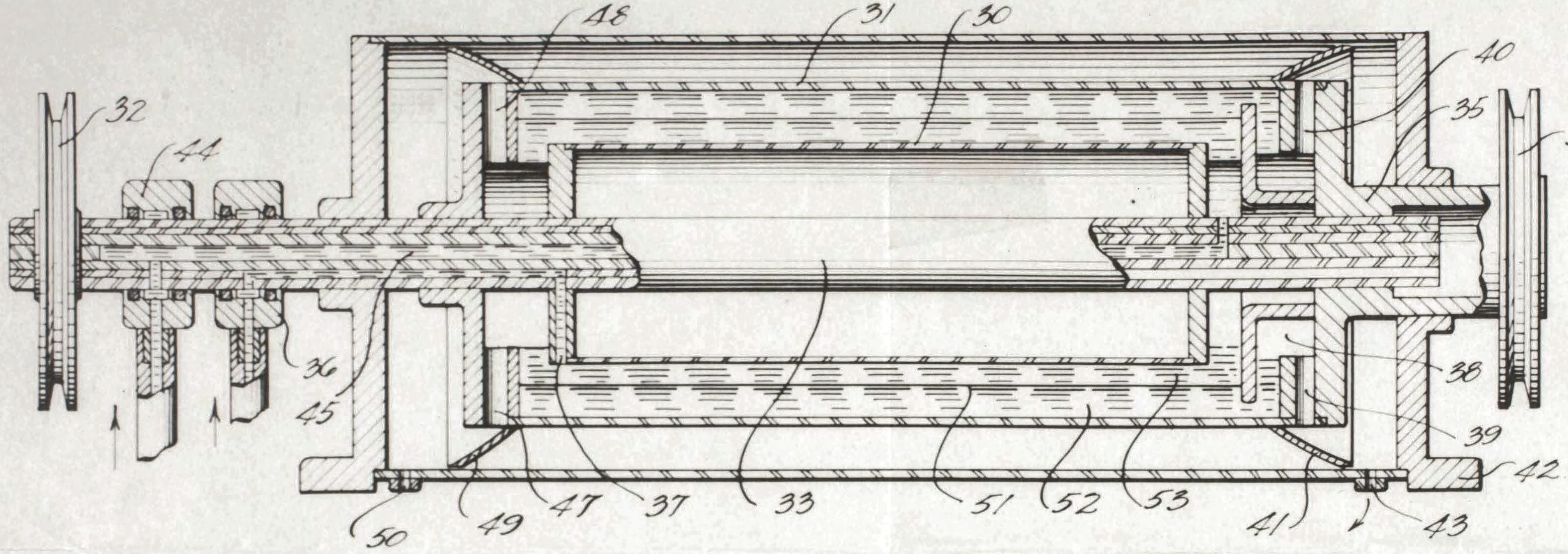
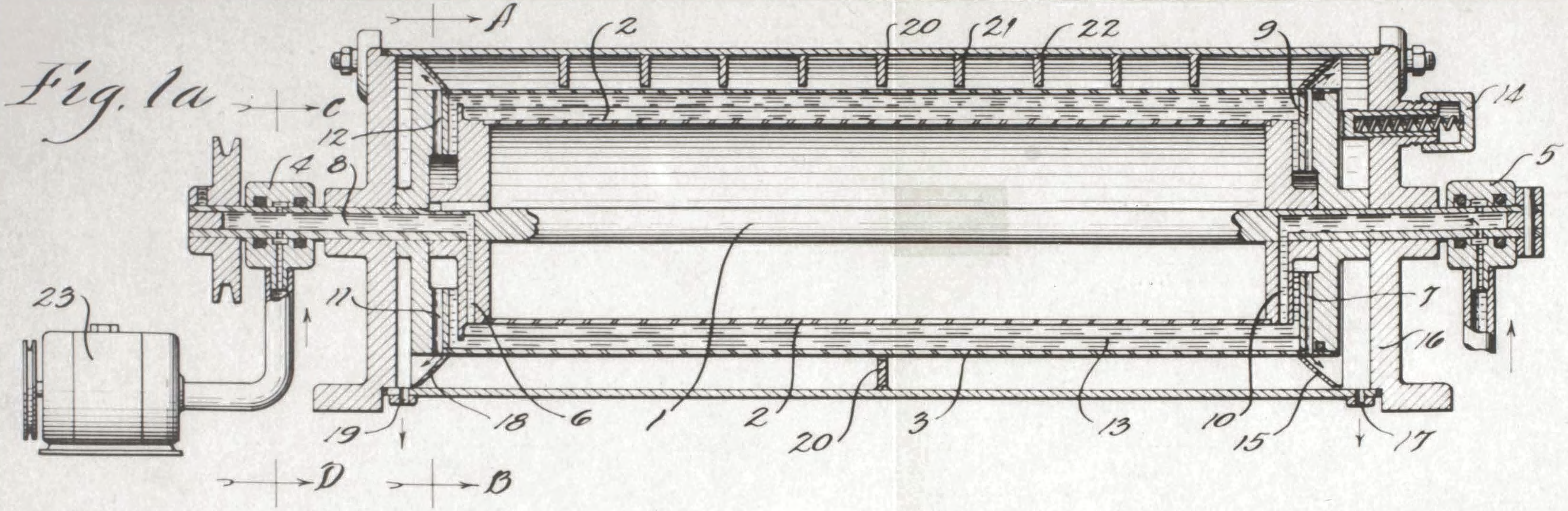


Fig. 2

Inventor

Attorney

Fig. 1a



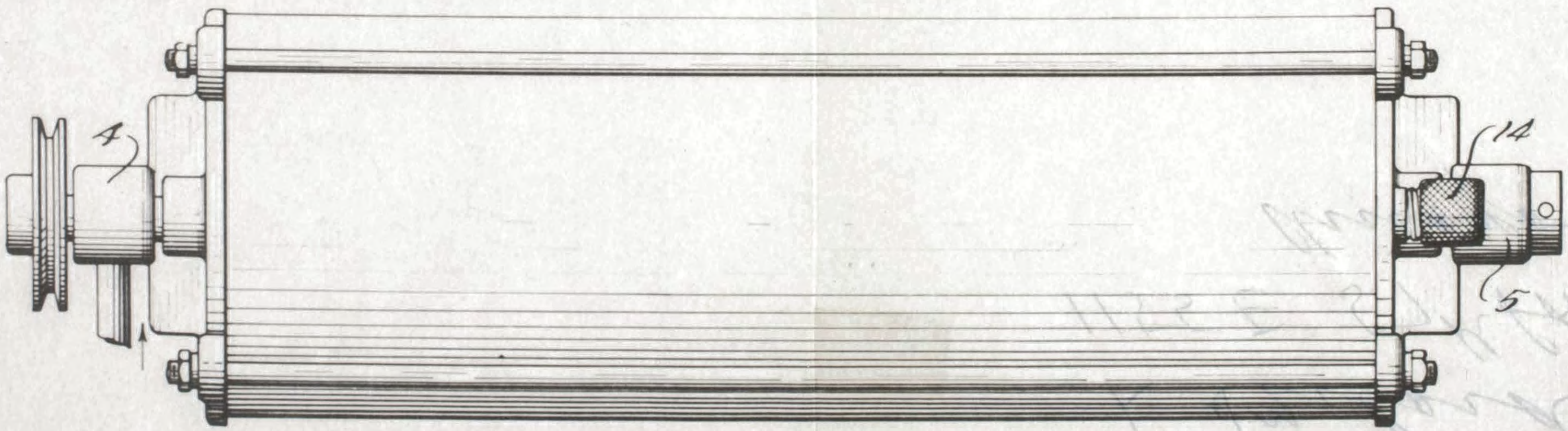


Fig. 1b

Inventor

Attorney

Fig. 3

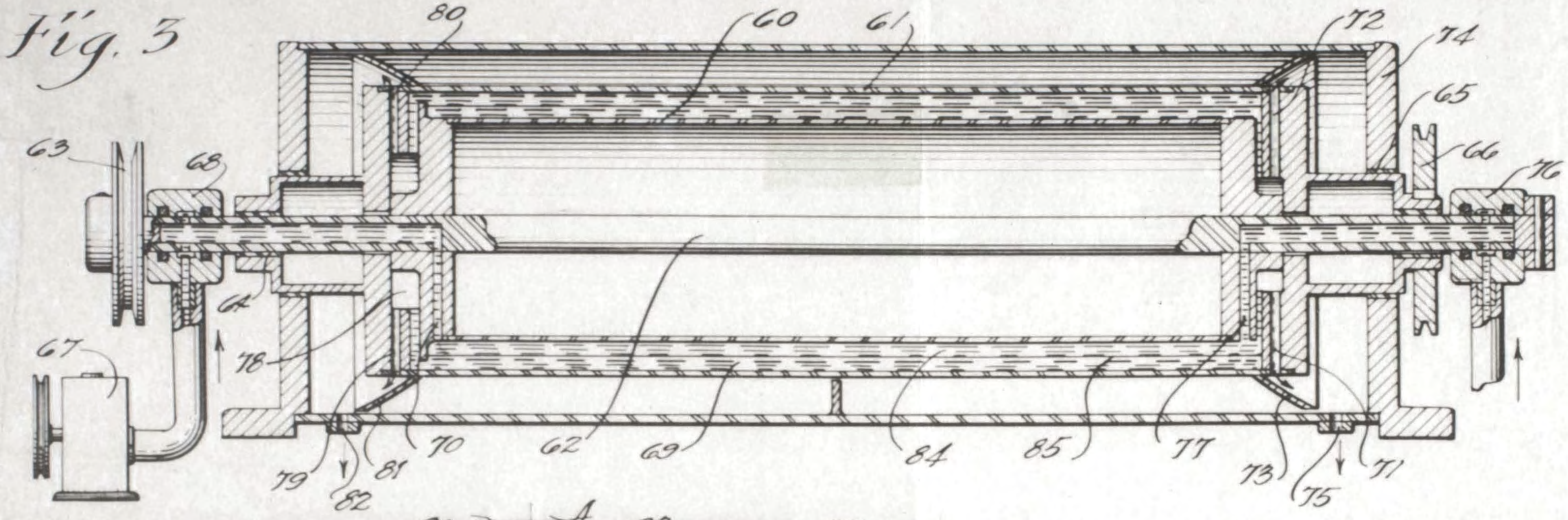


Fig. 4a

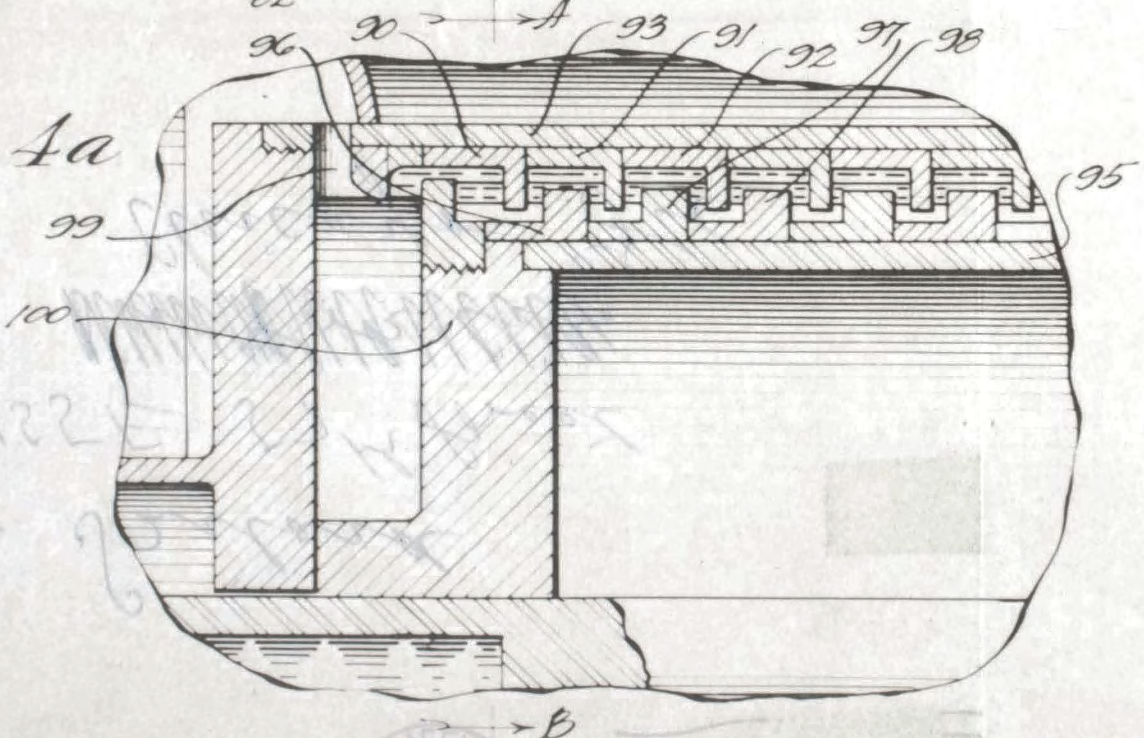
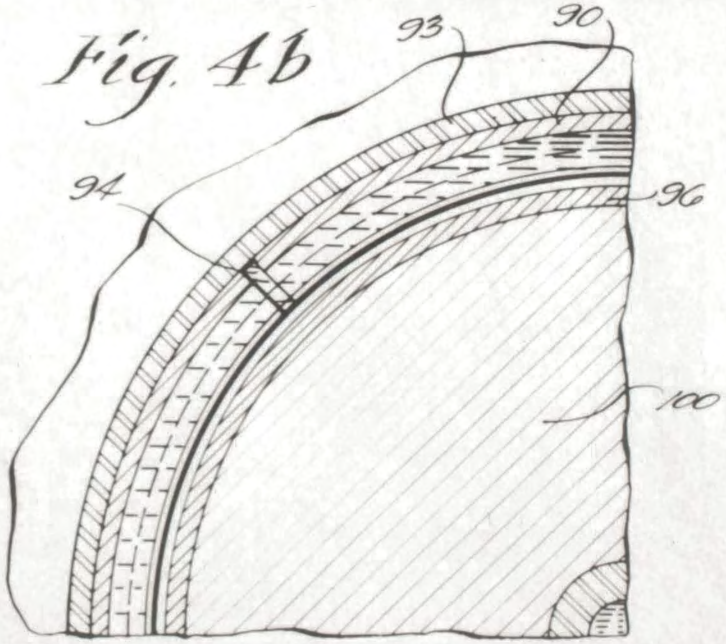


Fig. 4b



Inventor

Attorney

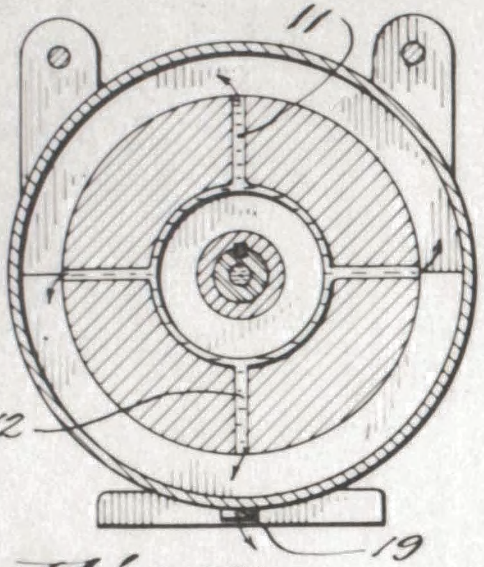


Fig. 5

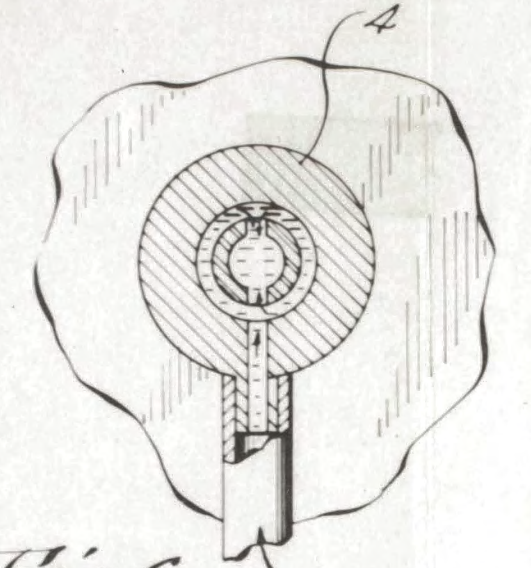


Fig. 6

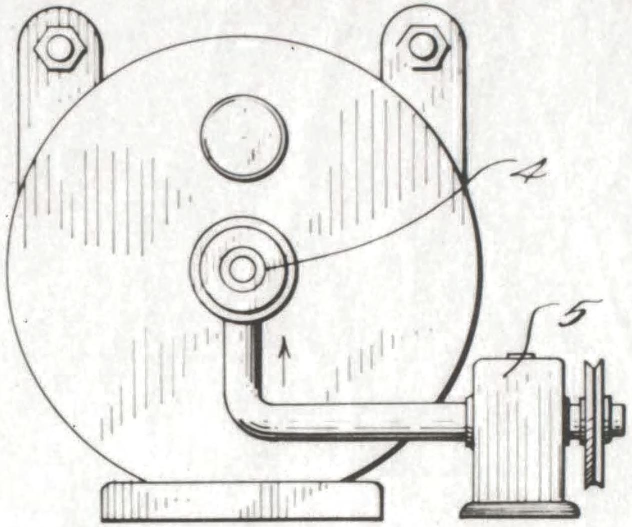
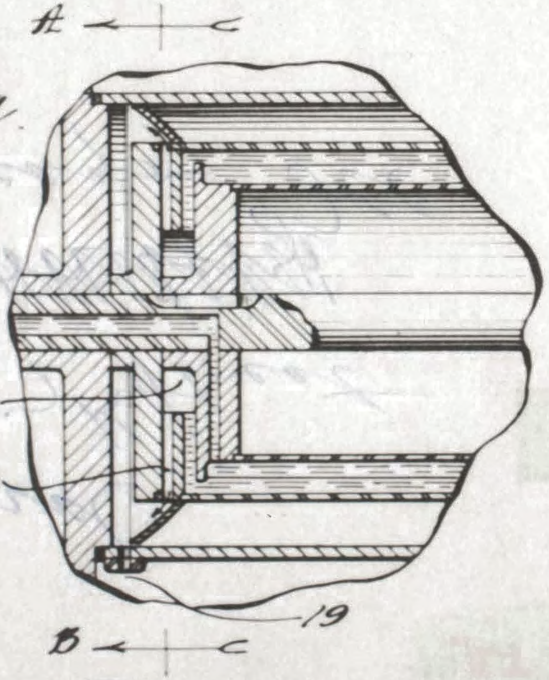


Fig. 10

Fig. 7a



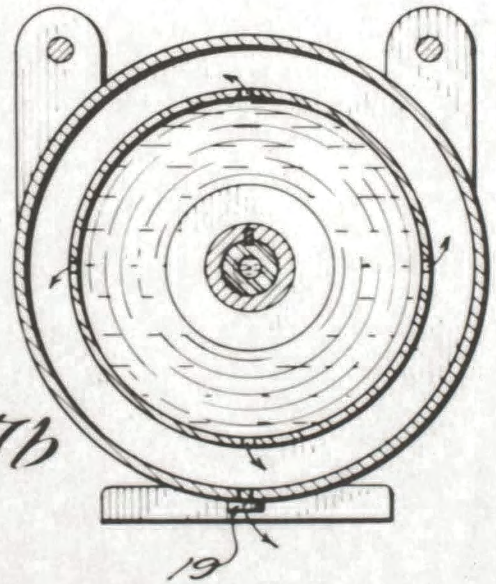


Fig. 7b

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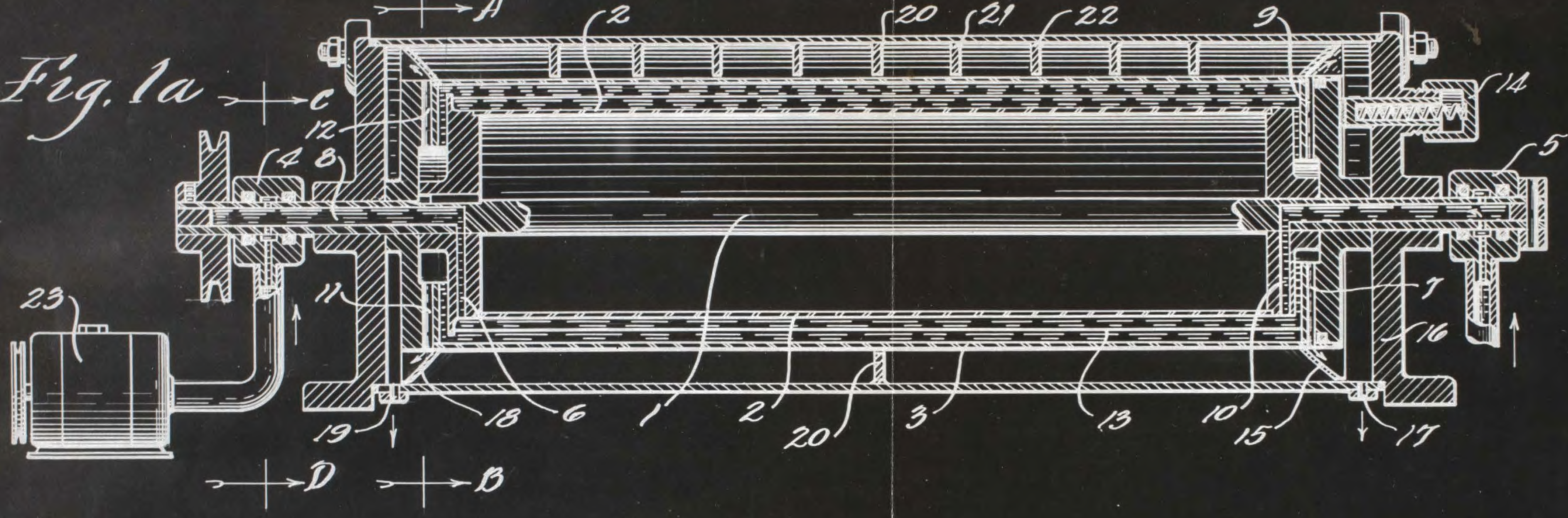
Fig. 1a



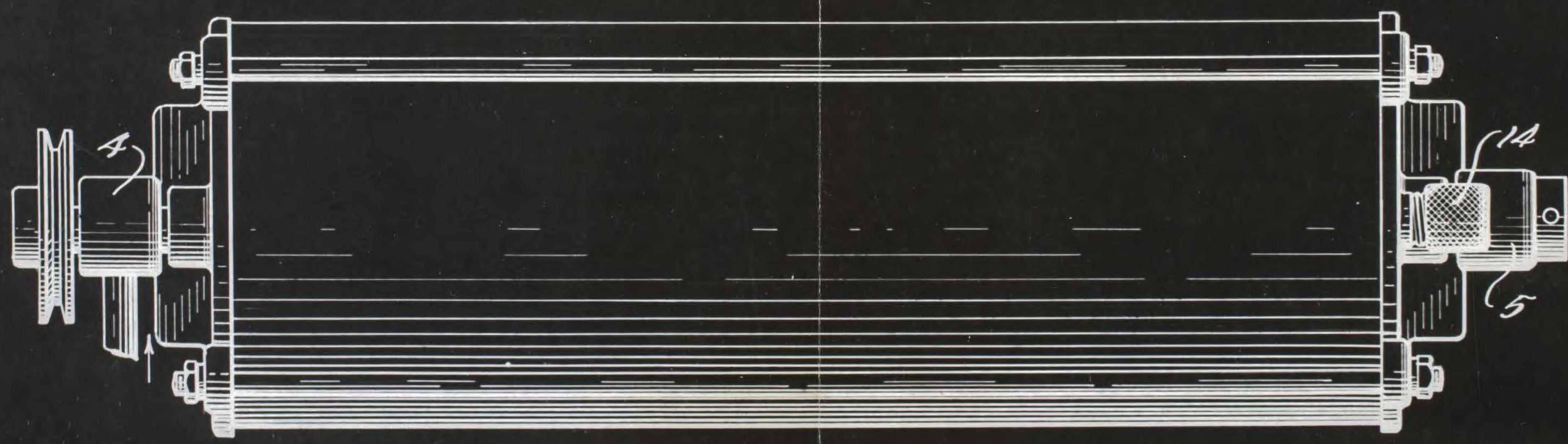


Fig. 1b

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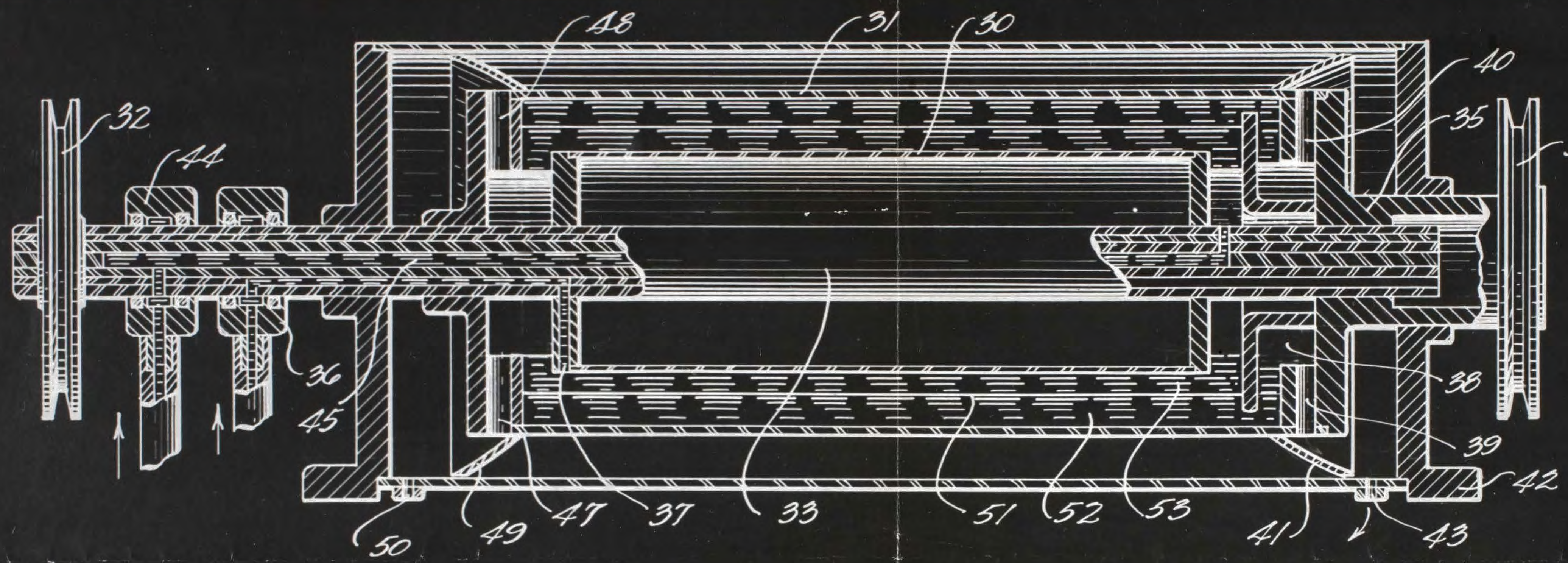

Fig. 2

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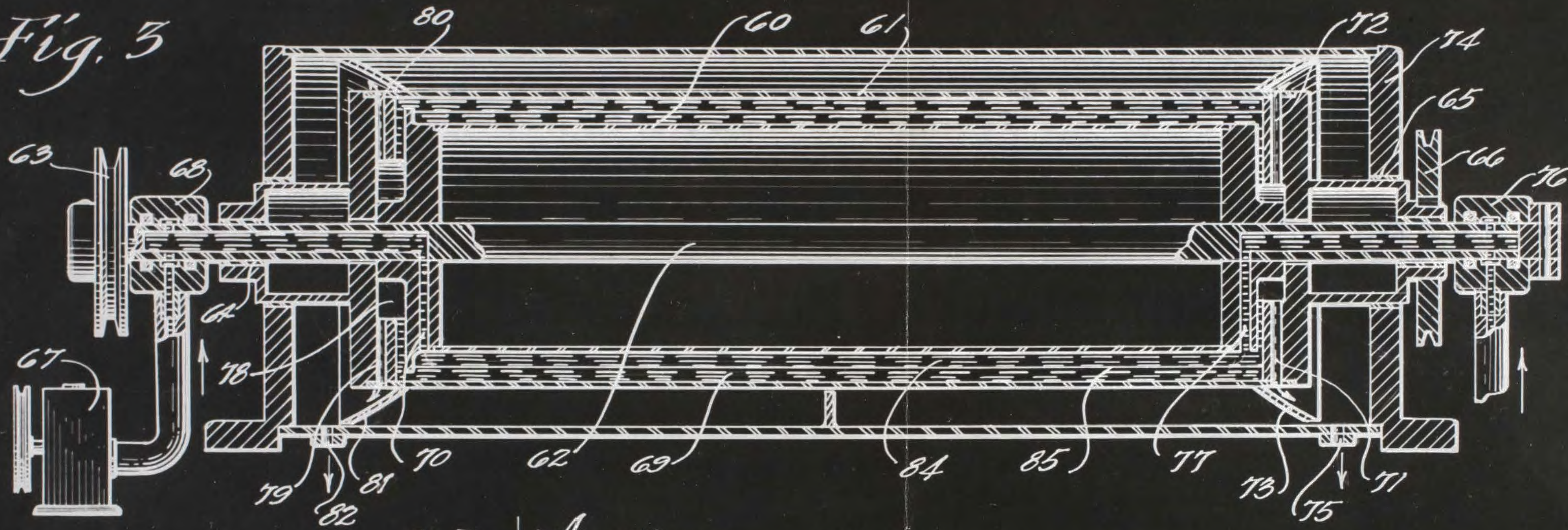
Fig. 3



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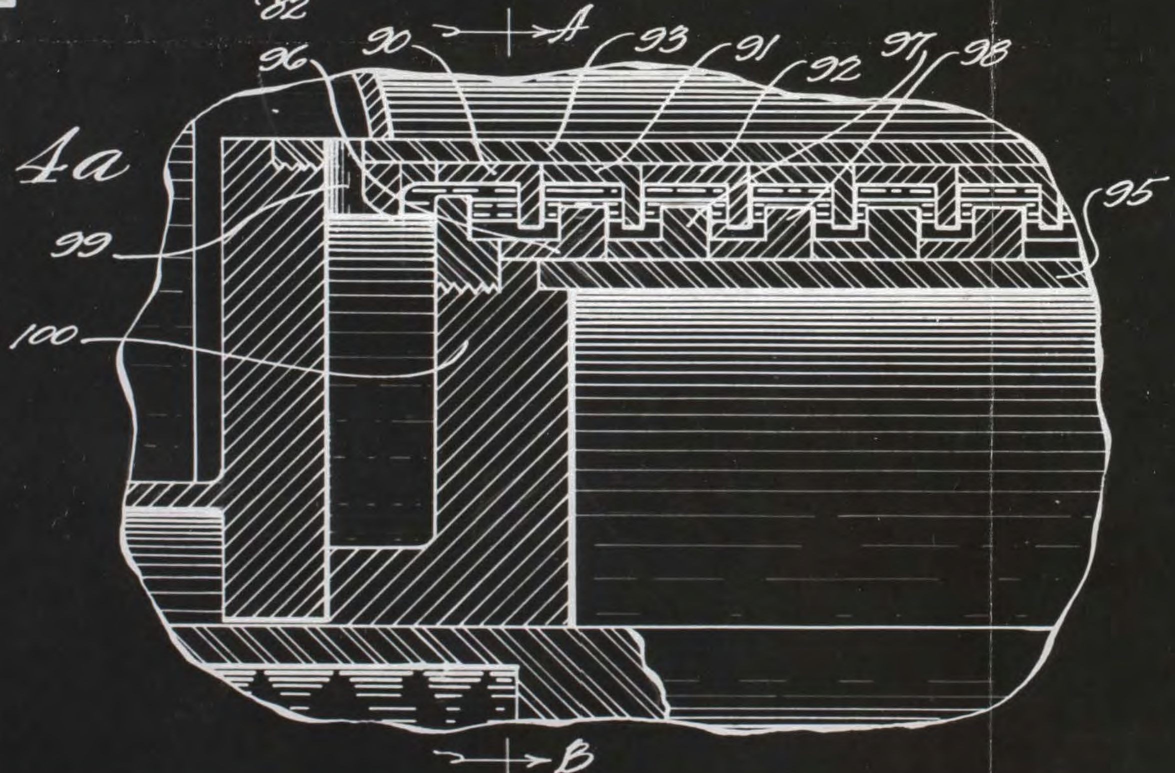

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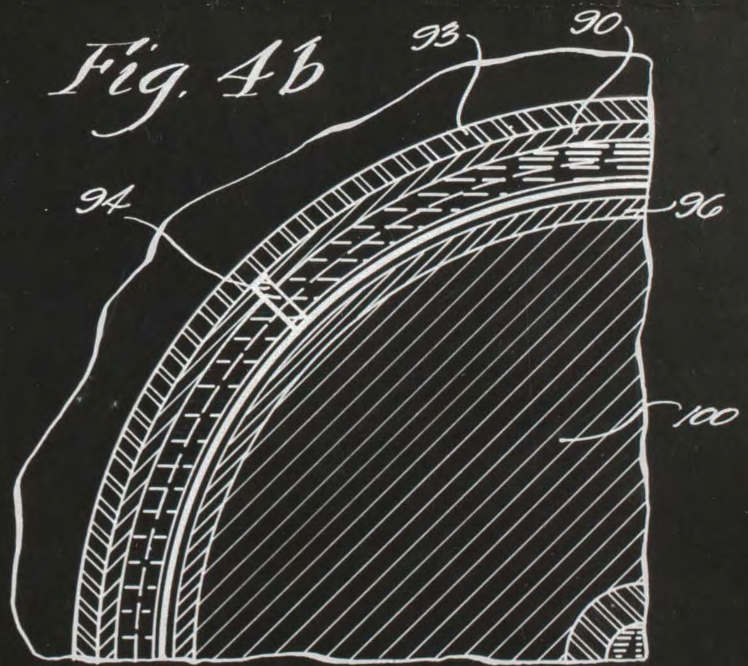

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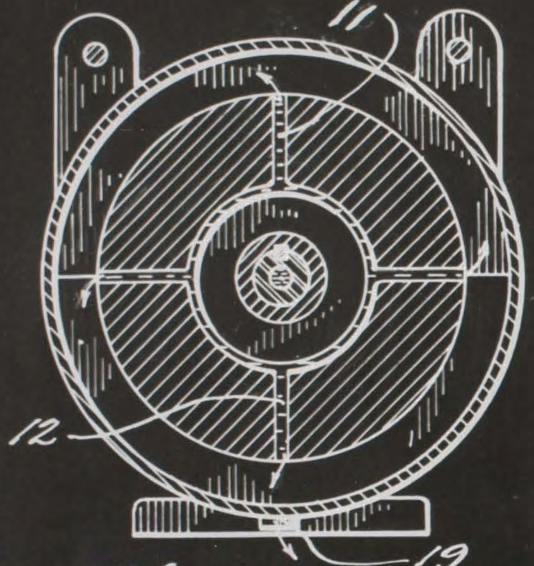

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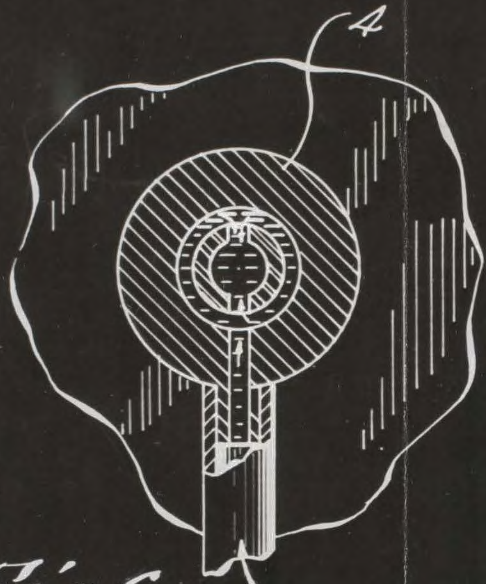

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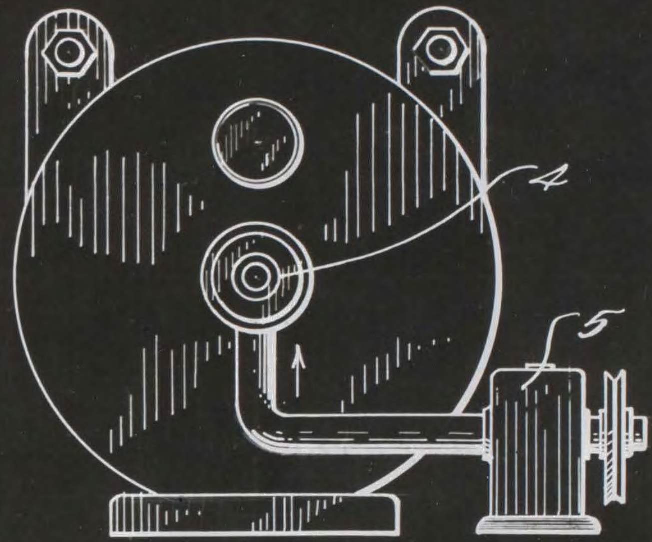
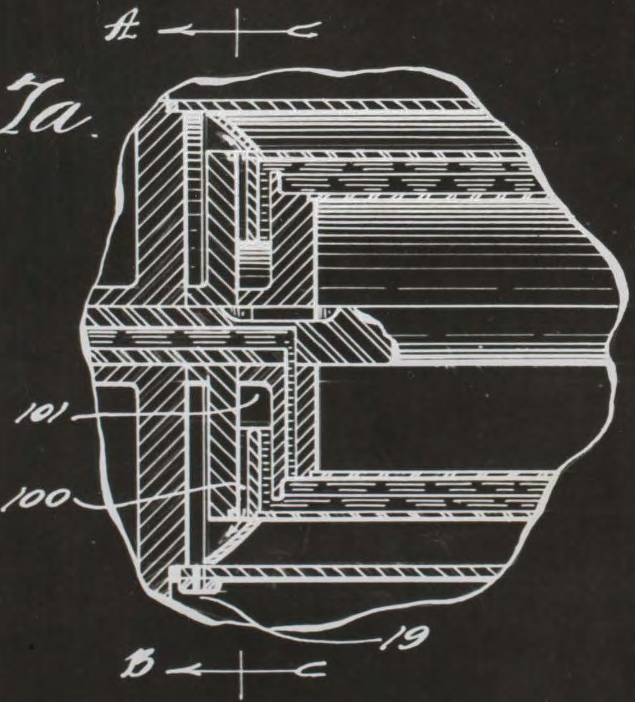


Fig. 10

Fig. 7a.



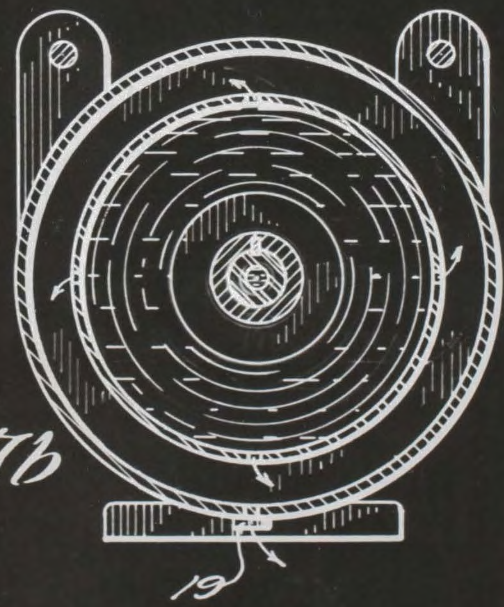


Fig. 7b

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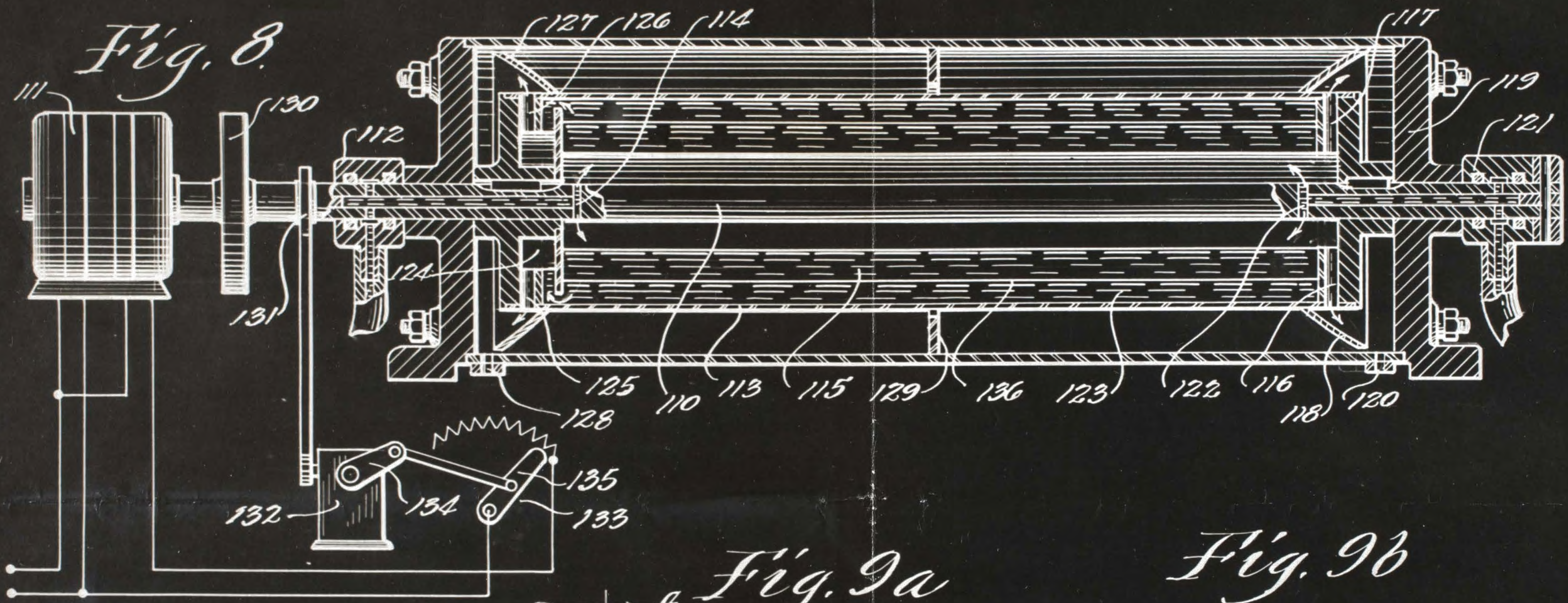
Attorney

Fig. 8.



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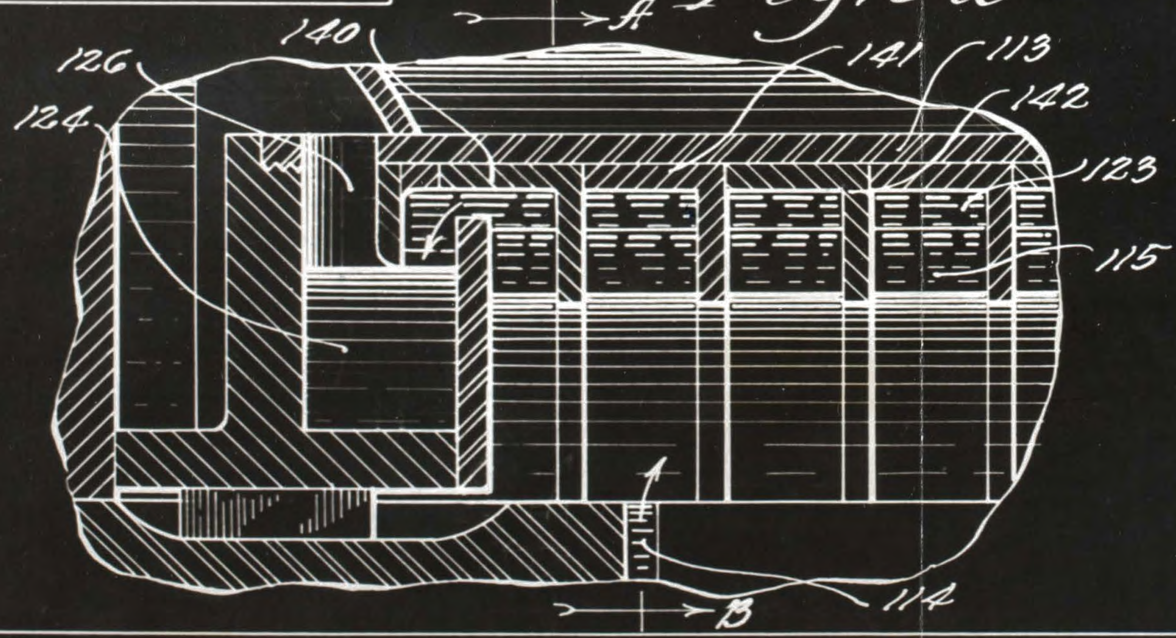

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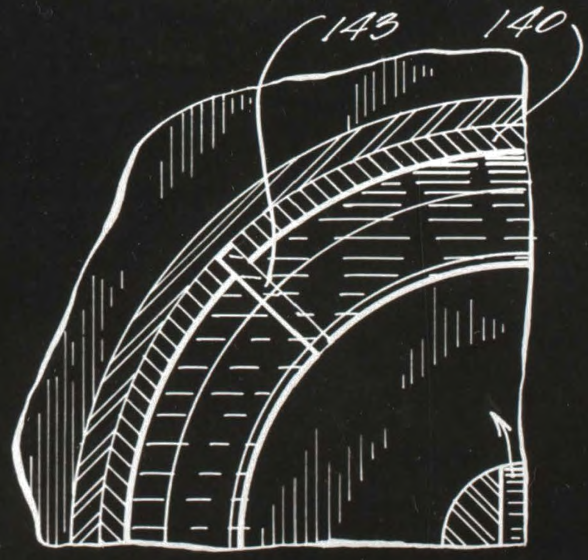

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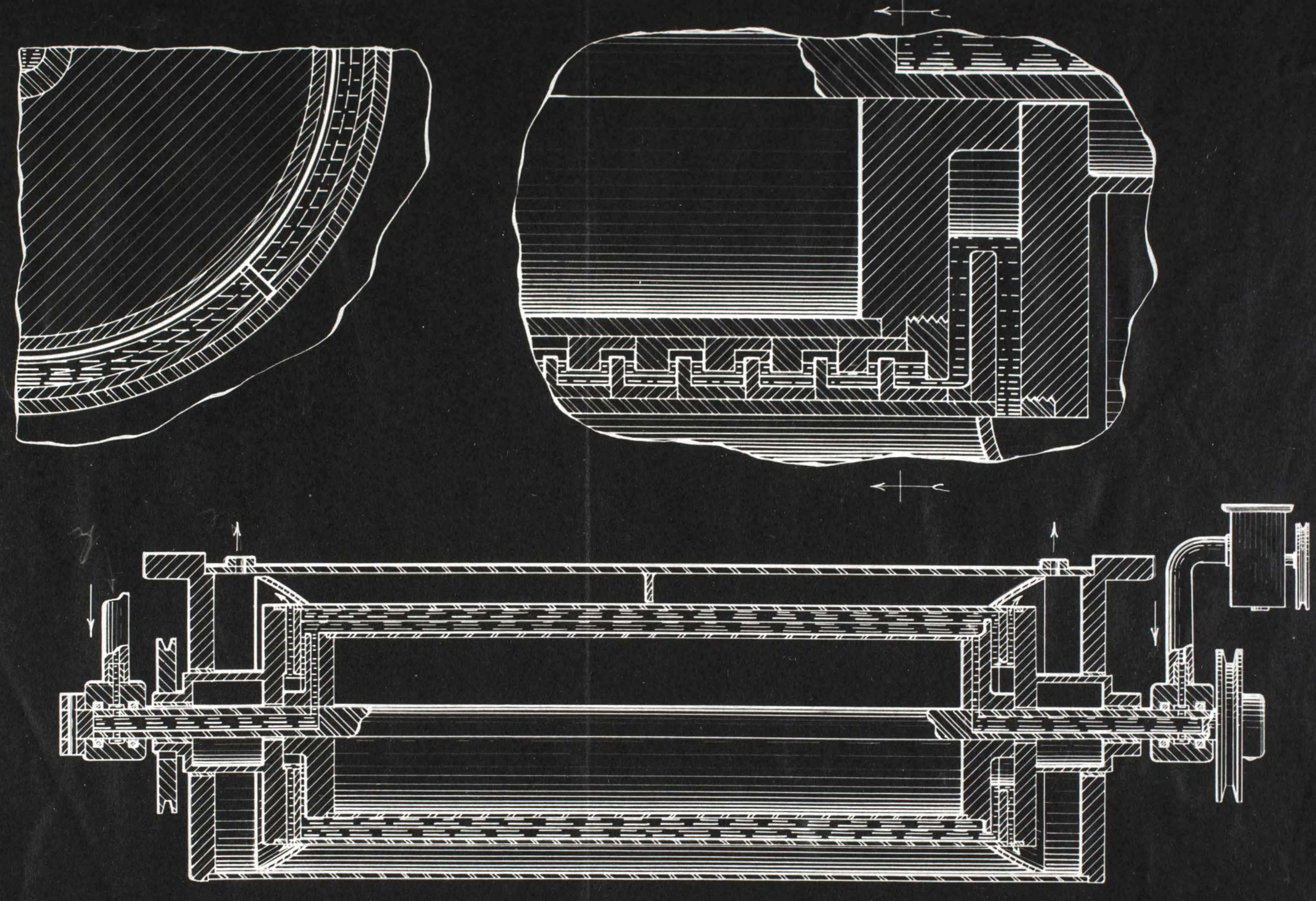

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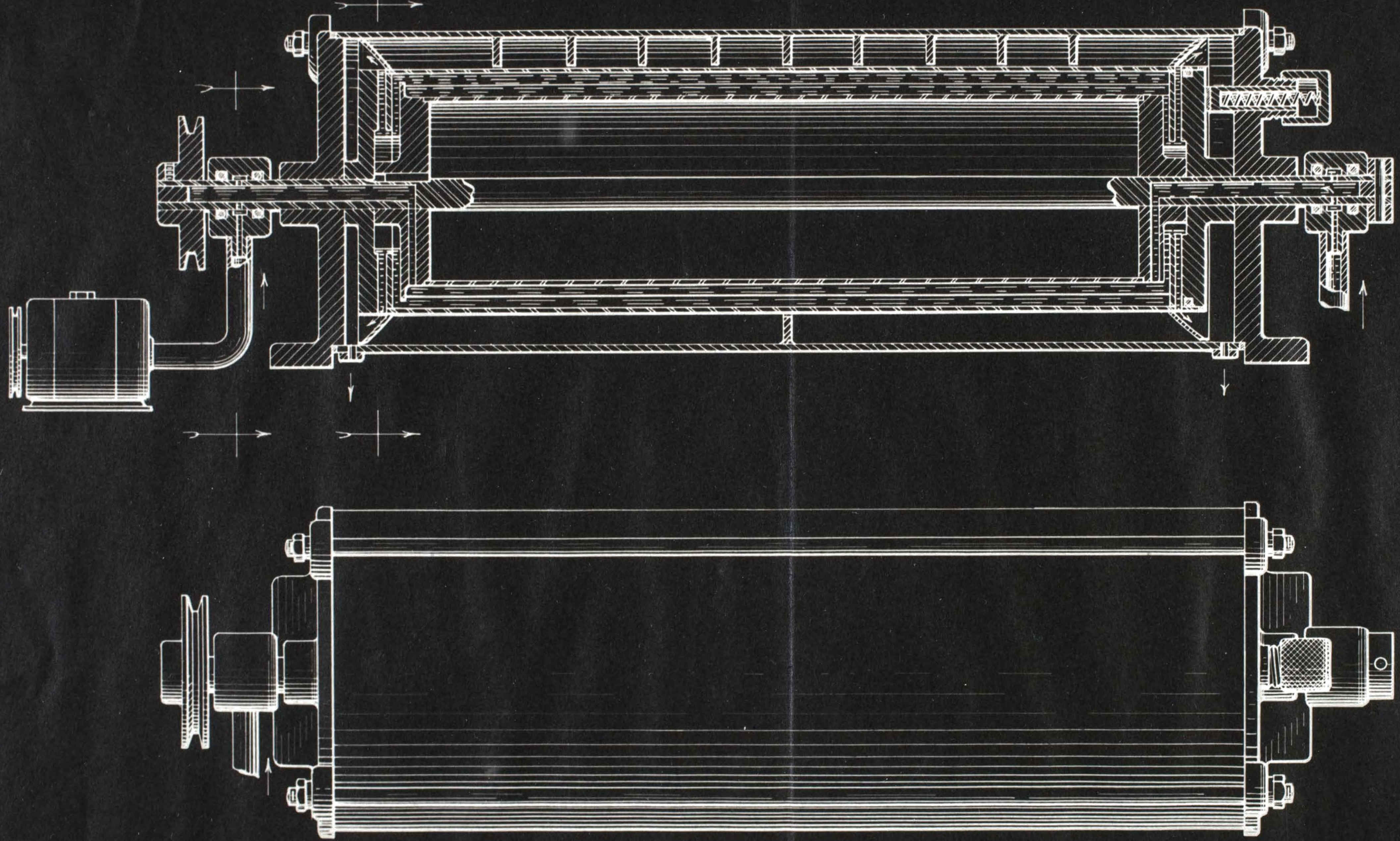

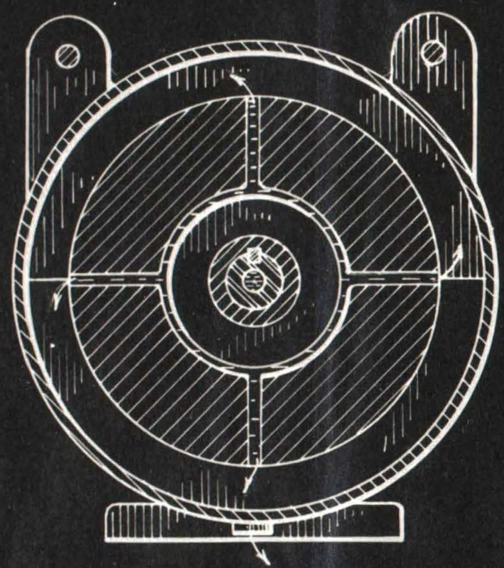

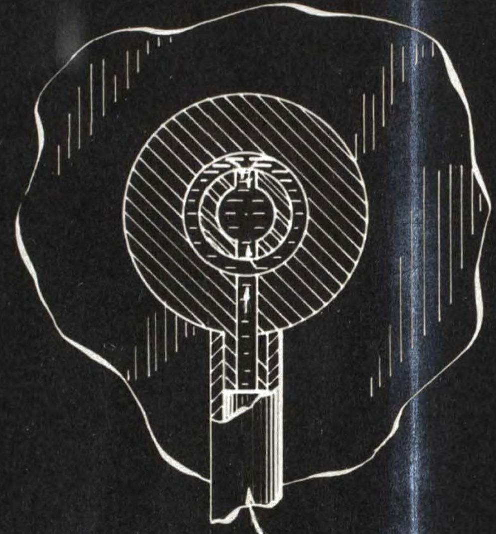

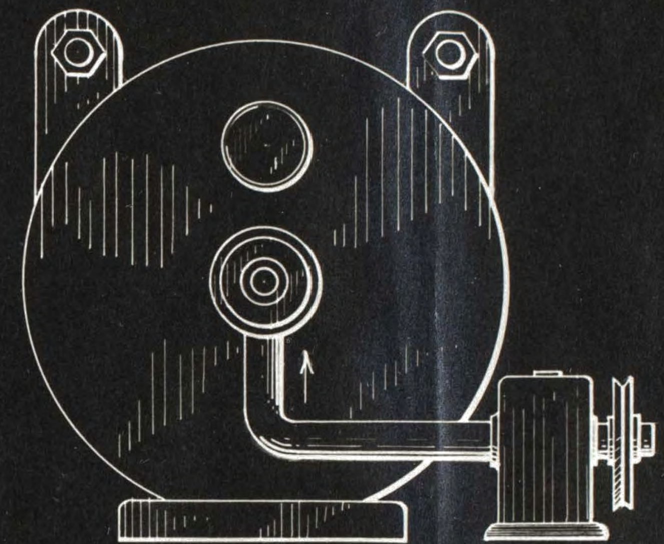

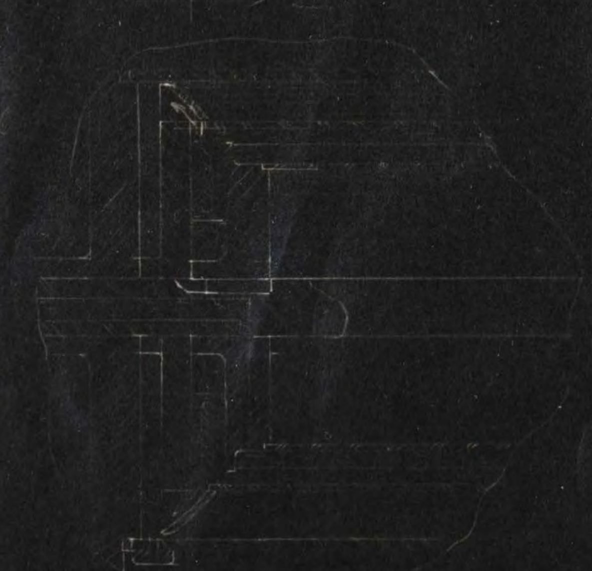

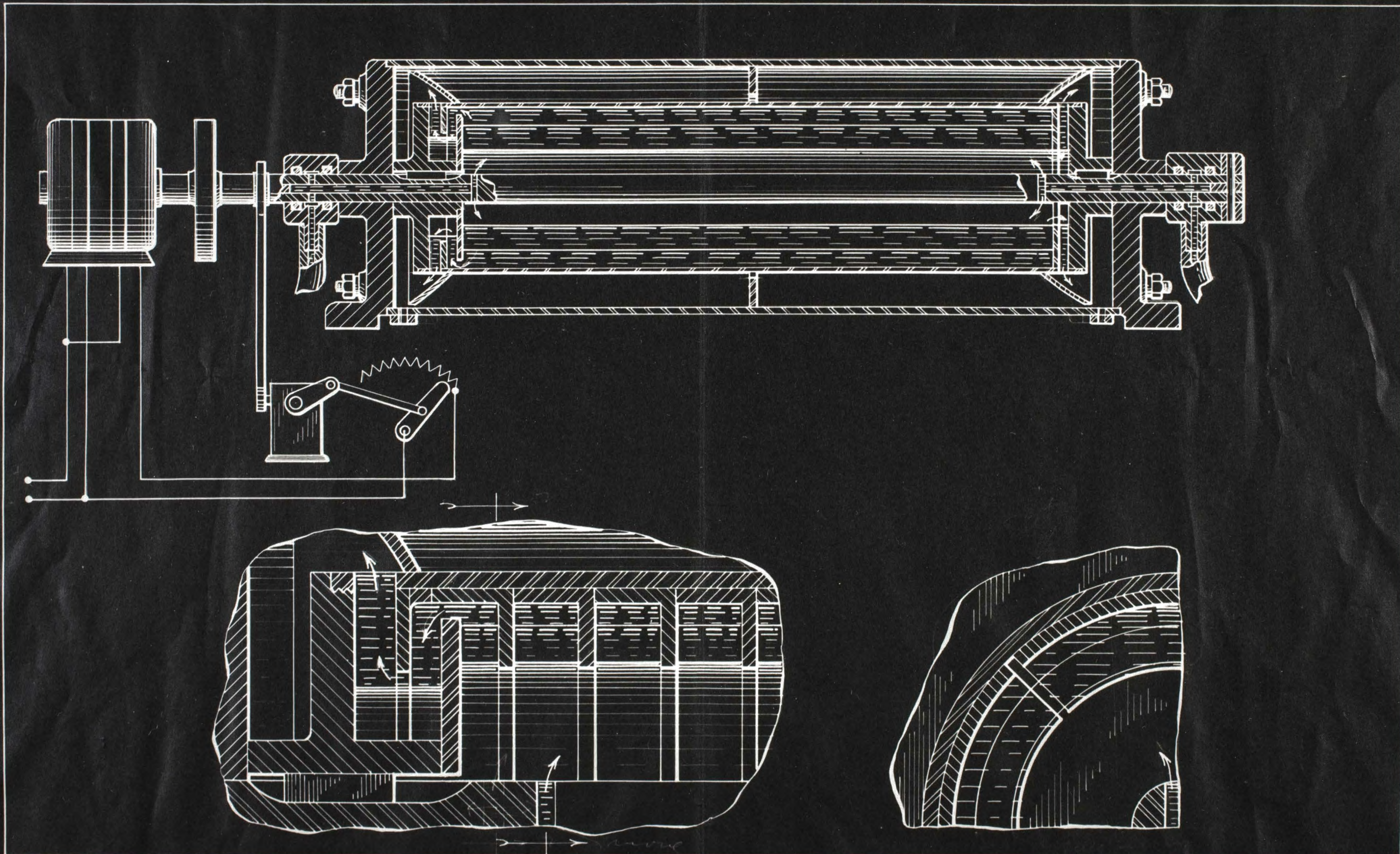

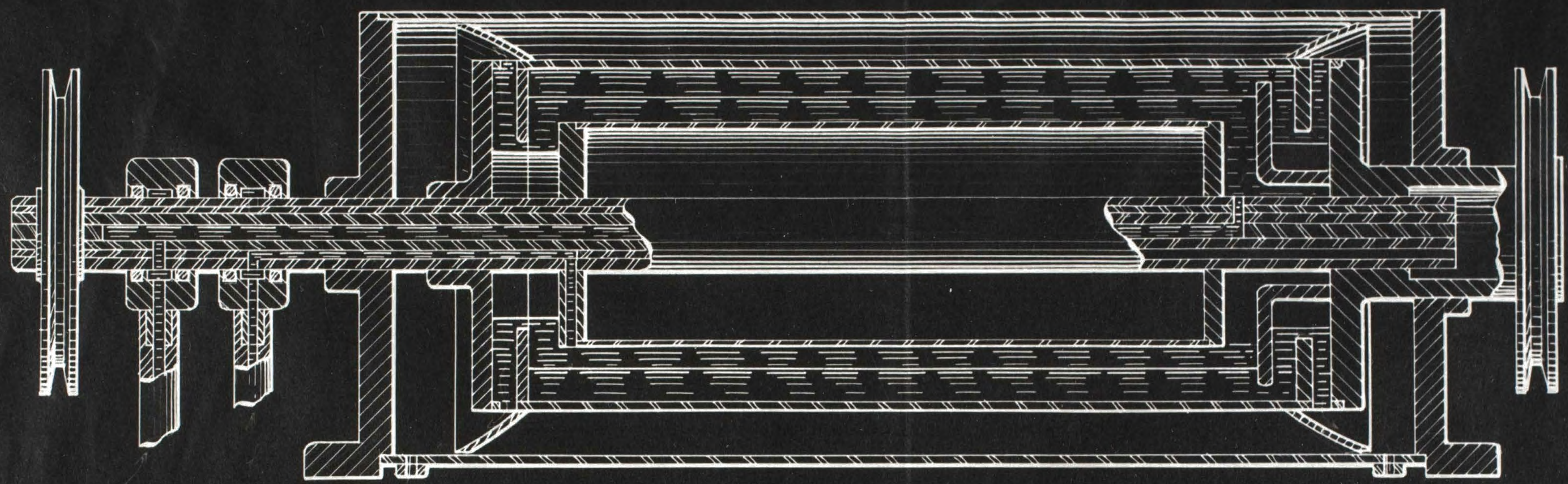

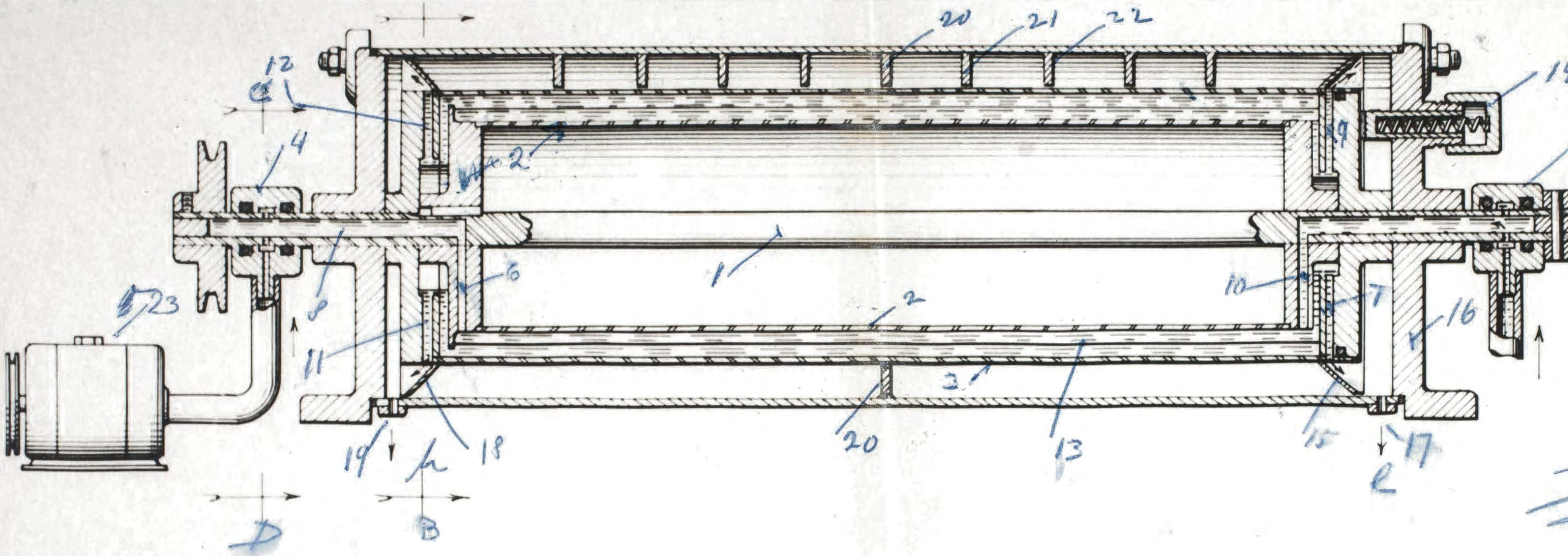

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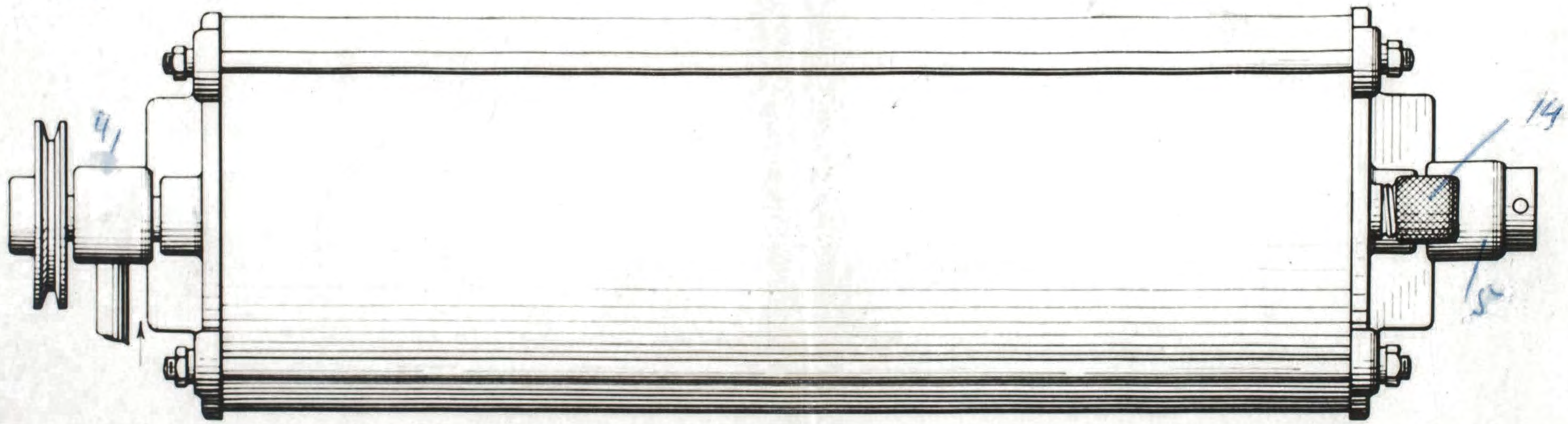

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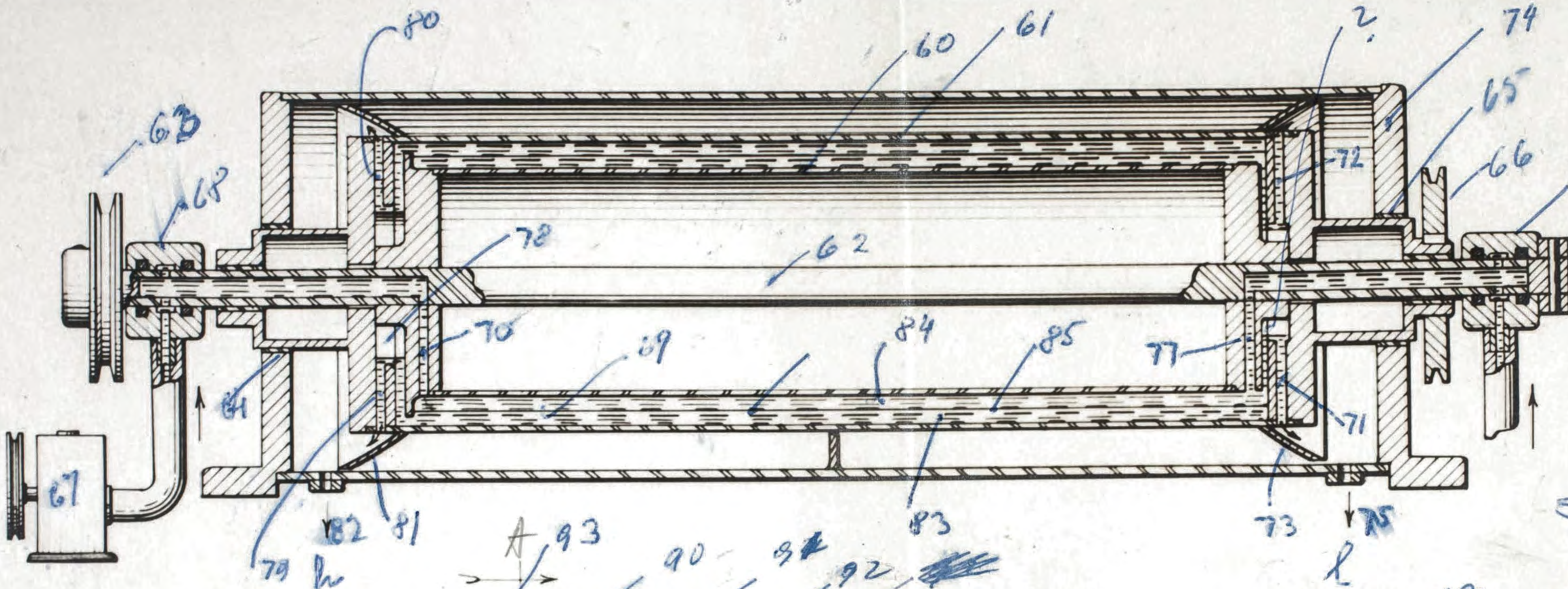

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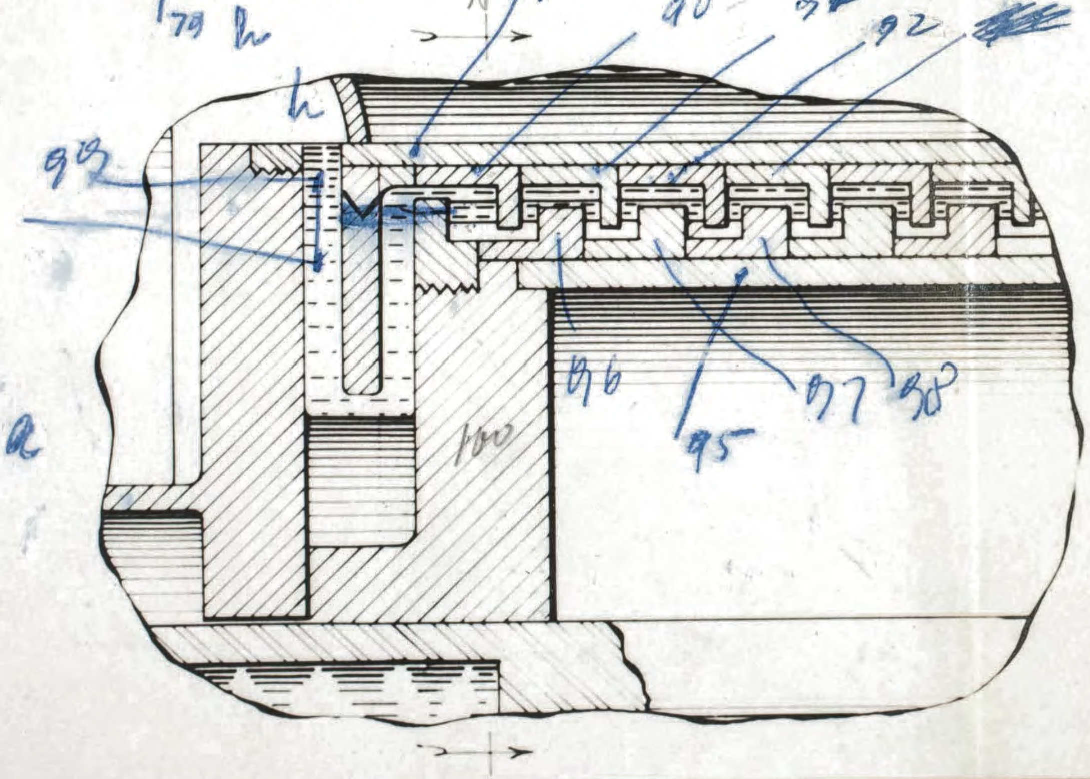

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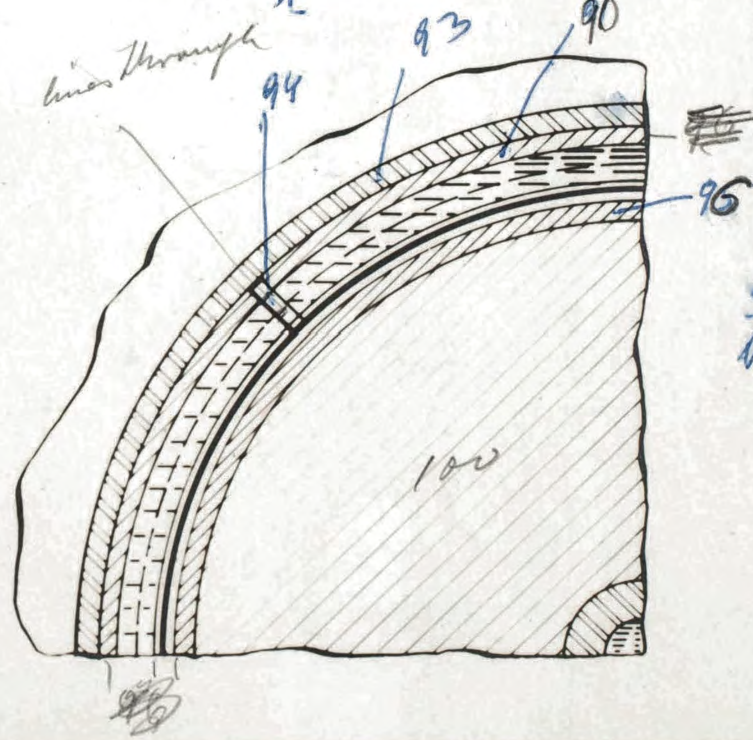

Fig 6

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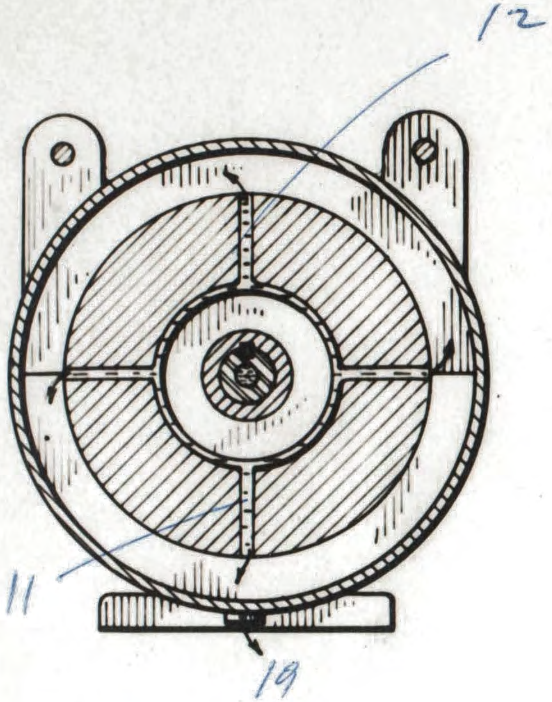

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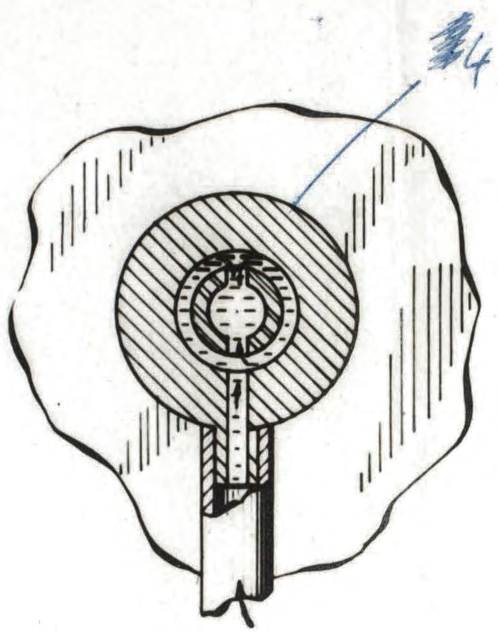

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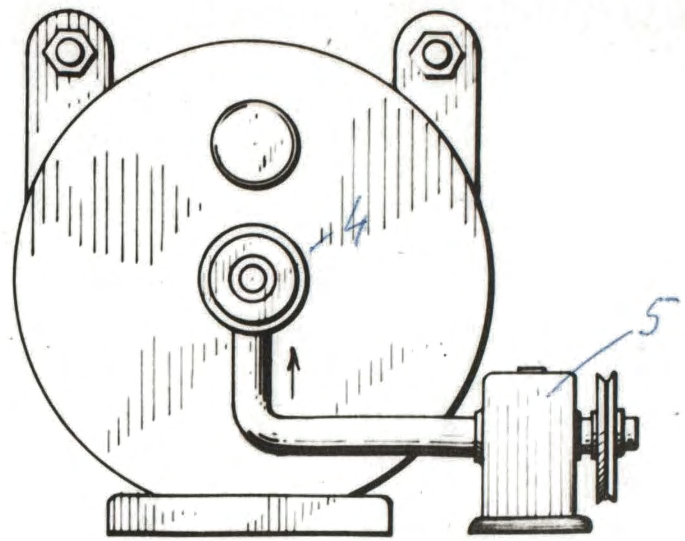

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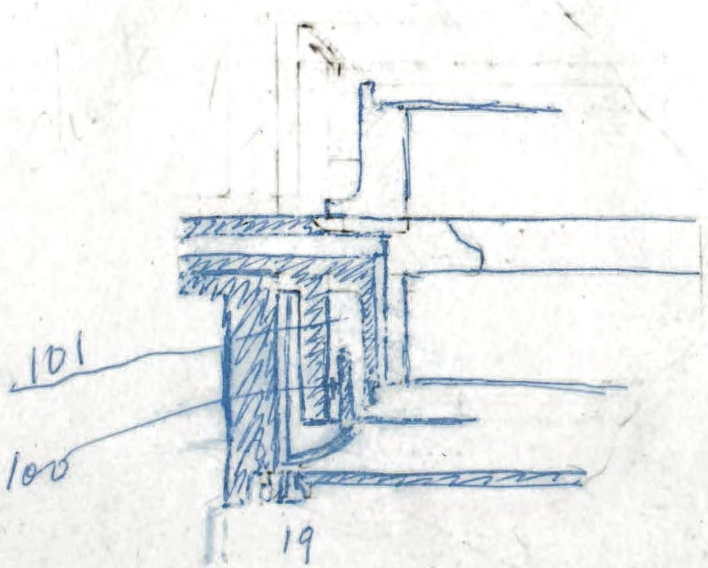

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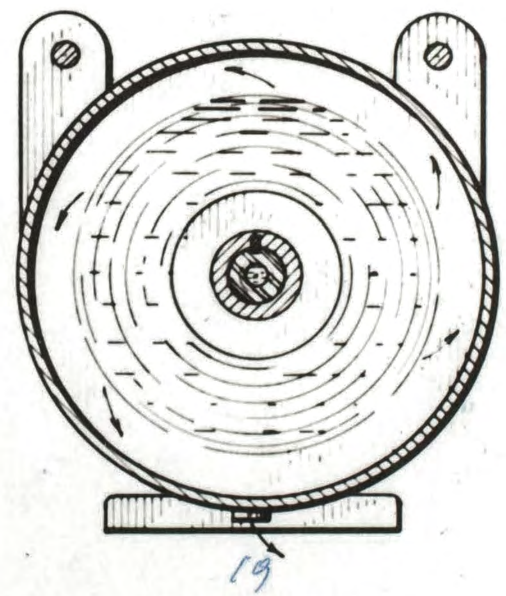

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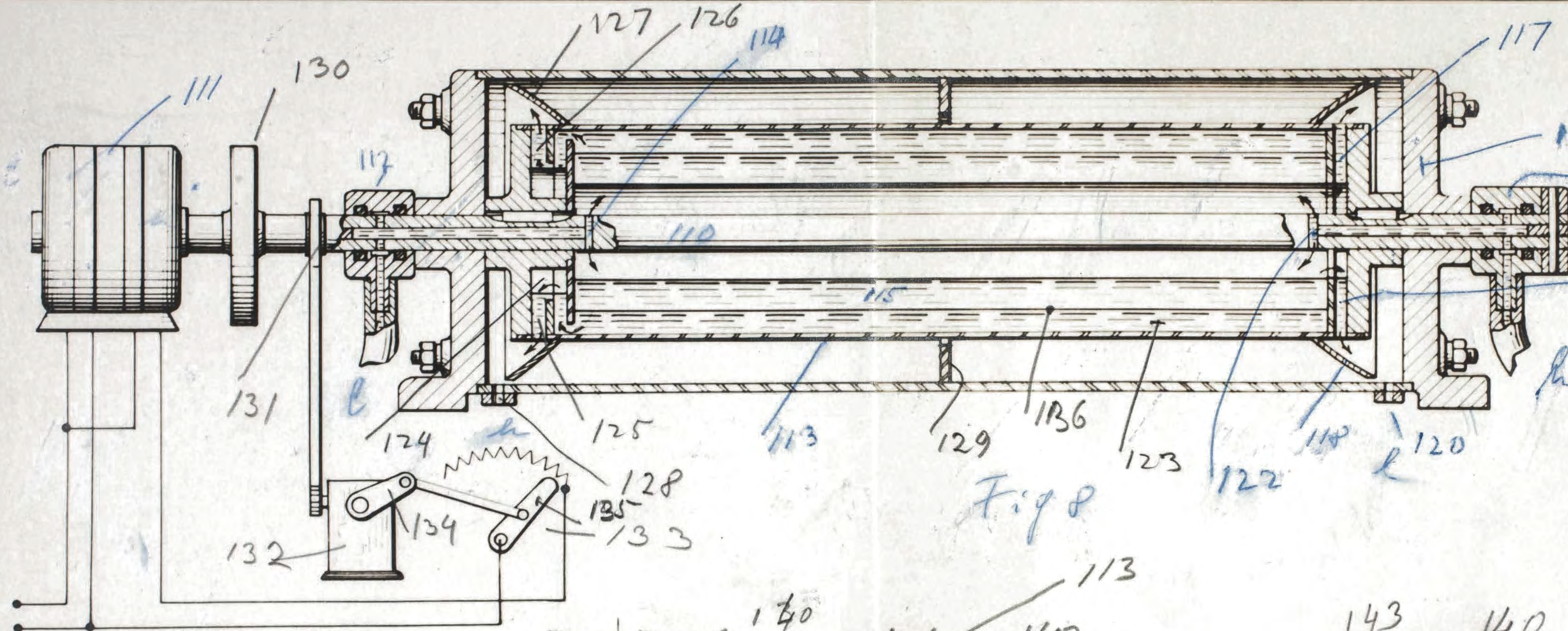

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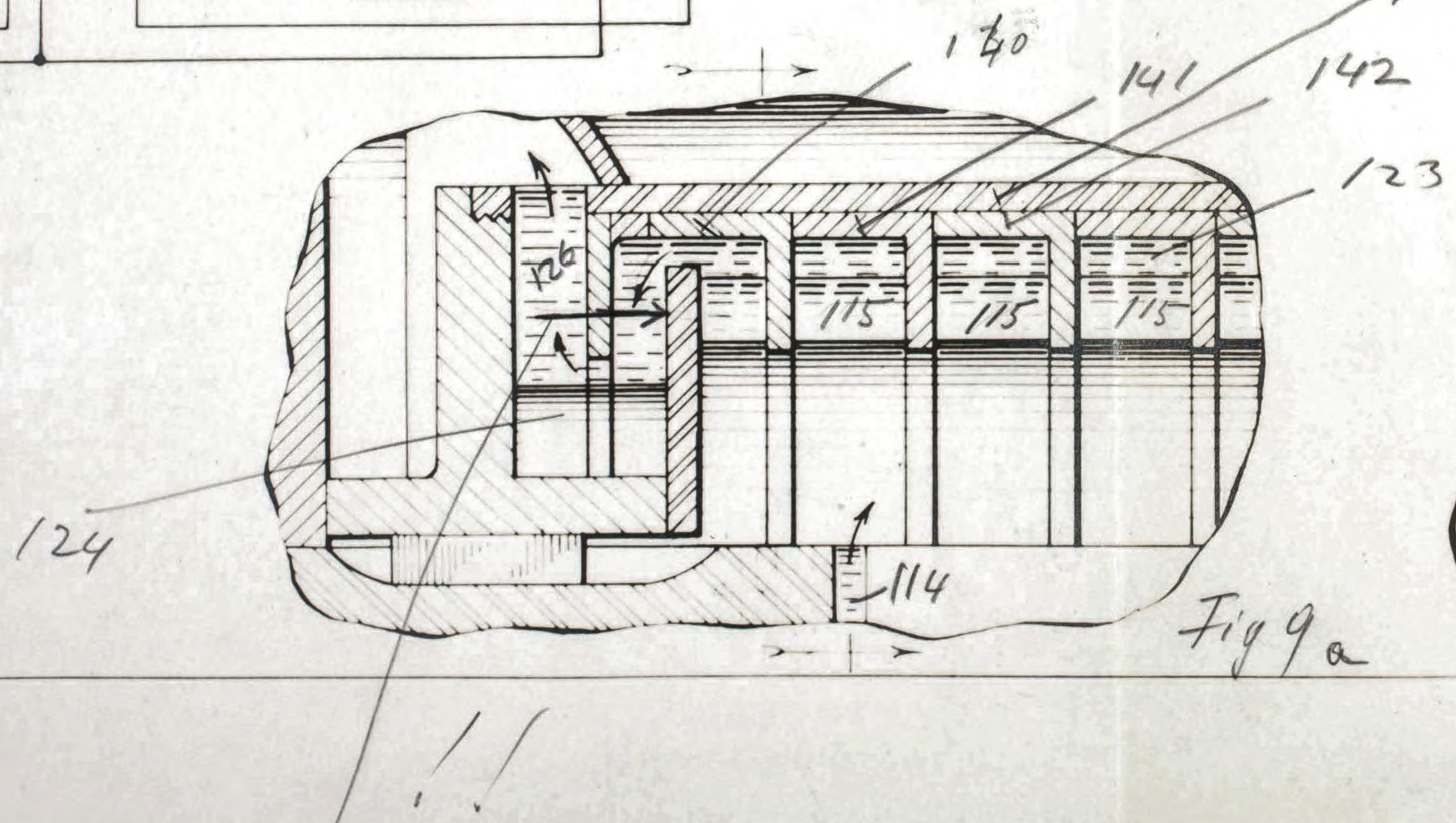

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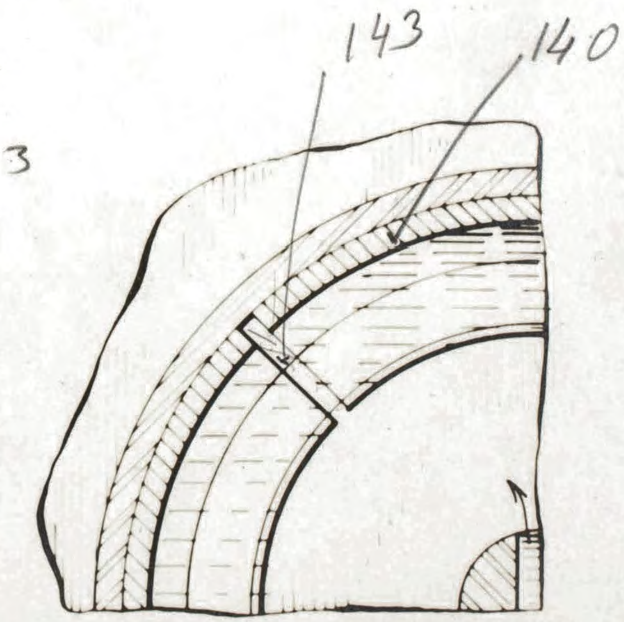

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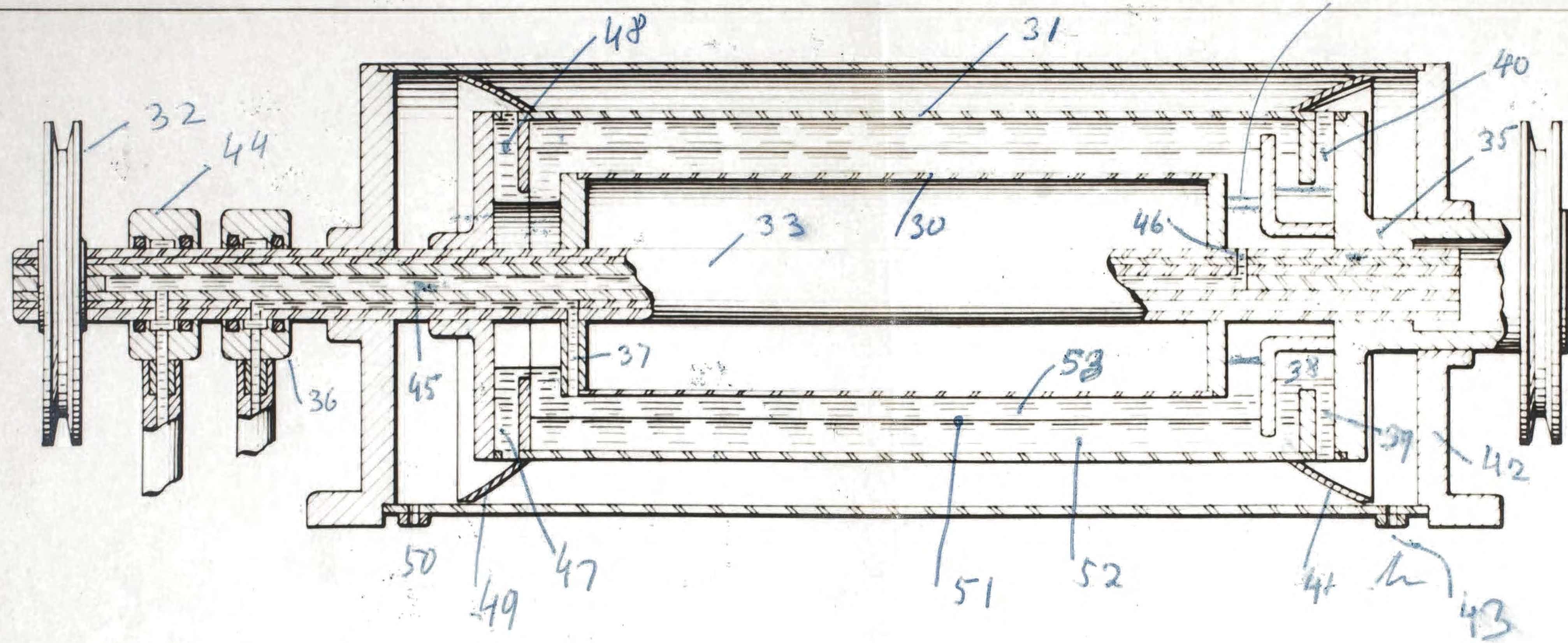
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Fig 2

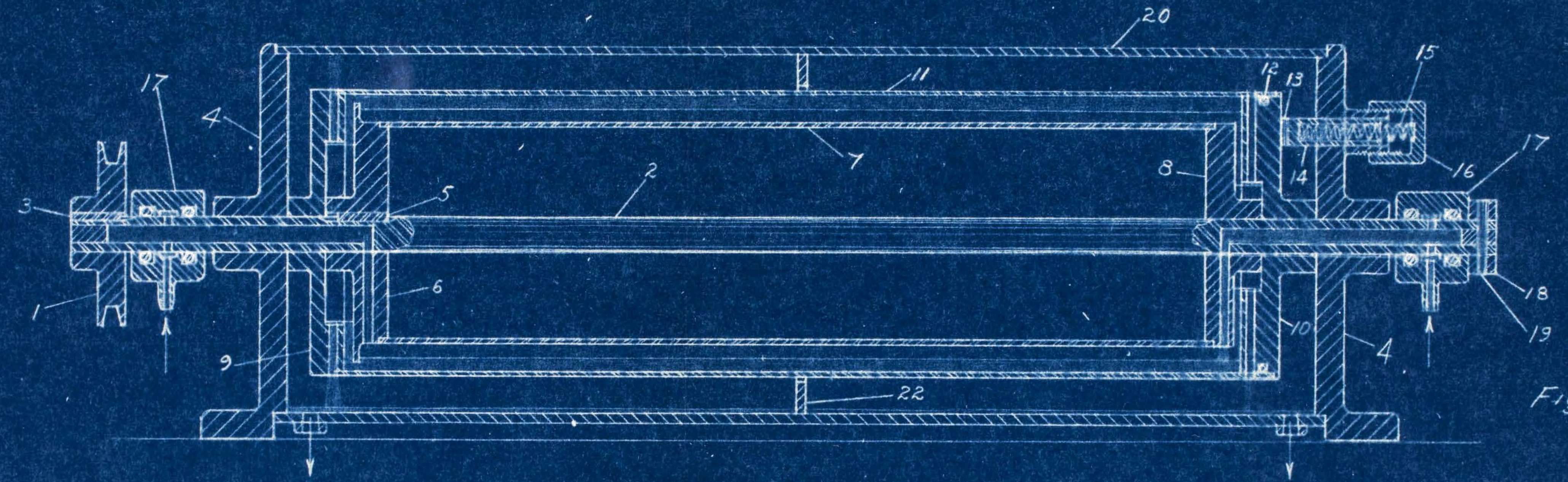
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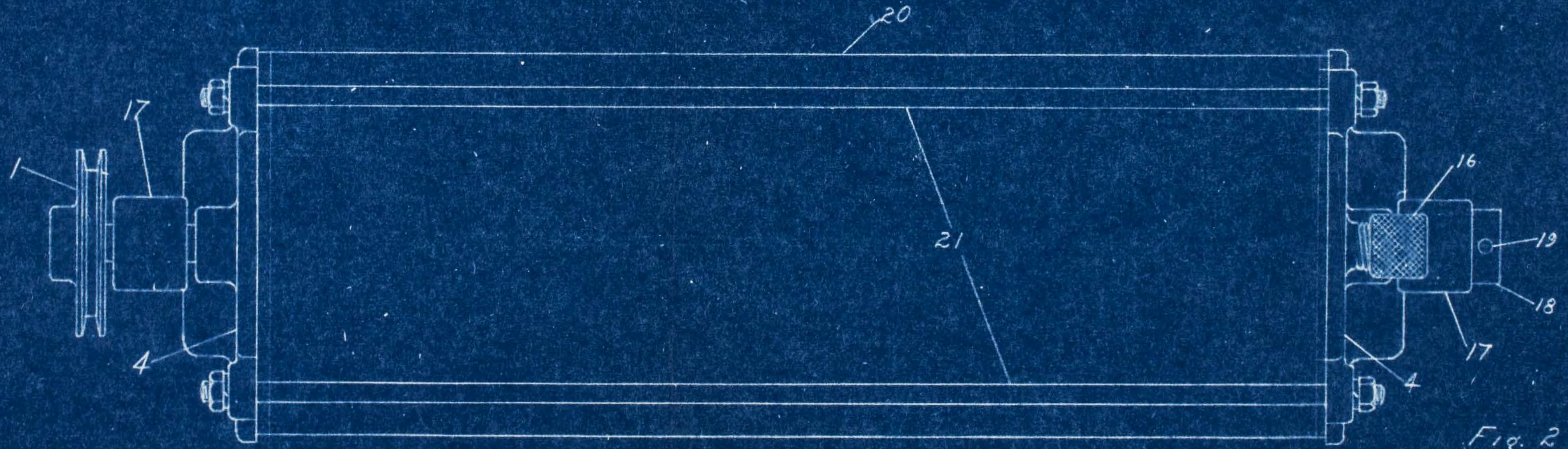
Fig. 1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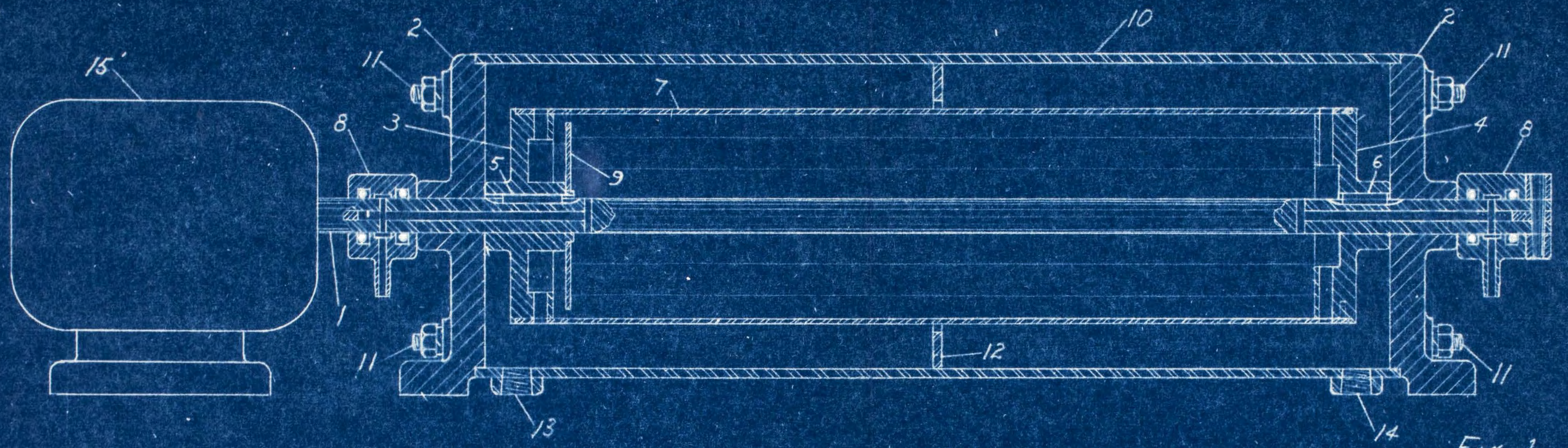

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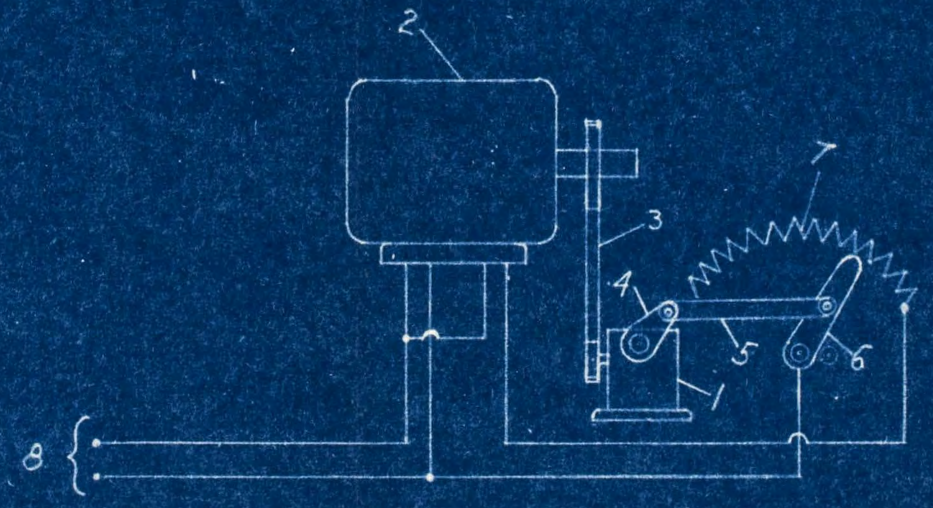

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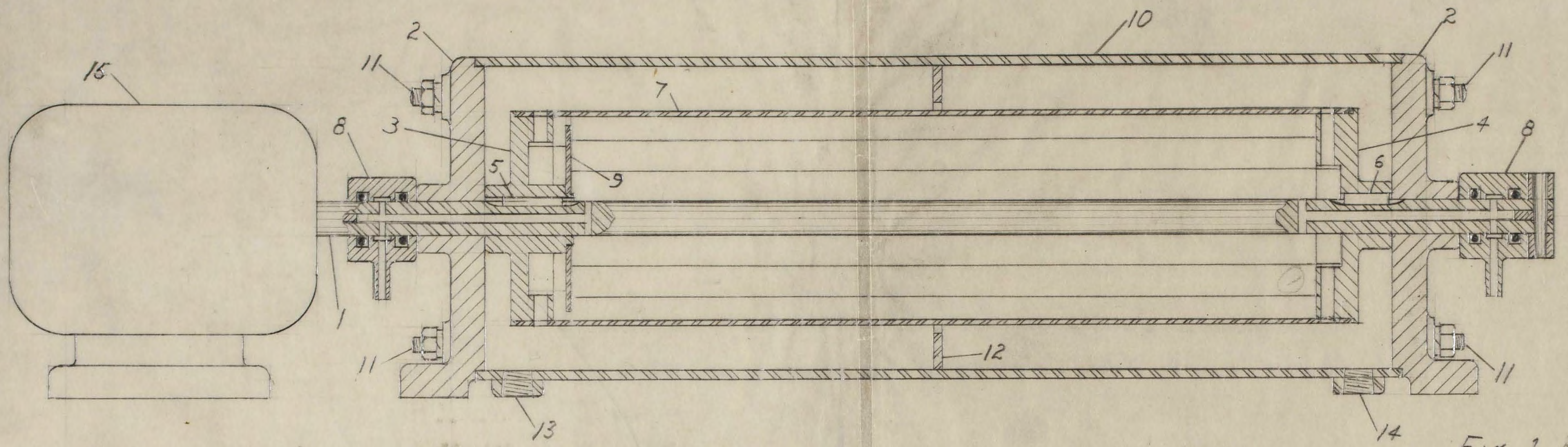

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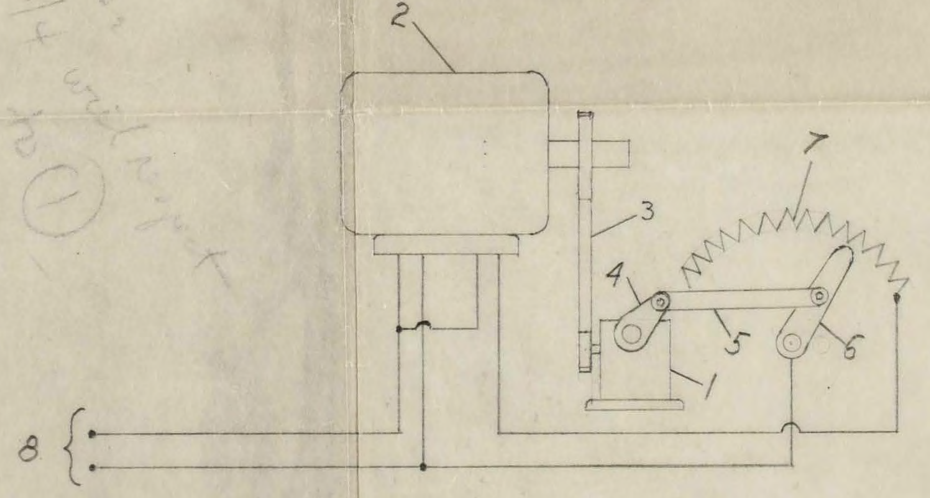

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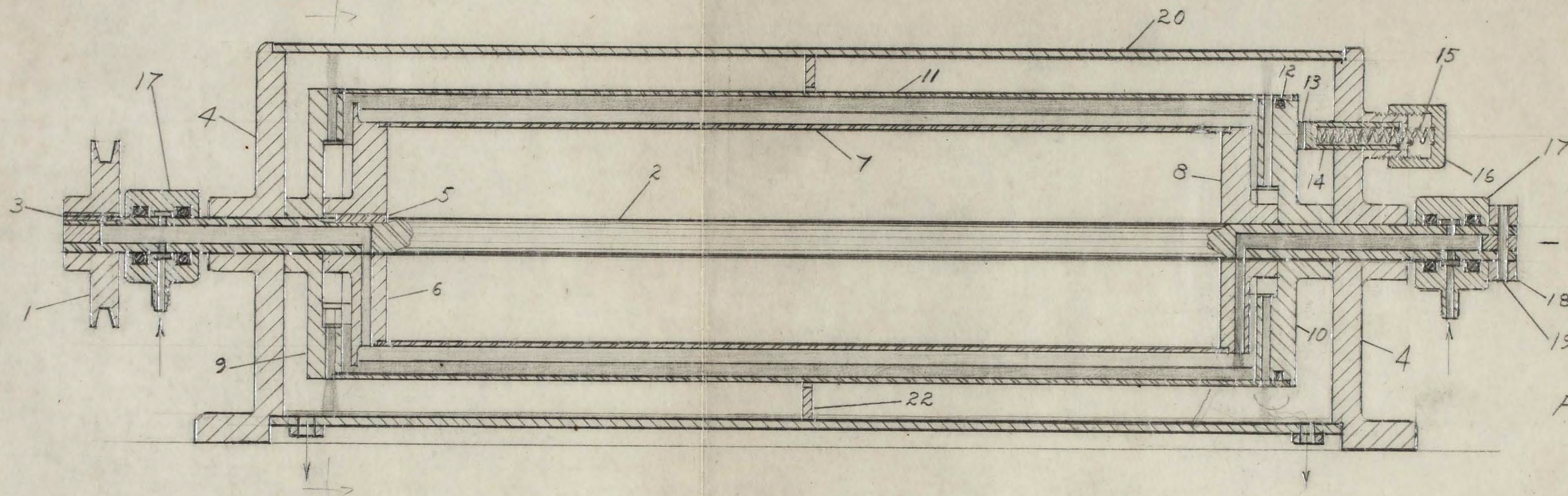
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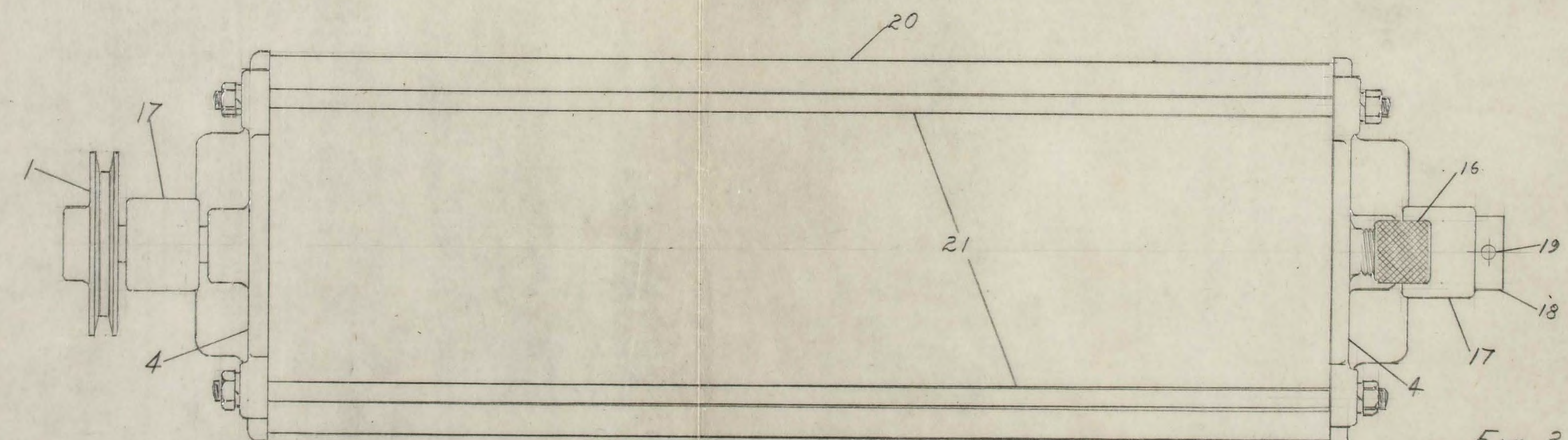
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Fig. 2