thrust at the starting is obtained by calculating transient operating conditions of the pump.

Conclusions

Experiments were carried out to investigate the axial hydraulic thrust caused by the pump starting. The following conclusions are deduced.

1 When the discharge pipe is not filled with water before starting, an upward axial thrust is caused under transient starting conditions. In this case the pump speed reaches its rated value in a condition of very low head, and the pump operating point passes transiently the high discharge range, where the impeller is subjected to the upward axial thrust. When the discharge pipe is filled with water before starting, the upward axial thrust is not observed. In this case the pumping head increases rapidly at the starting, and the pump operating point does not pass the high discharge range.

2 The axial thrust in the case of the balance holes drilled inside the water channels of the impeller is about twice those in case of the balance holes drilled outside the water channels. This difference is due to the pressure difference in the balance chamber in both cases.

3 The transient axial thrust, which is obtained from the axial thrust measured under steady operating conditions and from the transient pump operating conditions, agrees fairly well with that measured by the load cell.

4 When measurements of the axial thrust under steady operating conditions have been obtained, the maximum upward axial thrust at the starting is obtained by calculating transient operating conditions of the pump.

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DISCUSSION

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As a serious student in seeking the nature of axial thrust of vertical turbine pumps for many years, this writer wishes to express his heartiest appreciation for the excellent experimental work conducted by the authors. He enjoyed the paper so much that he only asks for more after reading it. Lacking facilities to measure the thrust during the transient period and the pressure distribution around the impeller, this writer has drawn conclusions by analyzing the thrust data available to him. These conclusions can now be checked against the experimental results of the authors. The sketchy discussion on the upthrusting phenomenon during pump starting, as given in reference [6] is confirmed and greatly detailed by the authors' work. The momentum change in the flow through the impeller has been considered by many as the sole cause of upthrust. But calculated upward force due to this momentum change is always small in comparison with that measured by scale, load cell or other device. This leads one to a speculation that pressure distribution must also contribute the upthrust. Fig. 9(*a*) verifies this conclusion.

Following are a few comments about this paper:

1 Nearly all the tests were conducted using impellers with holes drilled inside the water channels. To begin with, impellers with balance holes are not common. And to drill holes inside the water channel appears strange, as there is apparently no practical usage for this kind of impeller. Therefore, the purpose of this paper is apparently obscured by the use of an odd impeller configuration.

2 The authors did not show formulas for the thrust calculations, nor did they state that their findings would be applicable to all kinds of centrifugal pumps. Since thrust depends a great deal on the specific speed of the pump, caution should be exercised in extending the results to pumps with specific speeds far different from those used in the experiments.

3 The third sentence of the paper, "This upward thrust is not observed under steady operating conditions," is not a true statement. Fig. 6 shows upthrust under a steady condition. And field observation of continuous upthrusting is rather common.

4 Referring to Fig. 9(*b*), can the authors provide some explanation of why the pressure in the balance chamber is lower than that at the impeller eye?

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