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THEORETICAL AND EXPERIMENTAL INVESTIGATION OF FLOW FIELD IN RADIAL VANED IMPELLER

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ABSTRACT

The flow field in radial impeller of a centrifugal pump has been predicted by assuming two dimensional ideal flow. The Poisson's equation, describing the flow field, is solved numerically by relaxation method, for both circulatory and flow fields. The theoretical impeller head was calculated as the mean value of the head generated by each stream tube in the impeller flow pattern. In spite of neglecting the boundary layer effect, the experimental results show a satisfactory agreement with the theoretical results, at part loads. This shows that the main predominant factor controlling the pump characteristics at part loads is the vortex formation in the impeller channel, and that the boundary layer has a minor effect in that operating region.

Introduction

The flow investigation of flow in a radial vaned impeller, is of special interest to many investigators due to the simplicity of experimental and theoretical analysis. Several techniques have been used to solve the flow field in the pump impeller, such as the singularity, finite difference, and finite element methods, [1,3,4].

Herein, the relaxation method has been used to solve numerically the Poisson's equation describing the flow field, for different working conditions of speeds and flow rates. The flow inside the impeller channels may be divided into two parts, that due to rotational flow without discharge, and that due to flow without rotation. The channel flow pattern is obtained by superimposing these two parts of flow. The theoretical heads, for different flow rates and speeds, are calculated as the mean value of the heads generated by the channel stream tubes.

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Flow Field Inside the Impeller Passages

The fluid flow field inside the impeller passages is unsteady three dimensional flow. For radial type impellers, the relative flow field may be assumed as quqsi-stationary, which may be described by Poisson's equation,

$$\nabla^2 \psi = -2\omega \tag{1}$$

where ψ, is the stream function, and ω is the impeller rotational velocity, [5].

For two dimensional ideal fluid, the Poisson's equation can be written in difference form, in polar coordinates, as,

$$\psi_{i,j} = A_1 (A_2 \psi_{i+1,j} + A_3 \psi_{i-1,j} + A_4 (\psi_{i,j+1} + \psi_{i,j-1}) + 2\omega) , \tag{2}$$

where $\psi_{i,j}$ is the stream function at node (i,j), as shown in Fig.1, and , (the notations are given in the figure),

$$A_1 = 1/(2\ (1/S1^2 + 1/S^2))$$
$$A_2 = 1/S1^2 + 1/2rS1$$
$$A_3 = 1/S1^2 - 1/2rS1$$
$$A_4 = 1/S^2$$
$$S1 = \Delta r$$
$$S = r\Delta\theta \tag{3}$$

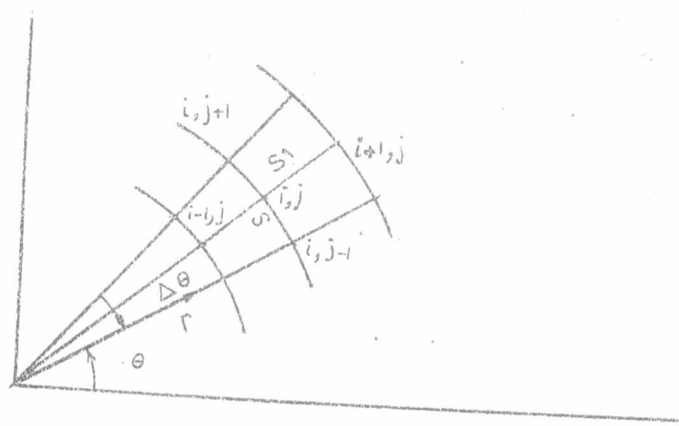

Fig.1. Polar Coordinates, Nodal Identification

The flow field may be divided to two main parts, [7],

- rotational flow without discharge, and
- flow field without rotation of the impeller. For radial vaned impeller, the flow field, without rotation, is of radial stream lines.

For the first part of flow field, equation (2) may be written for each nodal point of the pattern. The system of equations relating the stream functions at nodal points, can be solved by relaxation method [2,6]. The stream lines have been drawn by interpolation between the nodal stream functions, Fig.2.

The stream lines of the flow field without rotation, are radial lines. The stream function for each impeller channel is,

$$\psi_{ch} = Q / (z \cdot \bar{b}) \quad , \qquad (4)$$

where Q is the impeller volume flow rate, z is the number of vanes, and $\bar{b}$ is the impeller mean width.

Fig.3 shows the flow pattern, without rotation, for the radial impeller considered in the experimental part.

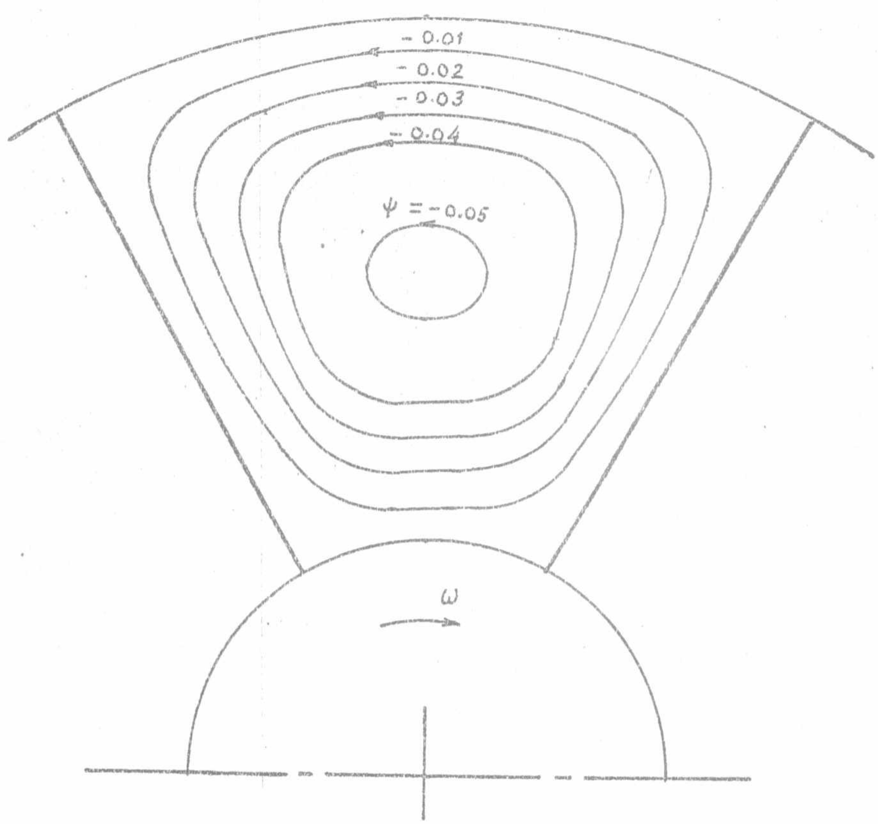

Fig.2. Rotational Part of the Stream Lines

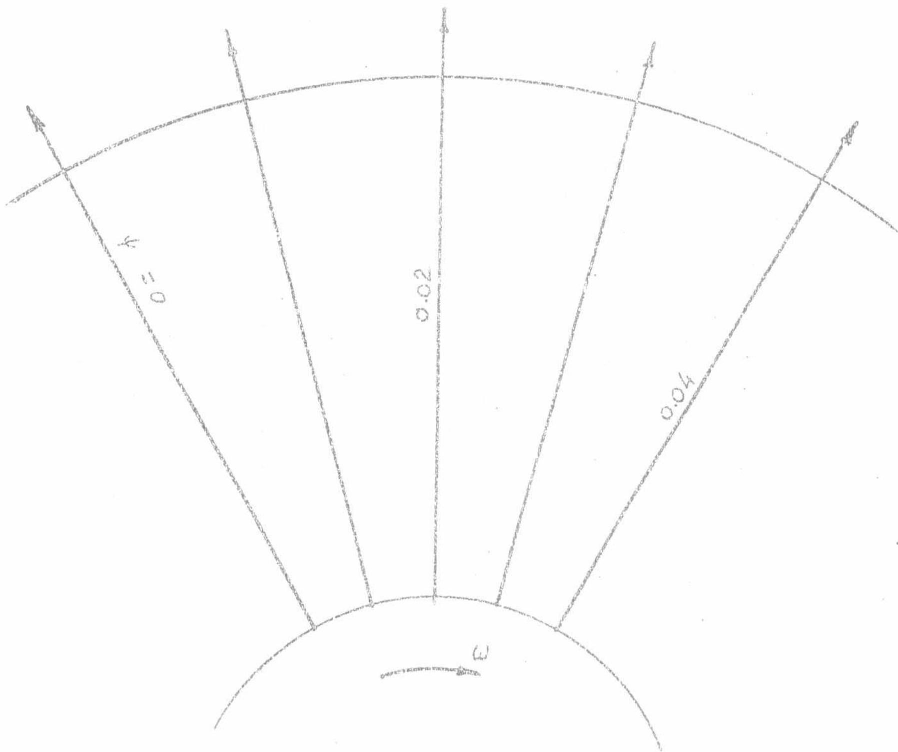

Fig.3. Flow Pattern without Rotation

The flow pattern for different flow rates, are obtained by superimposing both parts of flow rates. Figures 4 and 5 are two examples of the flow patterns for part and over flow rates. For part loads, of partial flow rates, the vortex zone affects widely the flow pattern, and hence the flow characteristics.

Impeller Theoretical Head

The impeller theoretical head for different flow rates, may be calculated as the mean head, produced by each stream tube of the impeller flow field. The theortical head, for finite number of vanes, is,

$$H_t = \sum_{i}^{n} Q_i \; H_i / \sum_{i}^{n} Q_i \tag{5}$$

where Q_i and H_i are the flow rate and head of the i-th stream tube. The theoretical head H_i for each stream tube has been calculated by drawing the velocity triangles at inlet and outlet of the impeller. Fig.6 shows the theoretical characteristics for the the radial impeller, which has been studied experimentally.

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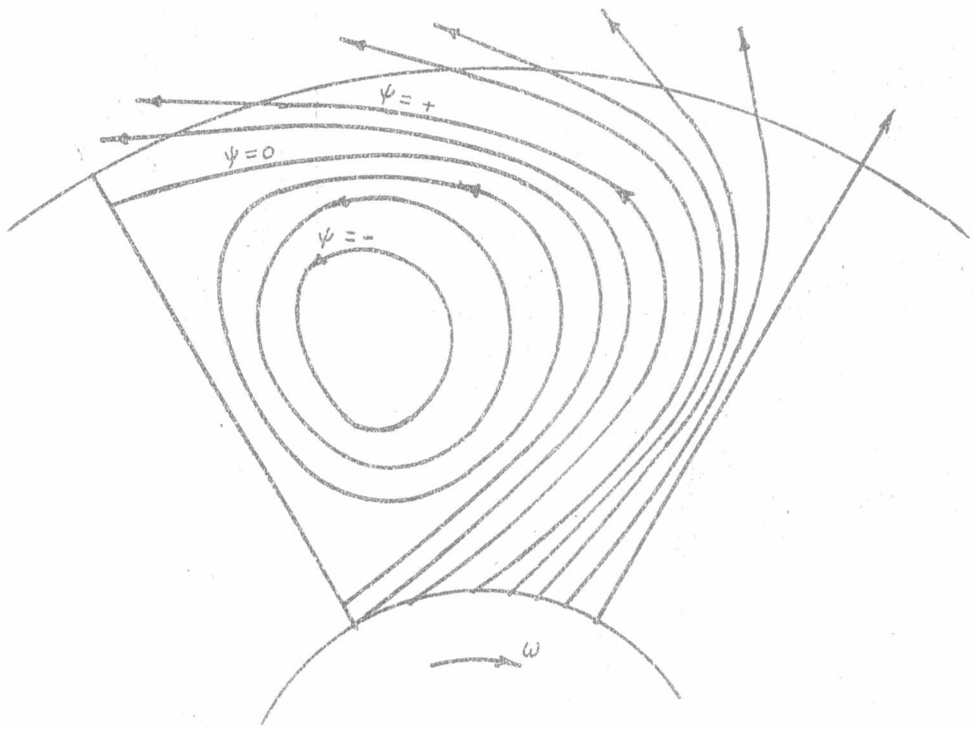

Fig.4. Flow Pattern for Partial Loads

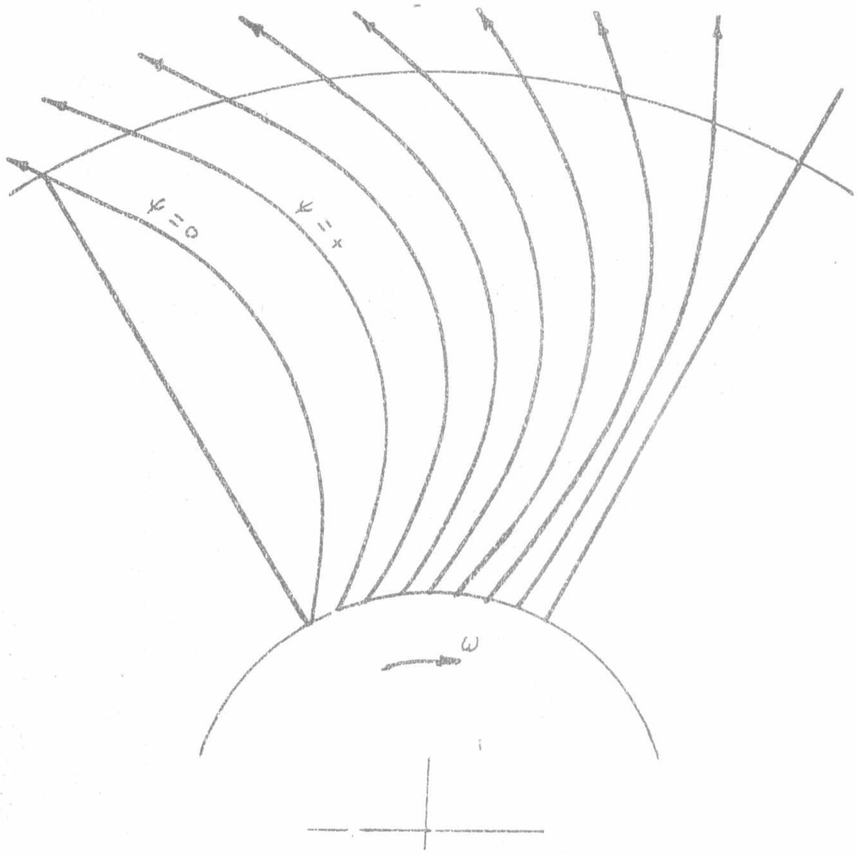

Fig.5. Flow Pattern for Overloads

Experimental Investigation

To verify the theoretical model, assumed for the flow pattern in radial vaned impellers, an impeller having the following dimensions,

inner diameter d_1 = 0.04 m,

outer diameter d_2 = 0.13 m,

inlet width b_1 = 0.014 m,

outlet width b_2 = 0.011 m,

number of vanes z = 6 ,

has been studied experimentally. The impeller was fitted in the casing of a centrifugal pump, and has been tested in a standard test rig, to measure the pump speed n, the flow rate Q, and the head H. For a speed of 2000 rpm, Fig.6 gives the experimental results, as well as the theoretical ones.

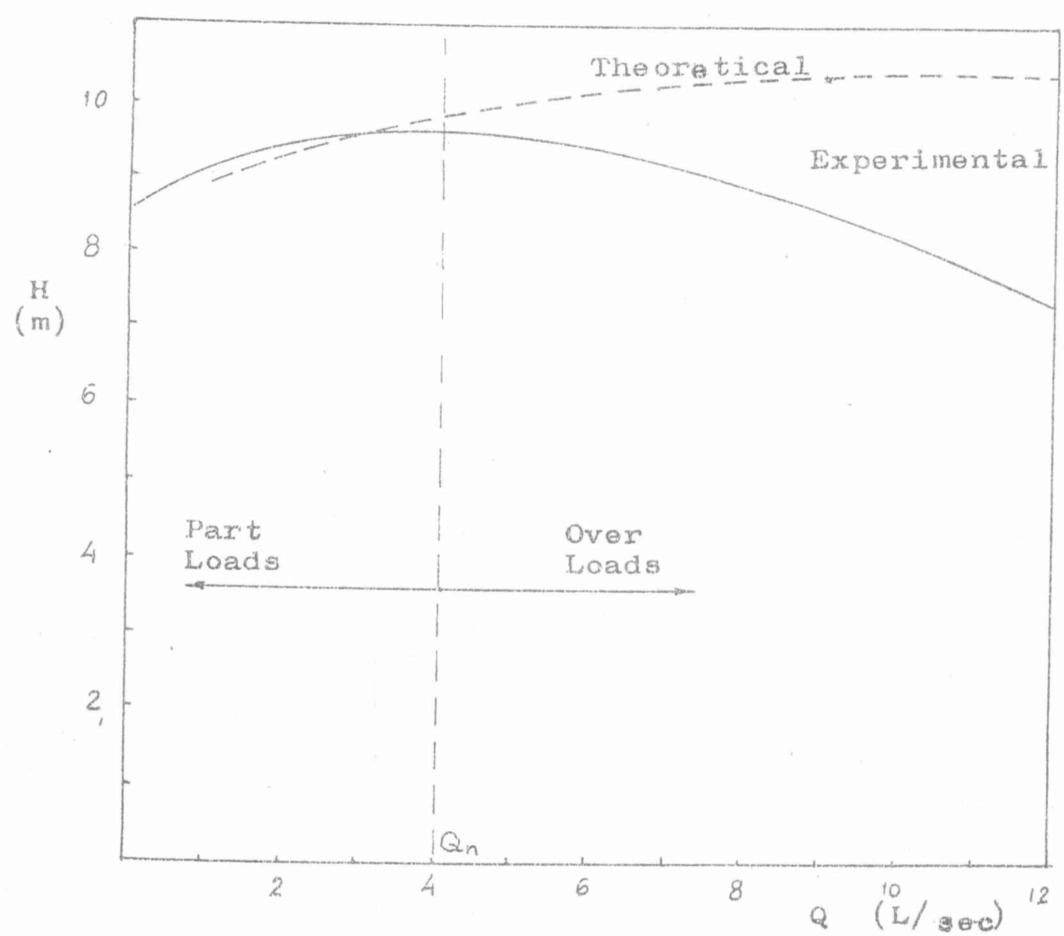

Fig.6. Experimental and Theoritical Results

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In spite of neglecting the boundary layer, and the three-dimensions effect, the experimental results have shown a satisfactory agreement with the theoretical ones, at part loads. At higher loads, flow rates, boundary layer as well as seperation effects, have to be taken into consideration. That shows the importance of the vortex formation and shedding on the flow pattern and the impeller characteristics. The boundary layer has a minor effect in these operating zones.

Conclusions

The solution of the flow field, by assuming a two dimensional ideal flow, shows that at partial flow rates, the vortex flow is the predominant factor that affect the impeller performance. At higher flow rates, the boundary layer effect as well as the flow seperation, have to be considered. The experimental investigation, on a radial vaned impeller, has verified the theoretical results, with satisfactory agreement.

References

1. Lotfy, A. " Pressure Fluctuations in Radial Flow Cent. Pumps at Part Loads", M.Sc. Thesis, Military Tech. College, Cairo (1981).
2. Olson, R.M. " Essentials of Engineering Fluid Mechanics ", 3rd. edition, Intext Educational Publishers, New York, (1973).
3. Kamimto, G. et al. " Theory of Centrifugal Type Impellers with Vanes of Arbitrary Form", Bulletin of JSME, vol. 2, (1959).
4. Kamimto, G. et al. " One Method of Calculating the Flow in a Centrifugal Type Impeller, Especially with Large Number of Vanes and with Splitted Vanes", paper no.B-12, proceeding of IAHR symposium, Sendai, Japan, (1962).
5. Massey, B. " Mechanics of Fluids", Van Nostrand, (1975).
6. Schield, F. "Theory and Problems of Numerical Analysis", Schaum's Outline Series, McGraw Hill Book Company, (1968).