CIVIL ENGINEERING DEPARTMENT
FRITZ ENGINEERING LABORATORY
HYDRAULICS DIVISION
Memorandum No. M-32

STATUS REPORT OF RESEARCH PROJECT
ON
IMPROVING DESIGN OF A HOPPER DREDGE PUMP

Prepared by
John B. Herbich

Prepared for
U.S. Army Engineer District, Philadelphia
Corps of Engineers
Philadelphia 29, Pennsylvania
Contract No. DA-36-109-CIVENG-59-112

January 1962
Bethlehem, Pennsylvania

F.L. Report No. 277.34.1
STATUS REPORT OF RESEARCH PROJECT

ON

IMPROVING DESIGN OF A HOPPER DREDGE PUMP

I. INTRODUCTION


II. EXPERIMENTAL STUDIES

A. General Comments

The detailed analysis of the performance of the pump under the variety of conditions investigated under phases 2 and 3 is under way as part of phase 4 of the project.

* Numbers in parentheses indicate References
B. Discussion of Results

1. Effect of Vane Shape

(a) Comparison of efficiencies between a plain arc and an involute curve (constant flow = 1000 gpm, all speeds, entrance angle 45°, exit angle 35°).

<table>
<thead>
<tr>
<th>Density (g/l)</th>
<th>Plain Arc (No. 1)</th>
<th>Involute Curve (TD-8)</th>
<th>Increase in Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>73.2</td>
<td>79.0</td>
<td>5.8</td>
</tr>
<tr>
<td>1170</td>
<td>72.1</td>
<td>78.9</td>
<td>6.7</td>
</tr>
<tr>
<td>1240</td>
<td>69.4</td>
<td>78.5</td>
<td>9.1</td>
</tr>
<tr>
<td>1320</td>
<td>67.8</td>
<td>77.4</td>
<td>9.6</td>
</tr>
<tr>
<td>1380</td>
<td>72.1</td>
<td>76.2</td>
<td>4.1</td>
</tr>
</tbody>
</table>

As shown above, the involute curve is considerably more efficient than the plain arc, particularly for densities of 1240 and 1320 g/l.

(b) Comparison of efficiencies between a logarithmic spiral and an involute curve (constant flow = 1000 gpm, all speeds, entrance angle 45°, exit angle 28°45').

<table>
<thead>
<tr>
<th>Density g/l</th>
<th>Logarithmic Spiral (TD-5)</th>
<th>Involute Curve (TD-6)</th>
<th>Increase in Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>82.9</td>
<td>82.4</td>
<td>-0.5</td>
</tr>
<tr>
<td>1170</td>
<td>78.9</td>
<td>80.9</td>
<td>1.0</td>
</tr>
<tr>
<td>1240</td>
<td>80.4</td>
<td>79.2</td>
<td>-1.2</td>
</tr>
<tr>
<td>1320</td>
<td>78.8</td>
<td>78.8</td>
<td>0</td>
</tr>
<tr>
<td>1380</td>
<td>77.1</td>
<td>77.9</td>
<td>0.8</td>
</tr>
</tbody>
</table>
There is very little difference in efficiency between a logarithmic spiral and an involute curve.

2. Effect of Exit Angle

The effect of vane exit angle on efficiency for various values of fluid density are shown in Figure 1. It appears that the maximum efficiency was between 22-1/2° and 28° 45' for densities of 1000 and 1170 g/l, and close to 22-1/2° for other densities.

There is a possibility that the maximum efficiency might occur for lower exit angle, particularly for densities of 1240, 1320, and 1380 g/l. An additional series of tests of an impeller with 16-1/2° exit angle and 45° entrance angle, and an involute shape would, no doubt, clear up this point. Additional funds, however, would be required to study this question.

Volute Studies

Further analysis of data is planned; it appears that the volute casing should be re-designed and the clearance between the volute tongue and the impeller reduced from the present 16 inches in the prototype by one-third, to about 11 inches. A word is being awaited from the sponsor's representatives whether this reduction is feasible from the operational standpoint.
High-Speed Movies

Several high-speed movies were taken of flow in the 4-1/2 inch plexiglas section of the suction pipe. One-eighth inch diameter plastic balls were introduced into the flow. The movies indicate some pre-rotation in the pipe, particularly at high rates of flow. Detailed analysis is being planned, and additional movies will be taken after the high-speed camera is returned from the repair shop.

Project Report No. 33

Twenty-five copies of the complete report on Phases 2 and 3 of the dredge pump investigation have been submitted to the sponsor late in December 1961.
REFERENCES


(2) Herbich, J.B. CHARACTERISTICS OF A MODEL DREDGE PUMP Fritz Engineering Laboratory Report No. 277-P.R. 31, Lehigh University, 110 pages September 1959

(3) Herbich, J.B. EFFECT OF IMPELLER DESIGN CHANGES ON Vallentine, H.R. CHARACTERISTICS OF A MODEL DREDGE PUMP Fritz Engineering Laboratory Report No. 277-P.R. 33, Lehigh University, 207 pages September 1961
Fig. 1  Effect of vane exit angle on pump efficiency
CIVIL ENGINEERING DEPARTMENT
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HYDRAULICS DIVISION
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STATUS REPORT OF RESEARCH PROJECT ON

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March 1962

Bethlehem, Pennsylvania

F.L. Report No. 277, 34.2
I. INTRODUCTION


II. EXPERIMENTAL STUDIES

A. General Comments

The detailed analysis of the performance of the pump under the variety of conditions investigated under phases 2 and 3 is under way as part of phase 4 of the project.

* See References for complete listing
B. Discussion of Results

1. Effect of Exit Angle

The effect of vane exit angle on efficiency for a number of densities, constant model flow of 1000 gpm, and constant model speed of 1440 rpm, was presented in Memorandum No. M-32. Additional plots for model speeds of 1150, 1300, 1550, 1650, and 1760 rpm, and for two model discharges of 800 and 1000 gpm were prepared.

In general, the maximum efficiencies for flow of 1000 gpm were obtained at vane exit angle of 22-1/2° for the majority of fluid densities and all speeds with the exception of 1150 rpm. The data for 800 gpm for the same speeds and densities tend to substantiate the conclusions drawn from the exit angle-efficiency curves for 1000 gpm. A typical curve tends to show that the most efficient exit angle may be below 22-1/2°.

The data also indicates that:

(a) Efficiency decreases as fluid density increases
(b) Higher efficiencies were obtained at 1000 gpm, as compared with 800 gpm, as was expected
(c) Since there is a possibility that the most efficient exit angle may be below 22-1/2°, it is recommended that an additional series of tests with an impeller having a 16-1/2° exit angle will be authorized.

C. Clearance Tests

One of the criteria of selecting a dredge pump impeller is the amount of clearance it has to permit passage of large objects through the pump.

(a) The first approach to this problem was to measure the smallest width between the impeller vanes on a two-dimensional drawing of an impeller. A sketch herewith shows the approximate location of this dimension.

The results of the measurements are shown in the table below. These measurements are of value when one considers the largest size spherical object that can pass through the impeller. However, they do not indicate the effect of vane design on passage of objects of other geometry, such as long and narrow objects. In such cases the three-dimensional nature of the impeller passages should be considered.
Table I

<table>
<thead>
<tr>
<th>Impeller Number</th>
<th>Critical Dimension (Cd) (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>1.8</td>
</tr>
<tr>
<td>TD-4</td>
<td>2.0</td>
</tr>
<tr>
<td>TD-5</td>
<td>2.1</td>
</tr>
<tr>
<td>TD-6</td>
<td>1.9</td>
</tr>
<tr>
<td>TD-7</td>
<td>2.1</td>
</tr>
<tr>
<td>TD-8</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Table I indicates that all trial design impellers have a slightly larger clearance, as determined by the "critical dimension", than the original impeller (No.1), with the exception of TD-8 which has an equal value to impeller No. 1.

(b) Since an object must pass through the grating on the drag head before it can enter the impeller, the greatest danger of clogging would come from an object that is long and narrow. To study the passage of such objects through the pump, wooden blocks of the following sizes were used:

<table>
<thead>
<tr>
<th>Block Number</th>
<th>Model Size (inches)</th>
<th>Prototype Size (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 x 1-1/2 x 4</td>
<td>8 x 12 x 32</td>
</tr>
<tr>
<td>2</td>
<td>1 x 1-1/2 x 5</td>
<td>8 x 12 x 40</td>
</tr>
<tr>
<td>3</td>
<td>1 x 1-1/2 x 5-1/2</td>
<td>8 x 12 x 44</td>
</tr>
<tr>
<td>4</td>
<td>1 x 1-1/2 x 6</td>
<td>8 x 12 x 48</td>
</tr>
<tr>
<td>5</td>
<td>1 x 1-1/2 x 6-1/2</td>
<td>8 x 12 x 52</td>
</tr>
<tr>
<td>6</td>
<td>1 x 1-1/2 x 7</td>
<td>8 x 12 x 56</td>
</tr>
<tr>
<td>7</td>
<td>1 x 1-1/2 x 8</td>
<td>8 x 12 x 64</td>
</tr>
<tr>
<td>8</td>
<td>1 x 1-1/2 x 9</td>
<td>8 x 12 x 72</td>
</tr>
</tbody>
</table>
It was attempted to fit these blocks through the impeller, making sure that they would also pass through the suction pipe into the pump.

The following results were obtained:

<table>
<thead>
<tr>
<th>Impeller</th>
<th>Smallest block not passing through impeller</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>8</td>
</tr>
<tr>
<td>TD-5</td>
<td>6</td>
</tr>
<tr>
<td>TD-6</td>
<td>2</td>
</tr>
<tr>
<td>TD-7</td>
<td>3</td>
</tr>
<tr>
<td>TD-8</td>
<td>7</td>
</tr>
</tbody>
</table>

Next, the drawings of the drag head of ESSAYONS were examined and a check made to determine the maximum length of the same cross-section (8" x 12") that would pass through the grating. The maximum length was found to be 46 inches, or halfway between blocks No. 3 and 4. Theoretically, therefore, such a block may not pass through impellers TD-6 and TD-7. However, considering this size range and the path the object must travel to reach the impeller, it may be concluded that clearance is not a major problem with any of the impellers tested.

(c) Additional check was made to determine the maximum block size which would clear the volute cut-off under the worst possible condition. With the present prototype clearance of 16 inches between volute tongue and impeller, block No. 6 would pass through the pump.
Should the clearance between volute cut-off and impeller be reduced to 11 inches, block No. 4 would pass through the pump.

D. Volute Studies

The design considerations indicate that the clearance between volute cut-off and impeller should be reduced to 11 inches. It is understood that a private company is considering reducing this distance to about 8 inches for a similar size dredge pump.

The volute casing is now being re-designed, using the 11-inch clearance value and four centers of circular arcs defining the volute shape (3).

It is recommended that additional series of tests with re-designed volute and the most efficient impeller be authorized.

E. High-Speed Movies

High-speed movies of flow in the suction pipe were analyzed, but no appreciable prerotation was observed for any speed or flow conditions.

A bronze impeller with a plexiglas shroud on the suction side was received from the manufacturer; however, as the preparations for movie taking were being made, the cameras was found to be defective and is being returned to the manufacturer's repair shop. This is unfortunate, as it will cause a total delay of approximately six weeks on this phase of the project.
F. Dimensionless Plots

Figures 19 to 22 of Reference 3, showed the performances of the impellers TD-5, TD-6, TD-7, and TD-8, in the form of dimensionless plots of gH/D^2N^2 versus Q/ND^3. In these plots N was calculated in radians per second, and H in feet of water. If the H units are expressed in feet of liquid, all the data tends to fall on the one curve for the H-Q relationship, as H in feet of liquid (Euler's head, etc.) is independent of density.

The curves were re-plotted and are presented in Figures 1 to 4.

III. PROJECT REPORT NO. 33

The following misprints were noticed in the Project Report No. 33.

p. 45 - Equation 9 SHOULD READ \( \alpha_D = \theta_D + \gamma_D - \beta_D \)

p. 57 - First line SHOULD READ:

"proper, 360° - \( \theta \), is equally ..."

IV. FUTURE STUDIES

It is recommended that additional studies should be performed with an impeller having a 16-1/2° exit angle, 45° entrance angle, and an involute shape vane.

It is also recommended that additional studies be performed with a re-designed volute.

We shall be glad to prepare proposals outlining this work.
REFERENCES


(2) Herbich, J.B. CHARACTERISTICS OF A MODEL DREDGE PUMP. Fritz Engineering Laboratory Report No. 277-P.R. 31, Lehigh University, 110 pages. September 1959

(3) Herbich, J.B. EFFECT OF IMPELLER DESIGN CHANGES ON CHARACTERISTICS OF A MODEL DREDGE PUMP. Fritz Engineering Laboratory Report No. 277-P.R. 33, Lehigh University, 207 pages. September 1961
Fig. 1 Dimensionless Head - Flow Curves for Impeller TD-5
Fig. 2 Dimensionless Head - Flow Curves for Impeller TD-6
Fig. 3 Dimensionless Head - Flow Curves for Impeller TD-7
Fig. 4 Dimensionless Head - Flow Curves for Impeller TD-8
STATUS REPORT OF RESEARCH PROJECT
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Prepared by
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U. S. Army Engineer District, Philadelphia
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Philadelphia 29, Pennsylvania
Contract No. DA-36-109-CIVENG-59-112

May 1962

Bethlehem, Pennsylvania

Fritz Laboratory Report No. 277.34.3
STATUS REPORT OF RESEARCH PROJECT
ON
IMPROVING DESIGN OF A HOPPER DREDGE PUMP

I. INTRODUCTION


II. EXPERIMENTAL STUDIES

A. General Comments

The detailed analysis of the performance of the pump under the variety of conditions investigated under phases 2 and 3 is under way as part of phase 4 of the project.

* See References for complete listing
B. **Discussion of Results**

1. **Effect of Exit Angle**

   It was recommended in Memorandum No. M-33 that an additional series of tests with an impeller having a 16 1/2° exit angle be authorized. A word is awaited from the Sponsor on this matter.

C. **Volute Studies**

   The volute casing has been redesigned, using the 11-inch clearance value and having four centers of circular arcs defining the volute shape. The method used was that described in Reference (3).

D. **High-Speed Movies**

   The analysis of high-speed movies of flow in the suction pipe was completed, but no appreciable prerotation was observed for any speed or flow conditions. The movie has been edited and spliced.

   In addition, movies taken earlier in the program have been edited and spliced.

   A bronze impeller with plexiglas shroud on the suction side was installed in the pump and preparations for high-speed
movie are being taken. However, the camera has not arrived back from the repair shop. After repeated inquiries we were assured that the camera will be delivered this week.

III ANALYSIS

A. Dimensionless Plots

Plots of dimensionless head versus dimensionless discharge or \( \frac{gh}{D^2N^2} \) versus \( \frac{Q}{ND^3} \) were presented in Memorandum No. M-33. A sample plot of dimensionless brakehorsepower \( \frac{BHP}{N^3D^5\rho} \) versus dimensionless discharge \( \frac{Q}{ND^3} \) was prepared and is attached to this report (Fig. 1).

The dimensionless head is sometimes called the head coefficient and the dimensionless discharge the capacity coefficient. With these curves we may determine head and brakehorsepower for any geometrically similar pump at a certain flow and speed.

The following is an example of the use of these curves.

Given: Pump geometrically similar to dredge pump with impeller TD-7

Impeller diameter of 60 inches
Density of mixture is 1200 grams/liter
Flow rate is 35000 gallons per minute
Speed is 200 revolutions per minute
Find: Brakehorsepower, head and efficiency

Solution: \( Q/ND^3 = 35,000 \left(2.228 \times 10^{-3}\right)/200 \left(0.1047\right)\left(60/12\right)^3 \)

\[ = 30.5 \times 10^{-3} \]

From Fig. 1, \( \text{BHP}/N^3 D^5 \rho = 7.35 \times 10^{-6} \)

Thus \( \text{BHP} = 7.35 \times 10^{-6} \left(N^3 D^5 \rho\right) \)

\[ = 7.35 \times 10^{-6} \left(200 \left(0.1047\right)^3 \right)(5)^5 \left(1.94\right)(1.2) \]

\[ \text{BHP} = 503 \]

Also, from Fig. 2, \( Hg/N^2 D^2 = 11.0 \times 10^{-2} \)

Thus \( H = 11.0 \times 10^{-2} \left(200 \left(0.1047\right)\right)^2 \left(5\right)^2 / 32.17 \)

\[ H = 37.7 \text{ feet of liquid} \]

Efficiency = \( \frac{\text{Water Horsepower}}{\text{Brake Horsepower}} \times 100 \)

Water Horsepower = \( Q \times H / 550 \)

\[ = \frac{35000 \left(2.228 \times 10^{-3}\right)(1.2)\left(62.4\right)\left(37.7\right)}{550} \]

\[ = 348 \]

Efficiency = \( \frac{348}{503} \times 100 \)

\[ = 69.3\% \]
REFERENCES

Herbich, J. B. et al
STATUS REPORT OF RESEARCH PROJECT ON IMPROVING DESIGN OF
A HOPPER DREDGE PUMP. Fritz Engineering Laboratory
Memoranda No. M-1 to M-6, M-8 to M-15, M-17, M-19 to M-22,
M-24, M-26 to M-28, M-31, M-32, M-33,
Lehigh University, 1958-1962

Herbich, J. B.
CHARACTERISTICS OF A MODEL DREDGE PUMP, Fritz Engineering
Laboratory Report No. 277-P.R. 31,
Lehigh University, 110 pages, September 1959

Herbich, J. B., Vallentine, H. R.
EFFECT OF IMPELLER DESIGN CHANGES ON CHARACTERISTICS OF
A MODEL DREDGE PUMP, Fritz Engineering Laboratory
Report No. 277-P.R. 33,
Lehigh University, 207 pages, September 1961
Fig. 1  Dimensionless Brake Horsepower - Flow Curves for Impeller TD-7
Fig. 2 Dimensionless Head - Flow Curves for Impeller TD-7
Civil Engineering Department
Fritz Engineering Laboratory
Hydraulics Division

Memorandum No. 35

DEPARTMENT OF CIVIL ENGINEERING
FRITZ ENGINEERING LABORATORY
LEHIGH UNIVERSITY
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STATUS REPORT OF RESEARCH PROJECT
ON
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Prepared by
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Prepared for
U. S. Army Engineer District, Philadelphia
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Philadelphia 29, Pennsylvania
Contract No. DA-36-109-CIVENG-59-112

July 1962
Bethlehem, Pennsylvania

Fritz Laboratory Report No. 277.34.4
STATUS REPORT OF RESEARCH PROJECT

ON

IMPROVING DESIGN OF A HOPPER DREDGE PUMP

I. INTRODUCTION


II. EXPERIMENTAL STUDIES

A. General Comments

The detailed analysis of the performance of the pump under the variety of conditions investigated under phases 2 and 3 is under way as part of phase 4 of the project.

* See References for complete listing
B. High-Speed Movies

The high-speed camera was received back from the Fairchild Camera and Instrument Company and the majority of the high-speed movies were taken during the report period. Three series of movies were taken:

1. One series with discharge kept constant at 1000 GPM and the following pump speeds: 1150, 1300, 1440, 1550, 1650, and 1750 RPM.

2. Second series with pump speed kept constant at 1440 RPM and the following discharges: 0, 200, 400, 600, 800, 1000, 1200, and 1400 GPM.

3. Third series with pump speed kept constant at 1300 RPM and the following discharges: 600, 800, 1000, and 1200 GPM.

All recent movies were taken with impeller No. TD-7 installed in the pump; the impeller has a plexiglas shroud on the suction side of the pump.

Analysis of the movies is proceeding at an accelerated pace, and the results of the analysis will be presented in the final report currently in preparation.

III. ANALYSIS

A. Dimensionless Plots

Dimensionless brake-horsepower $BHP/N^3D^{5/2}$ versus dimensionless discharge $Q/ND^3$ plots similar to Figure 1 of Memorandum M-34 were
prepared for other impellers. It is believed that dimensionless plots are very useful in predicting performance of prototype pumps.

B. Specific Speed - Efficiency Plot

A sample plot of specific speed versus efficiency was prepared for pump with impeller No. TD-7 handling water. The maximum efficiency is for a specific speed of about 1800 as compared with ESSAYON'S specific speed of 1680. (Fig. I)

C. Additional Plots

Additional plots are being prepared for the final report; these include, but are not limited to, the "efficiency % of normal" versus "capacity, % of normal", "head, % normal" versus "capacity, % of normal, etc."
REFERENCES

Herbich, J. B. et al

STATUS REPORT OF RESEARCH PROJECT ON IMPROVING DESIGN OF
A HOPPER DREDGE PUMP. Fritz Engineering Laboratory
Memoranda No. M-1 to M-6, M-8 to M-15, M-17, M-19 to M-22,
M-24, M-26 to M-28, M-31, M-32, M-33, M-34

Herbich, J. B.

CHARACTERISTICS OF A MODEL DREDGE PUMP, Fritz Engineering
Laboratory Report No. 277-P. R. 31,
Lehigh University, 110 pages, September 1959

Herbich, J. B., Vallentine, H. R.

EFFECT OF IMPELLER DESIGN CHANGES ON CHARACTERISTICS OF
A MODEL DREDGE PUMP, Fritz Engineering Laboratory
Report No. 277-P. R. 33,
Lehigh University, 207 pages, September 1961
SPECIFIC SPEED vs. EFFICIENCY
IMPELLER TD 4.7
$\rho = 1000 \text{ g/m}^3$.

**Fig. 1** EFFICIENCY as a function of SPECIFIC SPEED