

Nov. 24, 1953

H. KLEIN ET AL
COMPRESSOR SURGE INHIBITOR

2,660,366

Filed May 3, 1950

6 Sheets-Sheet 1

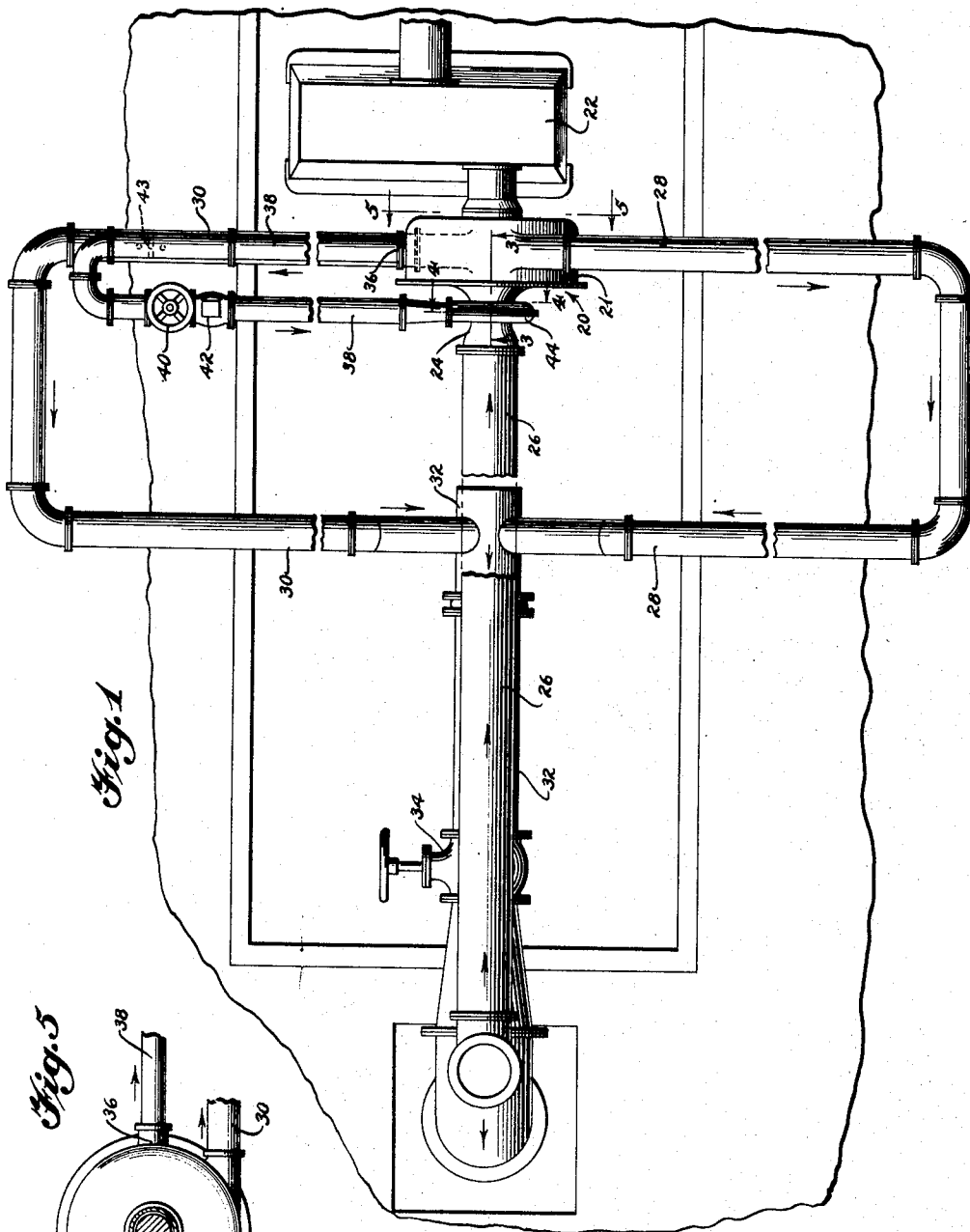


Fig. 1

Fig. 5

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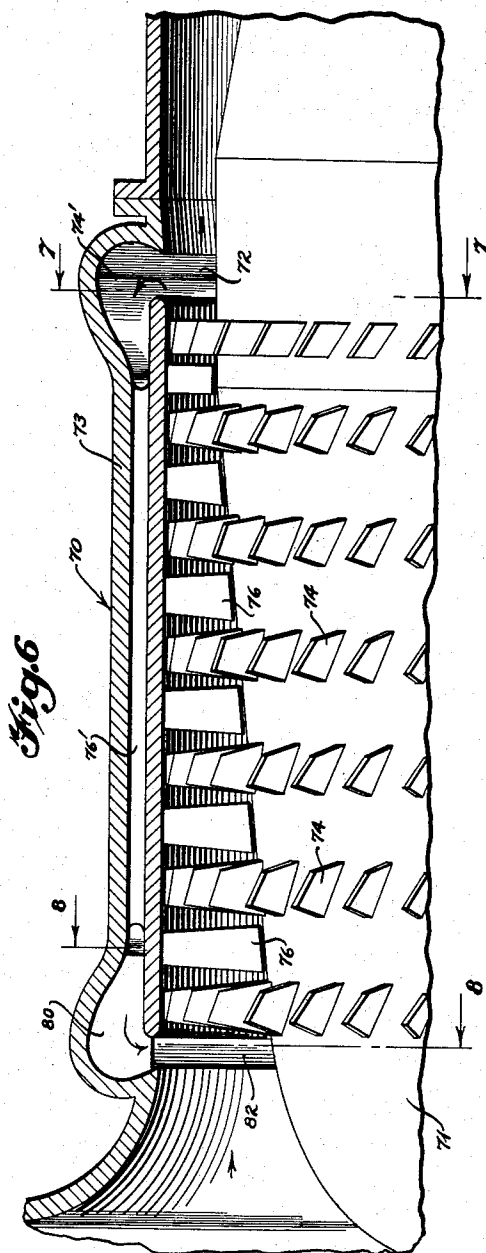
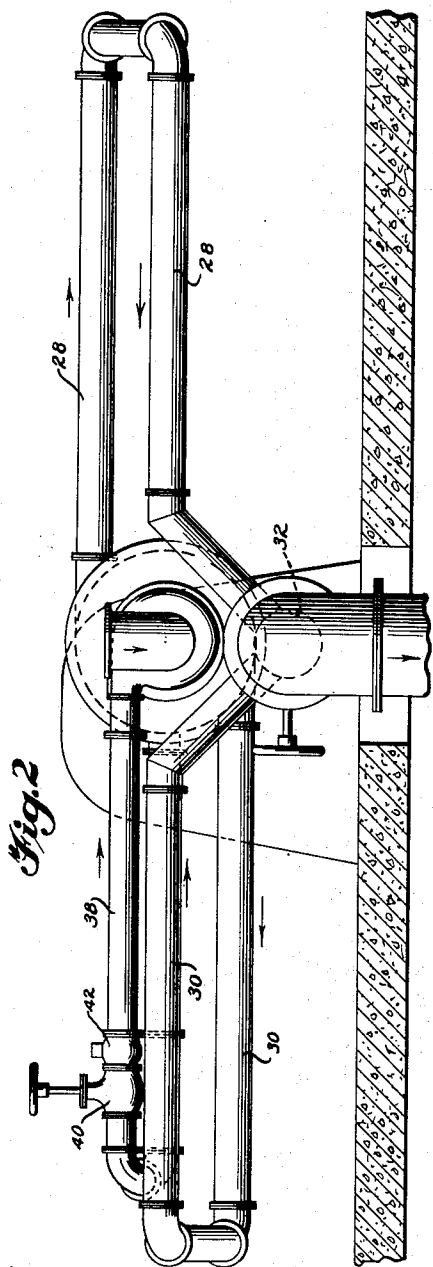
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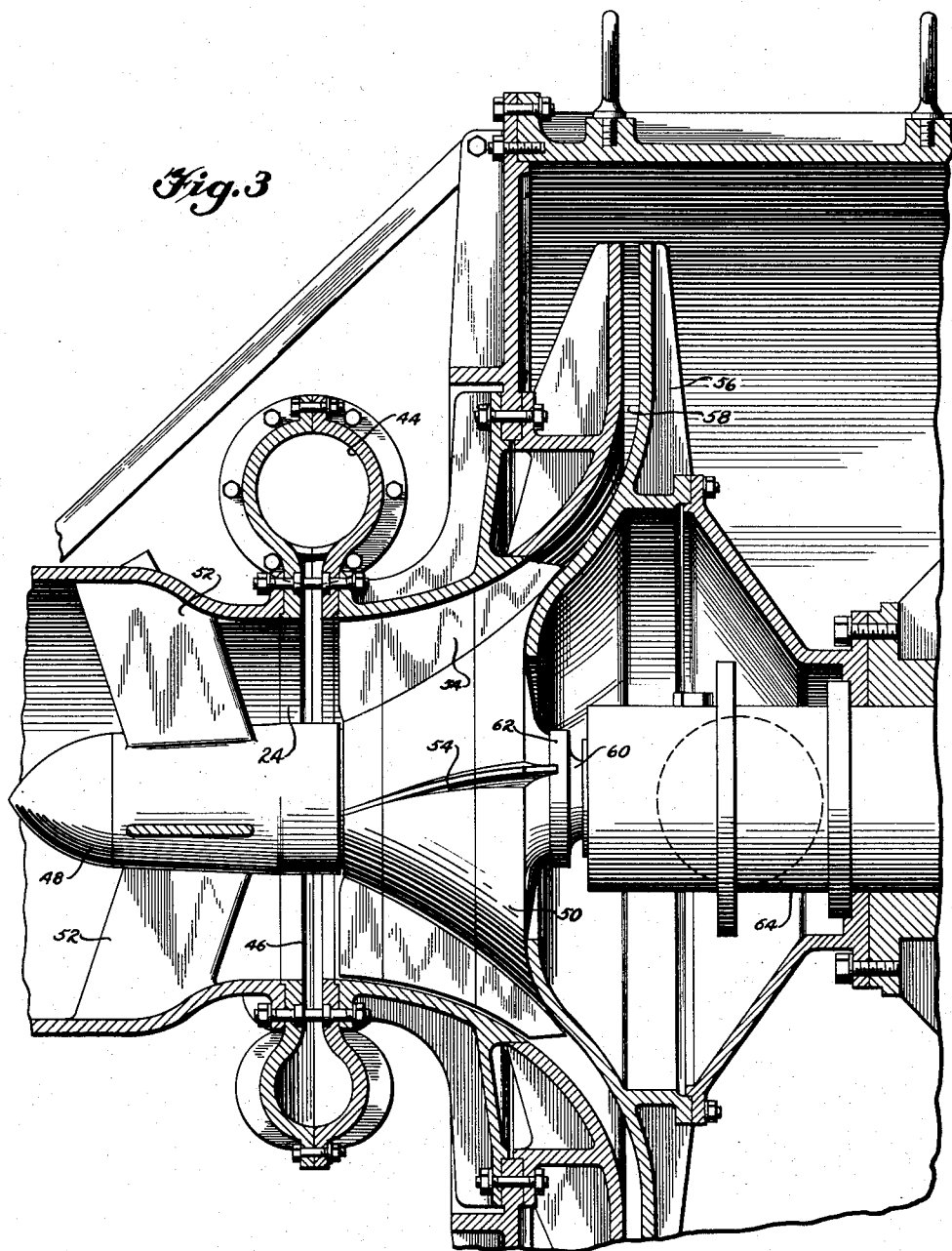
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6 Sheets-Sheet 4

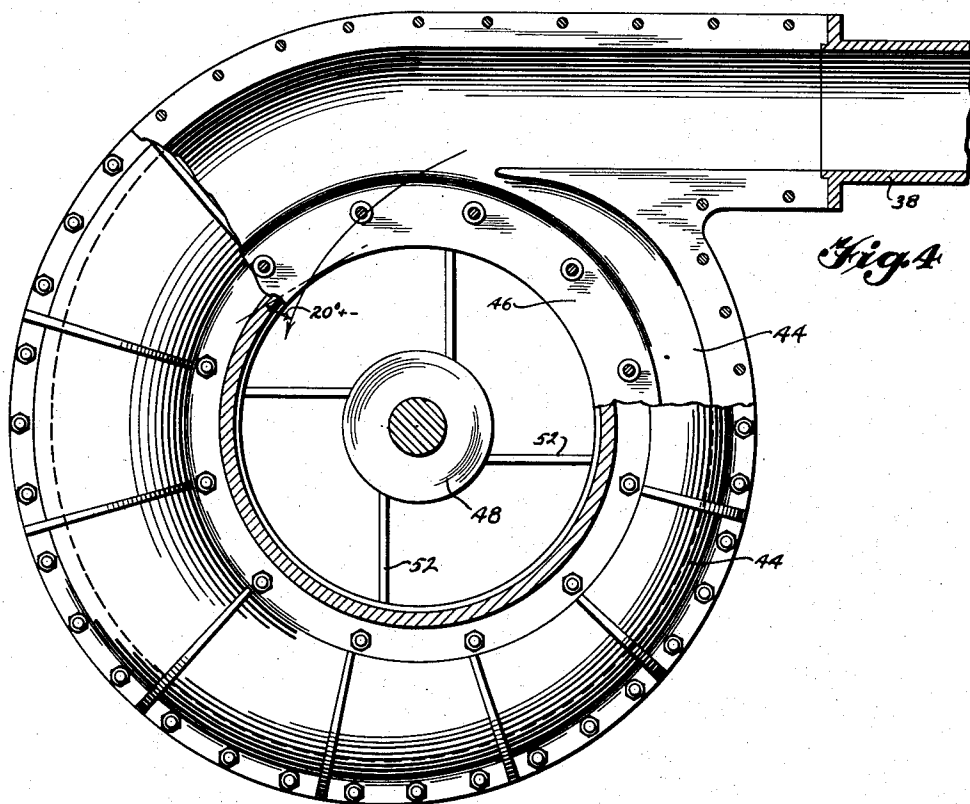


Fig. 4

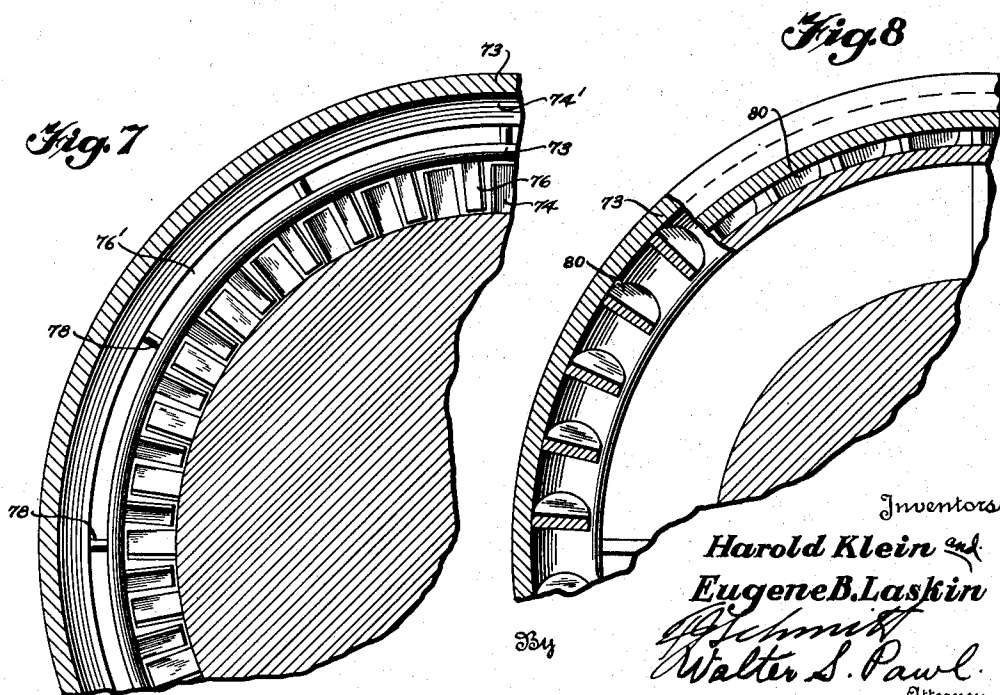


Fig. 7

Fig. 8

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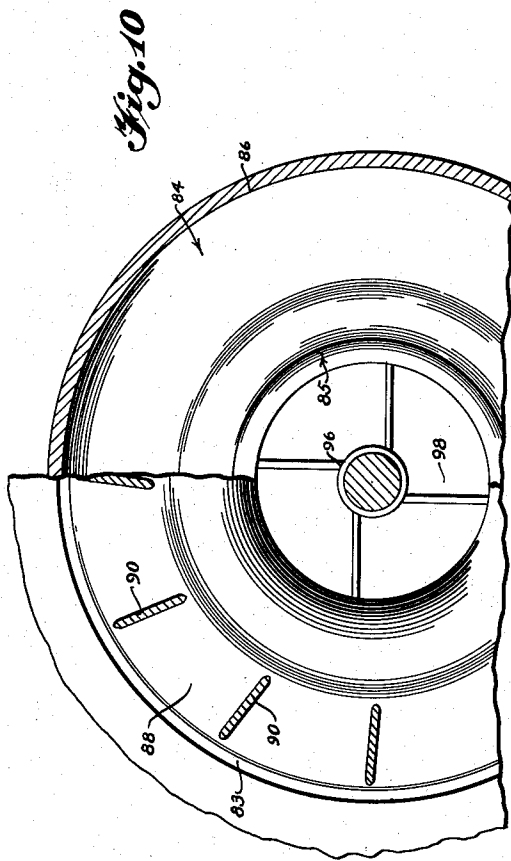
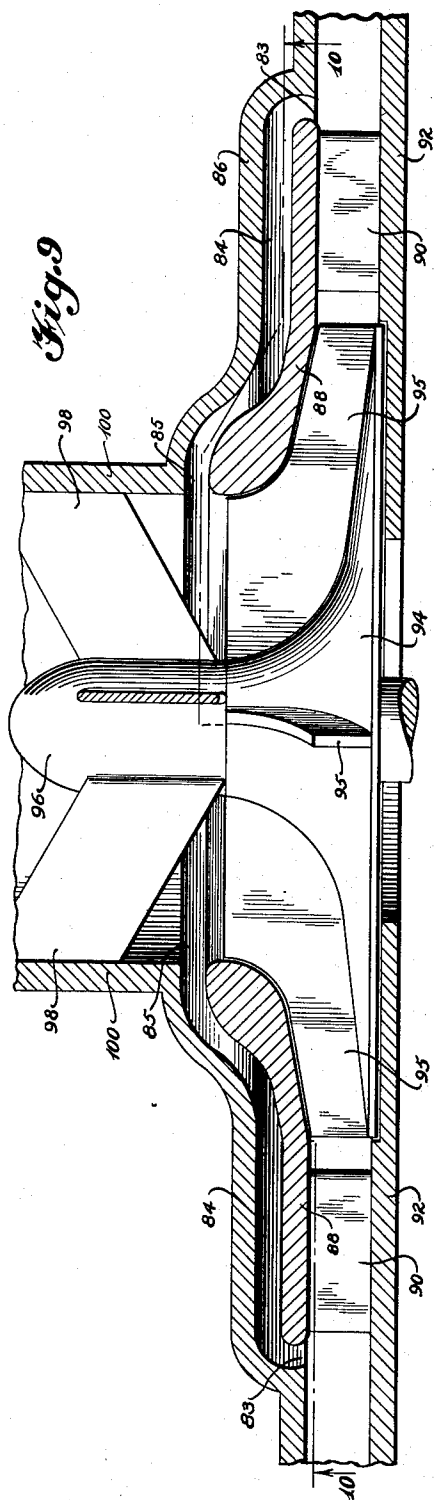
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6 Sheets-Sheet 5



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Filed May 3, 1950

6 Sheets-Sheet 6

Fig. 12

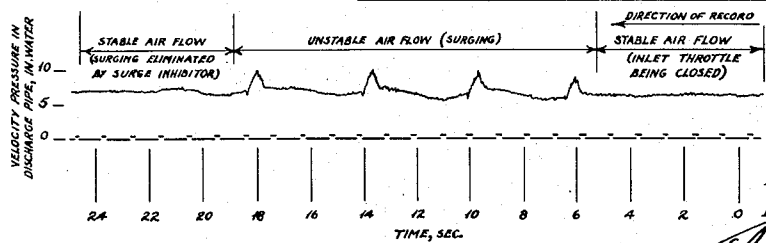
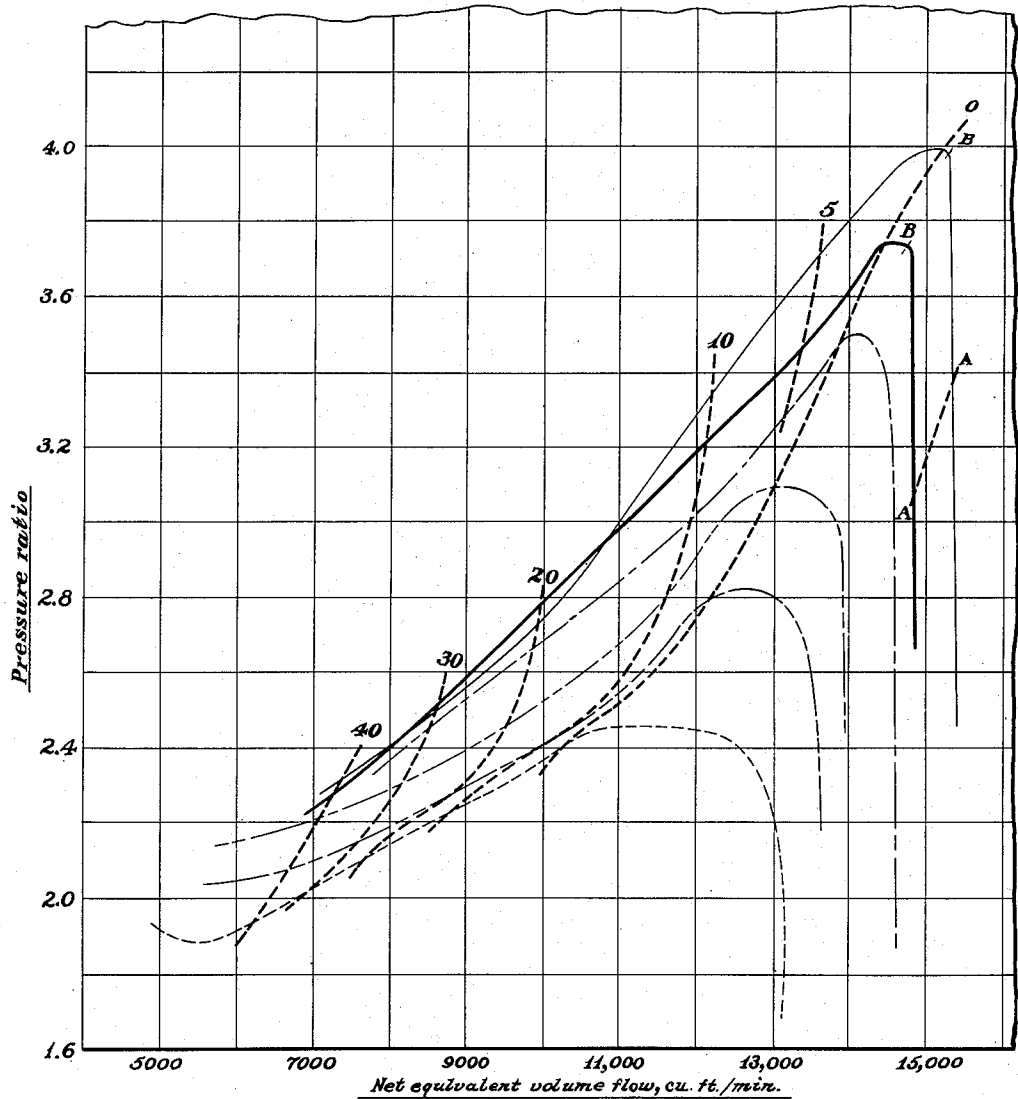


Fig. 11

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COMPRESSOR SURGE INHIBITOR

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Application May 3, 1950, Serial No. 159,802

5 Claims. (Cl. 230-115)

(Granted under Title 35, U. S. Code (1952),
sec. 266)

1

This invention relates to fluid compressors of both the radial and axial flow types and more particularly to a structural means and method of inhibiting surging in fluid flow in such compressors.

The general object of the invention is to provide a structural means which, when the compressor is in operation, eliminates the surging in fluid flow to which, at relatively high velocities, the above types of compressors are subject.

It is also an object of the invention to provide by this structural means, when combined with the structure of the above types of compressors, and increase in surge-free range of operation.

Other objectives, such as simplicity of construction, relatively low weight, ruggedness of construction, and low cost will be apparent from the following description, the hereto attached drawings which are merely illustrative of preferred embodiments of the invention and are not otherwise limitative thereto and from the claims in which the scope of the invention is defined.

In the drawings:

Fig. 1 is a plan view of an air compressor testing layout showing the means of taking a part of the compressed air from the collector case and introduction thereof into the compressor inlet.

Fig. 2 is an end elevation of the layout showing the tangential arrangement of the compressed air discharge pipes in vertical relationship to each other and the valved line of the recirculation system, i. e., the radial take-off from the collector case and the tangential introduction into the scroll discharging into the compressor inlet.

Fig. 3 is a sectional-elevational view of the compressor unit taken along line 3-3 of Fig. 1 looking in the direction indicated by the arrows.

Fig. 4 is a sectional-elevational view taken along line 4-4 of Fig. 1 looking in the direction indicated by the arrows and showing structural detail of the scroll.

Fig. 5 is a sectional-elevational view taken along line 5-5 of Fig. 1 looking in the direction indicated by the arrows and showing the arrangement of the collector case and the discharge outlets therefrom.

Fig. 6 is a partial sectional-elevational view taken longitudinally of an axial flow compressor provided with the means of this invention for recirculating a part of the fluid compressed.

Fig. 7 is a partial sectional-elevational view taken along line 7-7 of Fig. 6, looking in the direction indicated by the arrows.

Fig. 8 is a partial sectional-elevational view taken along line 8-8 of Fig. 6 looking in the di-

2

rection indicated by the arrows and showing the arrangement of vanes to impart rotation to the recirculating fluid.

Fig. 9 is a longitudinal axial sectional-elevational view through a modification (a radial flow compressor) showing a means of recirculating a part of the compressed fluid through the inlet.

Fig. 10 is a sectional-elevational view taken on line 10-10 of Fig. 9 looking in the direction of the arrows.

Fig. 11 is a velocity-pressure trace taken in one of the discharge pipes.

Fig. 12 is a graphic representation of the pressure ratio (discharge pressure to inlet pressure) as a function of the net equivalent volume flow, (cubic feet per minute) at several different equivalent tip speeds (feet per second).

In radial and axial flow compressors the phenomenon of surging is present when the tip velocity of the impeller or blades reaches a certain magnitude. It is a manifestation of an instability of flow in a compressor. The cause of this phenomenon is not well understood, but it is probably due to a combination of blocking of the flow of the gas by the impeller elements with conditions existing at the compressor inlet.

Whatever the cause may be anything which reduces or eliminates this phenomenon, thereby extending the range of operation of the compressor, is most desirable in the art. In principle this invention comprises a recirculation of a part of the compressed gas through the compressor. While such recirculation reduce the delivery at a given speed, the range of operation is extended. The gas for recirculation may be taken from any part of the flow passage of the gas through the compressor that is at a higher pressure than that existing at the inlet. In the application of this invention as shown in Fig. 1, the gas is removed from the collector case 21 through take-off header 36. The gas is put through accelerating scroll 44 which adds a high tangential velocity to the gas entering the impeller which is provided with a plurality of impeller blades. This tangential velocity is in the same direction as that of impeller blades and results in conserving much of the energy of compression put into the recirculated gas as kinetic energy of prerotation. This prerotation serves the very important purpose of reducing the resultant high relative gas speeds at the impeller inlet tip and thus reduces any shock conditions which might occur. In addition, recirculating gas operates the impeller at lower angles of attack which are favorable to prevent stalling. Recirculating this gas also puts more

3

gas through the impeller than is being delivered to the discharge duct. This results in a fuller flowing impeller than would be the case with non-recirculation. All of these factors act in such a direction as to eliminate surging and are reflected in the successful tests hereinafter described.

Further reference is now made to the drawings wherein in Figure 1 the testing layout assembly is shown as comprising a mixed flow rotary impeller type compressor shown generally at 20 which may be driven through speed increaser 22 by any power means such as a motor (not shown). Compressor 20 is provided with a venturi like inlet 24 which is connected to a source of gas by pipe line 26, which is provided with appropriate filters (not shown). Compressed gas is discharged from collector case 21 through pipe lines 28 and 30 which communicate tangentially with the compressor case as shown in Figure 5. Pipe lines 28 and 30 discharge into pipe line 32 by which the discharged gas may be conducted through pressure regulating valve 34 to the atmosphere or to some place of use. Compressed gas for recirculation through the impeller of the compressor may be taken out of collector case 21 radially by header 36 (see Figure 5) whence the gas is conducted by pipe line 38 through gate valve 40, butterfly valve 42 into scroll 44 which discharges into the throat of inlet 24. This is shown more particularly in Figure 3 where scroll 44 is shown discharging into inlet 24 through annular vent 46, which, as shown clearly in this figure, is narrowed by the converging scroll or volute walls to produce an accelerating effect on the inflowing air. It is pointed out that the single volute or turn of the scroll (Figs. 3, 4) terminates in an outlet opening into the volute inlet and that the cross sectional volute area uniformly diminishes from the inlet to a point near the outlet to insure a uniformity in gas movement through the vent 46. In this figure the forward bearing 48 of impeller 50 is shown. This bearing is supported by struts 52 which may be integral with the sidewalls of inlet 24 and with bearing 48 extending therebetween in substantially tangential alignment with the exterior surface of bearing 48. The impeller is driven by high speed shaft 60 which is connected to the impeller hub as at 62. Shaft 60 is supported in sealed thrust bearing 64 and extends through this bearing into speed increaser 22 (Figure 1). Impeller 50, which may be composite structure, (here shown as composed of three sections) is provided with blades 54. These blades, upon rotation of the impeller, advance the gas axially and radially through the impeller, increasing the velocity thereof and thereby compressing it. As here shown the impeller discharges the compressed gas into semi-vaneless diffuser 56. This diffuser is an annular chamber which conforms to the discharge end of the impeller and blades and in this embodiment directs the gas flow from the impeller radially outwardly. The forward part of the annular chamber is a clear space in which the gas discharged by the impeller will have a rotary motion. The discharge portion of the diffuser is provided with a plurality of radially positioned straight vanes 58 which convert the velocity of the gas into pressure.

The recirculatory system

The apparatus and method of operation of the recirculatory system constitutes the essence of the applicants' invention. The apparatus com-

4

prises a line of pipe 38 which is connected radially to compressor case 21 by header 36. Pipe line 38 is provided with gate valve 40 which is closed to prevent leakage when this surge inhibitor system is not in use and is in wide open position when the system is in use. The rate of flow is controlled by butterfly valve 42 and the mass rate of flow is measured by a submerged orifice in combination with a pressure drop measurement device as indicated at 43 in Figure 1. The gas is introduced tangentially into scroll 44 which is designed to discharge the gas into the throat of the inlet at a uniform flow therearound and at an angle of approximately 20° to tangent to the inside circumference of the inlet throat as shown by the arrow in Figure 4. This produces a whirling action in the gas passing through in the direction of impeller rotation having a tangential velocity of approximately 800 feet per second. In this manner a part of the energy of compression is utilized to prerotate the inlet air and thus relieve the impeller of a part of the work required to obtain a given pressure ratio. Because the tips of the impeller inlet blades operate at a high Mach number and reach a condition of critical flow before the rest of the leading edge of the blades, the prerotation added by the recirculated gas in this particular manner tends to delay the occurrence of compression shocks in this region as well as to decrease the angle of attack of the inlet air on the leading edge of the impeller blades.

Figures 6, 7 and 8 show the application of the applicants' principle of recirculation to a multi-stage axial flow compressor shown generally at 70. This compressor is provided with a rotor 71 around the periphery of which are arranged rotor blades 74 in a plurality of spaced circles or stages. In between these stages stator blades 76, carried by shell 78, are positioned.

In this embodiment gas for recirculation may be taken out after the final stage of blades through annular port 72 in shell 73 of the compressor and through which the gas passes into annular chamber 74'. In this chamber the gas may have a rotary motion, but as it is forced forwardly through passages 76' the flow of the gas is converted to rectilinearity by partition walls or vanes 78. This straight line flow distributes the gas evenly over the cross-section. Near the forward end of passages 76' the gas impinges upon vanes 80 which are positioned at an angle to the direction of gas flow to impart rotation to the gas in the direction of rotation of the rotor as it discharges through annular port 82. The rotary motion of this recirculated gas functions in the same manner as in the embodiment of the invention shown in Figures 1 to 5 of the drawings.

Figures 9 and 10 illustrate the application of the applicants' invention to a centrifugal supercharger. Here the surge inhibitor is axially symmetrical with respect to the impeller and comprises an annular chamber 84 positioned between front plate 86 of the impeller housing and plate 88 which is supported by vanes 90 on rear plate 92 of the impeller housing. Impeller 94, which is of the centrifugal or radial flow type, is provided with a plurality of radially extending blades 95 and is supported in bearing 96. This bearing is similar to that shown at 48 in Figure 3 and is supported in a like manner by struts 98 and sidewalls 100 of the inlet.

In operation air drawn through the inlet by impeller 94 is compressed thereby and discharged radially through diffuser vanes 90 into a reser-

5

6

voir tank (not shown). A part of the compressed air after passing through the diffuser vanes passes through annular port 83 into chamber 84 and thence through annular port 85 into the inlet in front of impeller 94. Surging in the air flow through this impeller is thereby inhibited over a relatively wide range of tip speeds.

Test performance

Tests were run on a mixed flow compressor in the test rig layout illustrated in Figure 1. Tests were run over a range of equivalent impeller tip speeds of 1255 to 1565 feet per second corrected to a standard inlet-air temperature of 59° F. for the tests with ambient inlet air. Tests at equivalent impeller tip speeds of 1653 and 1733 feet per second were made with refrigerated air at temperatures of -8° and -25° F. respectively. For all tests, the temperatures of the inlet air at any particular speed did not vary by more than $\pm 2^\circ$ F.

The tests were conducted in accordance with the standard procedures set up by the National Advisory Committee for Aeronautics for rating and testing centrifugal compressors. All tests were made with open outlet throttle and the volume flow was varied by the inlet throttle. Upon initial surging of the unit, the gate valve in the recirculation pipe was fully opened and the butterfly throttling valve was set to allow the minimum amount of discharge air necessary to recirculate through the surge inhibitor to suppress surging. The inlet throttle was further closed until surging was again encountered and the butterfly throttling valve further opened until surging ceased. This sequence of operation was repeated from closed to fully open throttle in the recirculation pipe.

Performance calculations were made in accordance with the method set up by the NACA Special Subcommittee on Supercharger Compressors: Standard Procedures for Rating and Testing Centrifugal Compressors: NACA ARR No. E5F13, 1945. Recirculated-air weight-flow were made as recommended by ASME standards in "Flow Measurement by Means of Standardized Nozzles and Orifice Plates, ch. 4, pt. 5, ASME Power Test Codes, 1940." The data are presented in accordance with the recommendations of the NACA Subcommittee on Supercharger Compressors: Standard Method of Graphical Presentation of Centrifugal Compressor Performance: NACA ARR No. E5F13a, 1945. Curves showing the percentage of net air weight flow necessary for recirculation to the impeller inlet for a given increase in net stable-air-flow operating range are also presented.

A typical velocity-pressure trace taken in one of the discharge pipes is shown in Figure 11. The sequence of operations represented is: stable air flow, surging, and recovery of stable air flow by the surge inhibitor. Once surging has been suppressed, the quantity of recirculated air can be slightly reduced without the recurrence of surge.

Extension in stable-air-flow operating range

A comparison of the stable-air-flow operating range of the compressor unit with and without the surge inhibitor in operation is presented in Figure 12, wherein the performance of the compressor is shown by a group of six curves which are graphs of the net equivalent volume flow in cubic feet per minute as a function of the pressure ratio. Each curve represents an equivalent tip speed in feet per second which was maintained

constant throughout the test. The curves from the bottom to the top of the chart represent equivalent tip speeds of 1255, 1373, 1462, 1565, 1653 and 1733 feet per second respectively. Also superimposed on this graph in broken lines are the curves representing from right to left the effect of the recirculation of air through the compressor in weight flow percentages of 0, 5, 10, 20, 30 and 40. The curves to the right of 0% recirculation curve represent the range in compressor operation without the surge inhibitor in operation. This 0% curve passes through surge points on the different curves. The restricted range of surge-free stable-air-flow is readily apparent in these curves. This is particularly true of the two curves of the highest tip speeds, viz., 1653 and 1733 feet per second. With these two tip speeds, a violent surging occurred also at pressure ratios of about 3.12 and 3.35 respectively. It was found that by a slight decrease in the net equivalent volume of flow from 14,800 to 14,350 a point B on the 1653 feet per second curve could be attained under conditions of stable-air-flow and without the use of the surge inhibitor. The same was also true of the 1733 feet per second curve. However, extension of the range of stable-air-flow from these two maximum points, into the range of surge free, lower volume flows could only be attained by the use of recirculated air. Thus, the portions of the curves to the left of the 0% recirculated air curve show that the extension of the surge free operating range into the lower volume flows by the recirculation of various weight percentages of the compressed air was entirely due to this recirculation. The volume flow of about 15,400 cu. ft. per min. of the 1733 feet per min. curve was extended down to a volume flow of about 7,000 ft. per min. at a pressure ratio of about 2.25 by the recirculation of about 40% by weight of the air from the pressure side of the compressor.

It was also found that the surge inhibitor, although designed to triple the stable-air-flow operating range at an equivalent tip speed of 1,550 feet per second, was capable of increasing the net stable-air-flow operating range more than eight times its original value at this tip speed.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. Apparatus for increasing the surge-free, stable-air-flow range of a rotary compressor by the recirculation of a part of the air compressed by the compressor therethrough, said compressor provided with a housed bladed impeller, an inlet and an outlet therefor, said apparatus comprising a conduit connecting the pressure side of said impeller with and around the interior of said inlet near the inlet face of said impeller for recirculating a part of the air flow through said compressor, and scroll means in the compressor inlet end of said conduit for imparting rotational movement to said recirculated air, accelerating said rotating air and projecting it tangentially into said compressor inlet at right angles to the direction of compressor air flow to thereby inhibit surging in the air flow through the compressor and to increase the surge-free, stable-air-flow range thereof, said scroll means including a single-turn tubular volute having an inner continuous opening therearound.

2. Apparatus for increasing the surge-free, stable-air-flow range of a mixed flow, rotary compressor having a bladed impeller, a housing surrounding said bladed impeller, a compressor case attached to said housing and positioned to receive the compressed air from said impeller, discharge pipes leading from said compressor case and a throated inlet attached to said housing for introducing air into said bladed impeller, said apparatus comprising a pipe line communicating with the interior of said compressor case and connected radially thereto, an orifice plate in said pipe line, pressure gages communicating with each side of said orifice plate for indicating the mass volume rate of flow of compressed air therethrough, gate valve means positioned in said pipe line for permitting and cutting off the flow of compressed air therethrough, butterfly valve means positioned in said pipe line for regulating the mass rate of flow of said compressed air through said pipe line and a tubular spiral scroll element positioned at the throat of said inlet, connected to said pipe line to receive tangentially with respect to itself the compressed air discharged by said pipe line and to discharge said received compressed air through an annular port in the interior periphery thereof and into the throat of said inlet at an angle to impart rotation to the inlet air in said inlet in the direction of rotation of said impeller.

3. Apparatus for increasing the surge-free, stable-air-flow range of a rotary compressor provided with a housed bladed impeller, a throated inlet therefor and a chamber surrounding the discharge end of said impeller for receiving compressed air discharged thereby, said apparatus comprising a tubular scroll element of diminishing cross-section surrounding the throat of said inlet and having an inwardly converging continuous peripheral and constricted discharge port

rectangularly transverse to the axis of inlet air flow and extending radially therefrom, and a conduit communicating with and connected to said chamber and scroll element whereby compressed air is received from said chamber passed through said conduit and discharged directly evenly and tangentially around and into said inlet, thereby to inhibit surging in the compressor air-flow and increase the surge-free, stable-air-flow range thereof.

4. The apparatus as defined in claim 1, said volute opening having a constricted exit width and flaring walls merging with the volute wall to form an air accelerating exit from said volute into the main inlet air stream.

5. The apparatus as defined in claim 1, said volute having an inlet connected to said conduit, the cross sectional area of said volute continuously decreasing in a direction progressing from its inlet, whereby the air movement through said opening is uniformly maintained.

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References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,111,498	Rotter	Sept. 22, 1914
1,281,216	Schellens	Oct. 8, 1918
2,327,841	Hagen	Aug. 24, 1943
2,342,219	Price	Feb. 22, 1944
2,357,527	Lundquist	Sept. 5, 1944
2,418,801	Baumann	Apr. 8, 1947
2,470,565	Ross	May 17, 1949

FOREIGN PATENTS

Number	Country	Date
56,393	France	July 16, 1952 (Addition to 999,797)
580,322	Great Britain	Sept. 4, 1946