

May 21, 1968

MASAO OSHIMA
CENTRIFUGAL PUMP

3,384,022

Filed April 27, 1966

5 Sheets-Sheet 1

Fig. 1
PRIOR ART

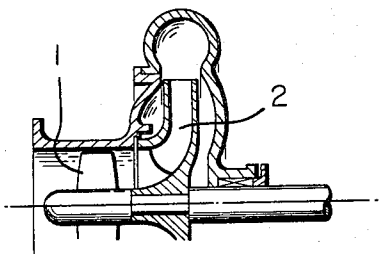


Fig. 2

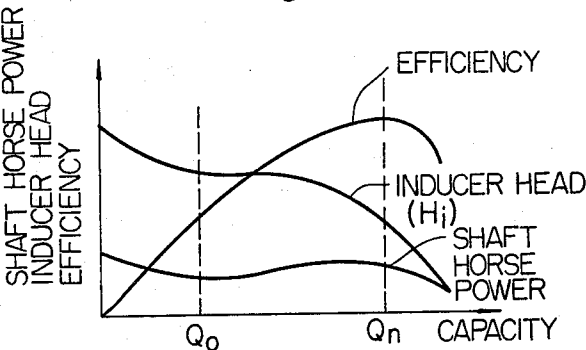
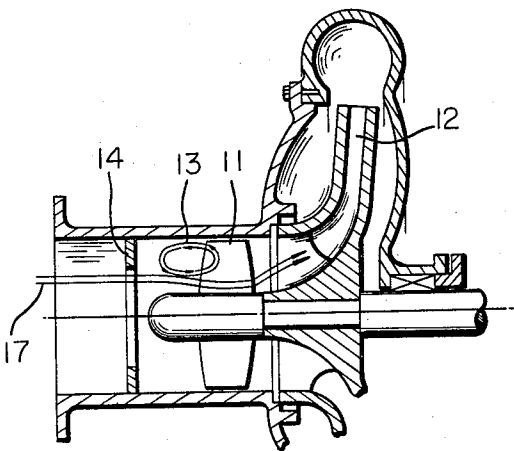


Fig. 3



INVENTOR.
Masao Oshima
BY Ernest G. Montague
Attorney

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Fig. 4

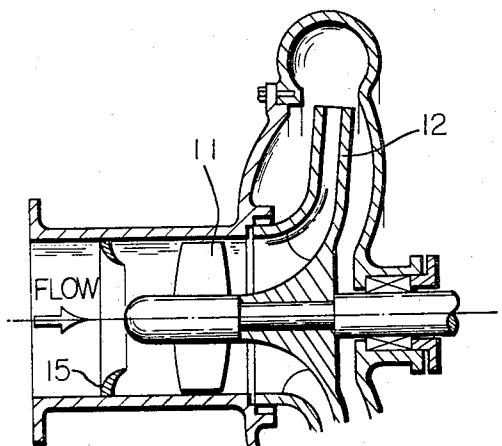


Fig. 5

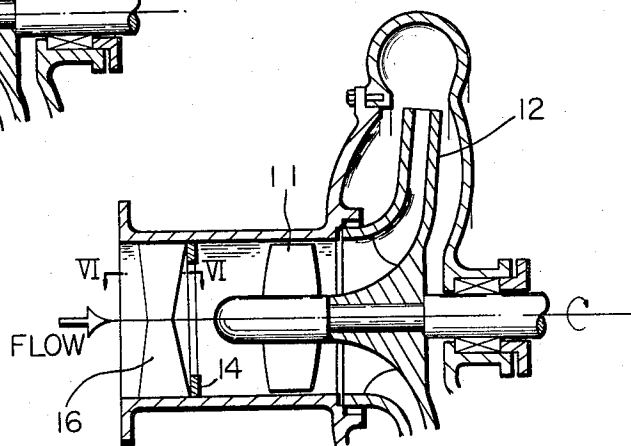
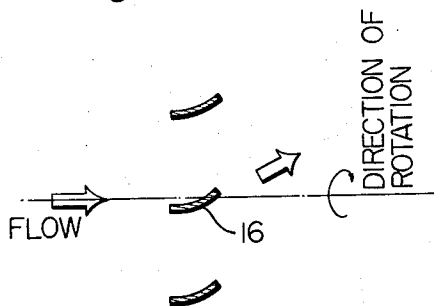


Fig. 6



INVENTOR
Masao Oshima
BY Ernest G. Montague
Attorney

May 21, 1968

MASAO OSHIMA

3,384,022

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Fig. 7B

WITH ORIFICE PLATE

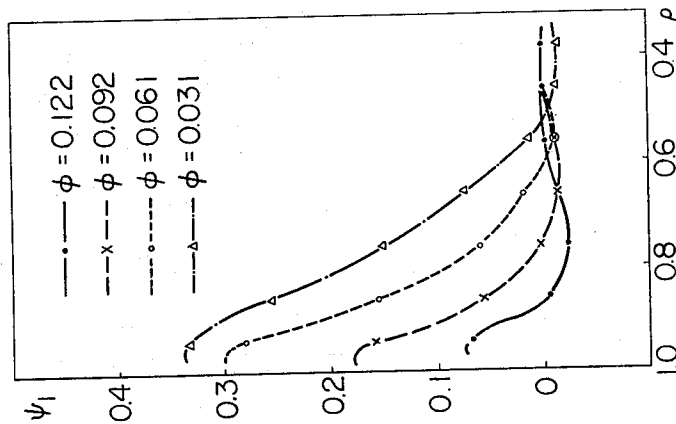
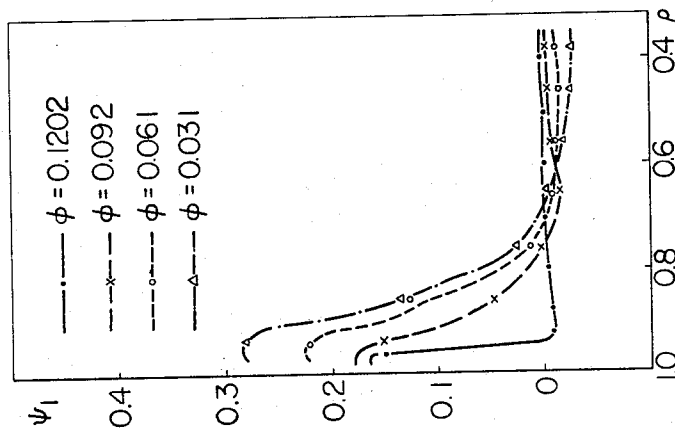


Fig. 7A

WITHOUT ORIFICE PLATE



INVENTOR
Masao Oshima
BY Ernest G. Montague
Attorney

May 21, 1968

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CENTRIFUGAL PUMP

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Fig. 8B

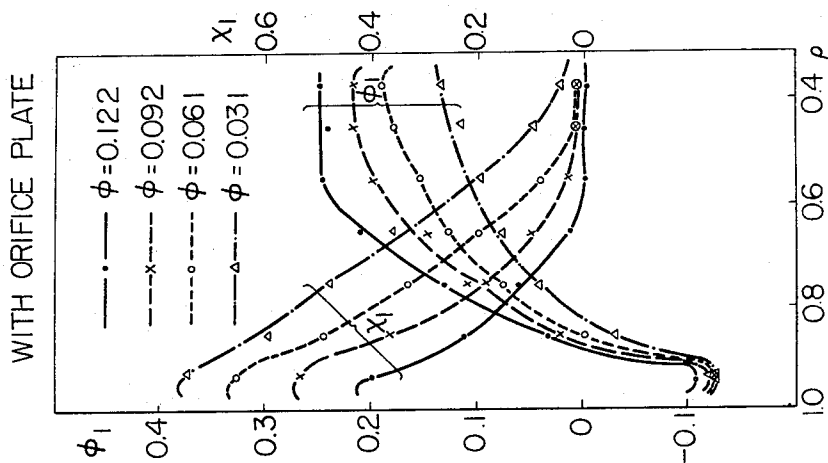
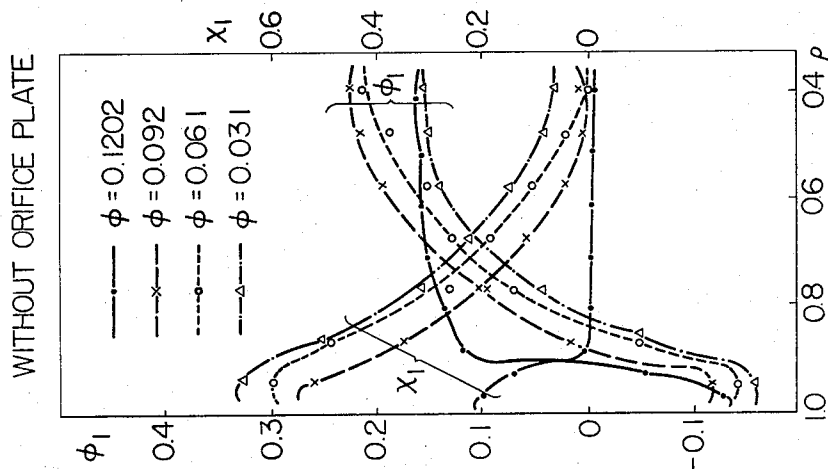


Fig. 8A



INVENTOR
Masao Oshima
BY Ernest G. Montague
Attorney

May 21, 1968

MASAO OSHIMA

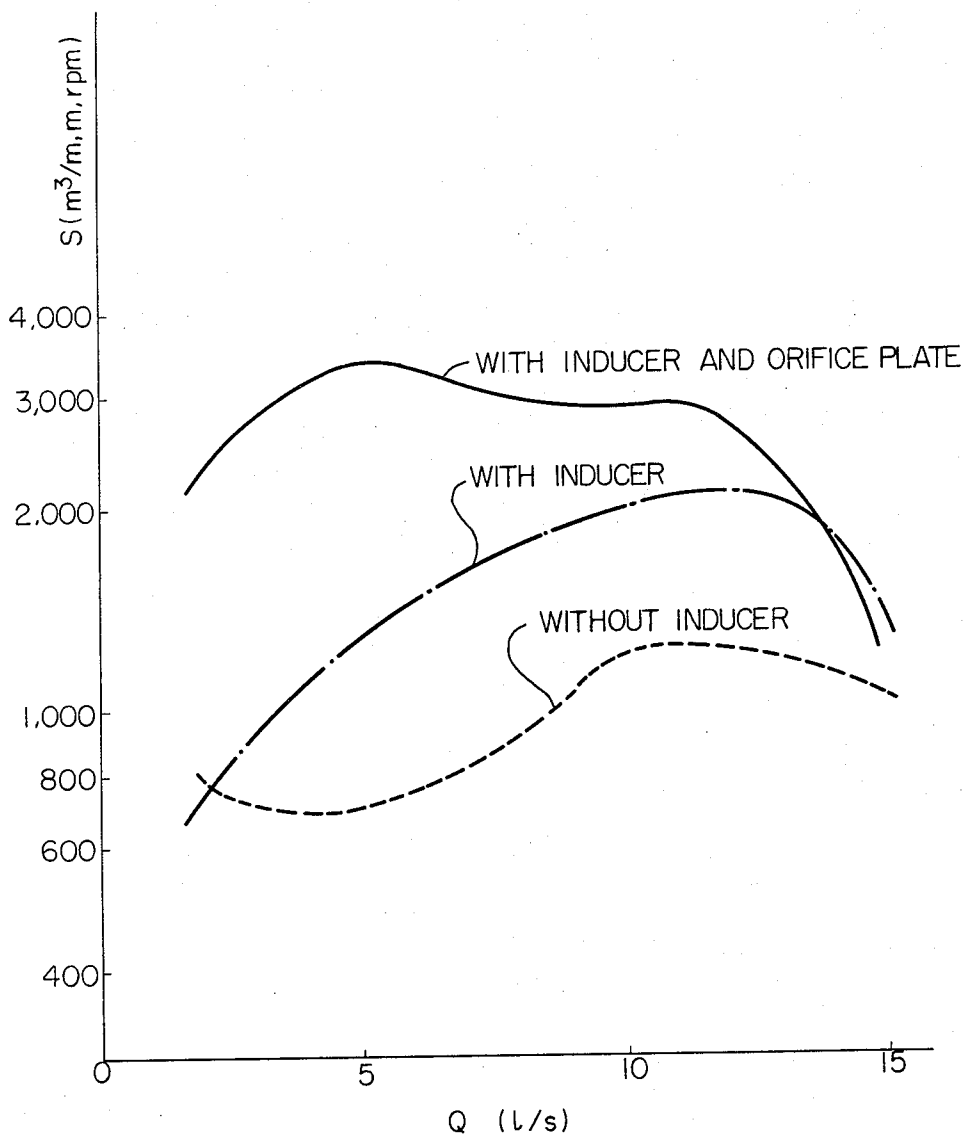
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Fig. 9



INVENTOR.
Masao Oshima
BY Ernest G. Montague
Attorney

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CENTRIFUGAL PUMP

Masao Oshima, Tokyo, Japan, assignor to Kabushiki
Kaisha Ebara Seisakusho (Ebara Manufacturing
Co. Ltd.), Tokyo, Japan, a corporation of Japan
Filed Apr. 27, 1966, Ser. No. 545,670
5 Claims. (Cl. 103-88)

ABSTRACT OF THE DISCLOSURE

A centrifugal pump comprising a main impeller, an inducer situated upstream of the main impeller, and a means for holding the reverse flow about the inlet of the inducer not to retrograde excessively towards the upstream during the operation of the inducer at a level below its normal capacity, that is, in the vicinity of the normal capacity of the main impeller, the inducer is of a normal capacity as large from 2.5 to 4 times that of the main impeller and the means for holding the reverse flow is located upstream from the inducer at a sufficient distance therefrom necessary for turning the reverse flow confluent with the incoming flow so as to thereby impart pre-rotations to the incoming flow prior to the sucking thereof by the main impeller.

The present invention generally relates to the improvement of centrifugal pumps and more particularly to inducers placed before main impellers of the centrifugal pumps which improve the suction performance thereof.

In a conventional centrifugal pump, with a gradual reduction in the net positive suction head (NPSH) value, cavitation first sets in at the inlet edge of the impeller blade which develops toward the outlet of the impeller. In this case, the area of the impeller passage is narrowed by the cavitation and consequently resistance against flow in the impeller is increased. As a result, the head applied to the liquid pumped is lowered gradually and finally the impeller is disabled from pumping action. When the head applied to the liquid by the impeller is lowered with cavitation by three percent of the non-cavitating (normal) value, the condition is generally said to have reached the cavitation critical point and the net positive suction head at this condition is designated as the critical NPSH.

As stated above, the drop in the impeller head caused by cavitation results from the fact that the cavitation reduces the effective area of the impeller passage increasing the flow resistance through the impeller. Therefore, to lower the critical value of the NPSH, it is effective to enlarge the width of the impeller passage and the inside spacing between the blades. From this view point, it is advantageous to reduce the number of blades and to reduce the thickness of the blades.

In centrifugal pump impellers, however, it is impracticable to reduce the number of blades beyond a certain limit, because the head applied to the liquid by the impeller is lowered in accordance with reduction in the number of blades. It is known, in this case, that provision of an inducer before the impeller is quite effective. Since the inducer is an axial flow type impeller, reduction in the number of blades can be compensated by increasing the blade length. Consequently, an inducer with two blades may be operated under a very low NPSH value with its large inside spacing between the blades. Thus it is advantageous to have the inducer produce a fraction of the required NPSH for the main centrifugal impeller. The fraction may be the portion of the NPSH which is required by the existence of the necessary number of blades of the main impeller.

Characteristics of an axial flow type inducer are the

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same as those of an ordinary axial flow impeller. Accordingly, the slope of the head-capacity curve is very steep near the maximum efficiency point. This characteristic is unfavorable for an inducer because although the inducer can be operated quite effectively below the normal flow capacity, producing a higher head than assigned to the inducer, the inducer head is lowered rapidly as the actual flow quantity exceeds the normal capacity and the inducer becomes useless and obstructive for the main impeller. This defect results from a coincidence of the normal flow capacity of the inducer with that of the main impeller.

The principal object of the present invention is to remove this defect which is inherent with conventional inducers. The present invention is based upon the following considerations:

(1) Pre-rotation in the flow just before an impeller is favorable because the magnitude of the inlet relative velocity is decreased.

(2) Though the slope of the head-capacity curve of an axial flow type impeller is steep near the normal flow, the head shows little variation against flow at such partial flows as reverse flow which occurs at the periphery of the impeller inlet when the flow is below about half normal flow.

(3) As the reverse flow occurs about the periphery of the impeller inlet, it imparts a circumferential velocity component to the incoming flow to the impeller. Consequently, the relative flow angle of the incoming flow tends to align with the inlet angle of the impeller blades and the condition becomes favorable for suppression of cavitation occurrence.

(4) In case where the suction pipe is a straight tube, the reverse flow at the impeller inlet flows back over a considerable length along the pipe. Herein the incoming flow approaches the impeller over this long distance flowing within the contracted passage surrounded by the reverse flow accompanying a considerable amount of head loss. Provision of an orifice plate before the impeller may hold back the reverse flow coming out of the impeller, resulting in a remarkable decrease in the head loss of the incoming flow toward the impeller.

(5) Since the outlet diameter of the main centrifugal impeller is considerably larger than the inducer diameter, the ratio of the power loss due to the reverse flow at the inducer inlet to the whole power applied to the set of the inducer and main impeller is appreciably smaller than in the case of a single axial flow impeller; i.e., the efficiency of the whole set of the pump is little impaired by the use of an inducer in its reverse flow range.

In view of the above considerations, an inducer according to the present invention has been so provided as to exert impeller action not only upon its downstream, as a conventional one does, but also onto the upstream thereof, imparting pre-rotation at the inlet of the main impeller with less head loss than that accompanied with inlet guide vanes. In the inducer of the present invention, the designed flow rate or normal flow capacity is chosen from 2.5 to four times, preferably approximately three times larger than that of the main impeller and therefore its operation is always accompanied by the reverse flow at the inlet, and furthermore an orifice plate is provided almost immediately before the inducer in order to keep the reverse flow from extending upstream uselessly into the suction pipe. Effectiveness of such arrangement is described in the above items (1) to (5). In this arrangement, it is obvious from the preceding explanation that provision of a nozzle in place of the orifice plate may bring forth exactly the same effect.

On the other hand, the incoming flow toward the orifice plate has no circumferential velocity component, where-

as the reverse flow from the inducer inlet is characterized by its large circumferential velocity component. Accordingly, a considerable amount of friction loss may possibly occur immediately after the incoming flow passes through the orifice plate, resulting from the difference in the magnitudes of the circumferential velocity components of the incoming flow and the reverse flow. From this consideration, it is advantageous for the inducer effect to add a set of inlet guide vanes, directly before the orifice plate, to impart to the incoming flow a circumferential velocity component in the same direction as that of the inducer rotation.

With the above and other objects in view which will become apparent in the following detailed description, the present invention will be clearly understood in connection with the accompanying drawings, in which:

FIGURE 1 is a fragmentary longitudinal sectional view illustrating prior art conventional inducer installed before a centrifugal main impeller;

FIG. 2 is a set of characteristic curves of an axial flow impeller or an inducer;

FIG. 3 is a longitudinal sectional view illustrating an inducer and orifice plate of the present invention installed before a centrifugal main impeller, showing the flow pattern about the inducer;

FIG. 4 is a longitudinal sectional view illustrating a modified form of the invention having an inducer and nozzle installed before a centrifugal main impeller;

FIG. 5 is a longitudinal sectional view illustrating a further embodiment of the present invention in which an inducer, orifice plate and set of inlet guide vanes are installed before a centrifugal main impeller;

FIG. 6 is an illustration of the inlet guide vanes substantially taken along line VI—VI of FIG. 5;

FIG. 7A is a graph illustrating total pressure distributions immediately before an inducer of the present invention, without an orifice plate;

FIG. 7B is a graph illustrating the total pressure distributions immediately before an inducer of the present invention with an orifice plate;

FIG. 8A is a diagram illustrating the velocity distribution for the same condition and position as in FIG. 7A, without an orifice plate;

FIG. 8B is a graph illustrating the velocity distribution for the same condition and position as in FIG. 7B with an orifice plate; and

FIG. 9 is a graph illustrating test results on suction performance of a centrifugal pump operating with an inducer and orifice plate of the present invention as well as test results for operating with an inducer only and without it, for comparison, in which the suction performance is represented in terms of suction specific speed plotted against flow.

Referring now to the drawings, and in particular to FIG. 1, a conventional inducer 1 is shown and the main impeller 2. The normal flow Q_n of a conventional inducer is chosen at the normal flow of the main impeller. Characteristic curves for the inducer itself are shown in FIG. 2. As is indicated in FIG. 2, the inducer head H_i is lowered rapidly as the flow is increased beyond the normal flow Q_n and eventually the inducer has a negligible effect at a larger flow.

According to the present invention, the normal flow Q_n of the inducer is chosen at from 2.5 to 4 times preferably approximately three times larger than that of the main impeller. As illustrated in FIGS. 3 or 4, an orifice plate 14 or a nozzle 15 respectively, is provided almost immediately before the inducer 11. Then the inducer 11 is to be operated at the flow Q_0 for the normal flow of the main impeller 12, yielding little change in the inducer head over an appreciably wide flow range. In the present invention, since the normal flow of the inducer 11 is chosen approximately three times larger than that of the main impeller 12, the outside diameter of the inducer is about 1.44.

(i.e. $\sqrt[3]{3}$)

times larger than that of a conventional inducer.

The total pressure and velocity distributions immediately before the inducer 11 of the present invention are represented in FIGS. 7A, 7B, 8A and 8B. In these figures, ρ is the ratio of the radial distance of each point to the outside radius of the inducer, ψ a total pressure coefficient given by $\psi_i = GH/U_i^2$ wherein H is the total pressure at each point, U_i the peripheral velocity of the inducer tip and G the acceleration of gravity; ϕ_i the ratio of axial velocity component to U_i , X_i the ratio of the circumferential velocity component to U_i and ϕ a flow coefficient which is the ratio of average axial velocity component at the inducer outlet to U_i . FIGS. 7A, 8A and 7B, 8B are for conditions without and with the orifice plate, respectively. The normal flow for the inducer which was tested was $\phi = 0.22$.

As noted from FIGS. 8A and 8B, the reverse flow at the inducer inlet 13 (FIG. 3) occurs at a flow below about half of the normal flow. The normal flow of an inducer according to the present invention is, as stated before, chosen approximately three times larger than that of the main impeller. This consideration is based on the fact that the ordinary operating range of a centrifugal pump is up to 1.5 times the normal flow of the main impeller and the reverse flow at the inducer inlet occurs below half of the inducer normal flow.

The reverse flow comes out of the inducer with a very large circumferential velocity component; i.e., it flows out in a spiral motion with large velocity. Then the circumferential velocity component is transmitted to the incoming flow 17 (FIG. 3) on account of the liquid viscosity, so that the incoming fluid, likewise flows into the inducer in a spiral motion. Furthermore, since the circumferential velocity component is in the same direction as that of the inducer rotation, the magnitude of the relative velocity at the inducer inlet is made smaller compared with the case of no pre-rotation in the incoming flow. The fact is particularly favorable to suppress cavitation occurrence. Provision of an orifice plate almost immediately before the inducer affects appreciably the total pressure distribution at the inducer inlet, as shown in FIGS. 7A and 7B, so that the total pressure is increased conspicuously about the periphery where cavitation is apt to occur.

Referring now again to the drawings, and more particularly to FIG. 9, a set of test results on suction performance of a centrifugal pump with and without, for comparison, an inducer according to the present invention is illustrated. The normal pump capacity in the tests was 10.5/s. In FIG. 9, pump capacity is plotted on the abscissa and suction specific speed ($m^3/mn.$, $m.$, r.p.m.) on the ordinate. The outer diameter of the inducer tested was 100 mm. and, it was operated on fresh water at normal temperature. The running speed was 3500 r.p.m. The dashed line represents a test result for the main impeller only, the dash-and-dot line represents the case with only the inducer installed before the impeller and, the solid line represents the case with the inducer and orifice plate placed almost immediately before it according to the invention. The conspicuous advantage of the present invention will be readily appreciated from the fact that the value of suction specific speed attained was 3000 at the pump normal flow with the inducer and orifice plate according to the invention operating on water at a normal temperature, and appreciably larger values of suction specific speed were obtained than for the case with the main impeller only over the whole flow range.

It should be noted that, on working of the present invention, a set of inlet guide vanes 16 (FIGS. 5 and 6) may also be placed immediately before the orifice plate 14 or the nozzle 15 so as to impart to the incoming flow a circumferential velocity component in the same direction as that of the inducer rotation.

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While I have disclosed several embodiments of the present invention, it is to be understood that these embodiments are given by example only and not in a limiting sense, the scope of the present invention being determined by the objects and the claims.

I claim:

1. In a centrifugal pump having a main impeller and an inducer installed before said main impeller, the improvement comprising an inducer having a normal capacity from 2.5 to 4 times as large as that of the main impeller, and a means for holding the reverse flow about the inlet of said main inducer within a range necessary for turning said reverse flow mixed with the incoming flow and imparting thereby pre-rotation to the confluent stream prior to the sucking thereof by said main impeller.

2. The apparatus, as set forth in claim 1, further including means for imparting to the incoming flow a circumferential velocity component in the same direction as that of the inducer rotation.

3. The apparatus, as set forth in claim 2, wherein said means for imparting a circumferential velocity component comprises a set of inlet guide vanes disposed immediately before said holding means.

4. The apparatus, as set in claim 1, wherein said holding means comprises a substantially flat plate member having a central opening for passing the incoming flow there-through, said plate member being disposed upstream to said inducer and spaced therefrom by a distance sufficient

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for turning said reverse flow mixed with the incoming flow and imparting thereby pre-rotations to the confluent stream prior to the sucking thereof by the main impeller.

5. The apparatus, as set forth in claim 1, wherein said holding means comprises a nozzle member consisting of an annular portion and a flange portion extending axially inwardly from said annular portion to form a central passage for the incoming flow, said nozzle member being disposed upstream to said inducer and spaced therefrom by a distance sufficient for turning said reverse flow mixed with the incoming flow and imparting thereby pre-rotations to the confluent stream prior to the sucking thereof by the main impeller.

References Cited

UNITED STATES PATENTS

1,465,097	8/1923	Sherzer	103—97
2,013,078	9/1935	Slocum	103—88
2,393,933	1/1946	Poole	230—120

FOREIGN PATENTS

184,066	4/1955	Austria.
514,076	9/1952	Belgium.
424,248	3/1943	Italy.
106,869	9/1924	Switzerland.

HENRY F. RADUAZO, *Primary Examiner.*