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USE OF AIR IN TESTING HYDRAULIC MACHINES

by

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Translated From Le Genie Civil
April 30, 1938, Pages 371-374

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Denver, Colorado

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Hydraulic turbines have today attained such a degree of perfection that important advances seem difficult to realize. This progress has been due principally to the tendency toward higher speeds which among other advantages leads to more compact construction.

In the modern high speed turbine the correct shape of the parts that are in contact with flowing water and the finish of the surfaces play a considerably larger role than in a slower-speed wheel and the importance of this role cannot be overestimated. The modern vanes have become very sensitive to inaccuracies of form and manufacture which imposes on the engineer the necessity of making further studies of the particulars of flow and justifies a rigorous study of all the details.

The most recent progress in the design of hydraulic machines has been obtained by utilizing the latest results of experimental hydrodynamics. The conception of a "mean flow" which constitutes the basis for hydraulic calculations is not sufficient for explaining the more delicate particulars of flow such as the influence of the boundary layer and separation, the importance of which has been demonstrated by experience.

In making a detailed study of flow phenomena the engineer prefers the procedure of model testing. Up to the present time the use of water for systematic research on the elements or on the assembly of hydraulic machines was the usual thing because water is the fluid which presents itself to the mind of the hydraulic engineer and little use has been made of the knowledge that liquids and gases act in an analogous manner under many conditions.

However, the possibility of utilizing a gas, particularly air, as the experimental fluid, offers many advantages over the purely hydraulic method.

A new aerodynamic division for studying hydraulic turbines has been installed in the laboratories of the Escher Wyss Company at Zurich for the purpose of investigating the possibility of replacing water by air and determining the limits within which this procedure is dependable. This new type of installation permits both a qualitative and a quantitative measurement of the complete characteristics of hydraulic machinery just as well as a hydraulic laboratory. The results of completed studies with air and with water on the same working models agree perfectly.

Compared with hydraulic studies this new method of testing has the advantage of facilitating the measurement, at every point, of the installation of the characteristic values of the machine; heads, pressures, velocities, and velocity distributions. The accuracy of measurement is at least as good as that obtained with water and even better when the steady state can establish itself instanteously and when it can be maintained easily.

In hydraulic studies, the entire installation and in particular the model where measurements are desired, is situated below the water surface and this makes it difficult for the direct observation of flow which is very instructive. This is not the case for installations using air. Besides the operation with air is much less cumbersome than with water and this increases the rapidity of measurements.

Aerodynamic Station for Hydraulic Turbine Testing

In this type of set-up a blower forces air to flow through the machine being tested or through a model which exactly reproduces it. The quantity of air flowing is measured precisely with a standard measuring nozzle. The hydraulician will have difficulty in making use of air in place of water in a test set-up because he cannot overcome the idea of air as an easily compressible fluid, whereas in the construction of hydraulic machines liquids are considered incompressible. On first thought air seems to him to be the fluid least indicated for replacing water. However, if one approaches the problem from the viewpoint of the physicist or the aerodynamician, one can see that in the region considered in practice, the differences are quite small and that there is a precise numerical relationship for pressures and velocities between a liquid and a gas. In setting up the limits it is observed that the compressibility of air does not enter the phenomenon in a troublesome manner, that is to say, on determining the point up to which air can be treated as a liquid, it is sufficient to use the general equation for the dynamics of gases.

This problem has been treated in detail in the "Schweizerische Bauzeitung" of October 17, 1937 under the title "Aerodynamic Stations for Testing Hydraulic Turbines". Without reproducing this article here, we will indicate briefly the results and the essential applications for the research engineer.

As we have stated, air in the region which interests us undergoes only insignificant variations in density during the course of its passage through the machine.

In Bernoulli's equation:

$$p + \frac{W\,V^2}{2g} + W\,Z = \text{constant}$$

the density W/g of air varies but fortunately not enough to upset calculations. Figure 2 shows the variation in density of air in motion compared to air at rest. for different velocities. Around 100 meters per second (328 feet per second) this correction is only about 4 percent. Thus it is possible when velocities are much less than this value to assume constant density as in the case of water in the continuity and energy equations. The computations show that the influence of compressibility of air in the formula for velocity head is even less than for the equation of continuity. This can be seen on figure 3 which gives the correction to be applied to velocity head for different velocities. According to the computation the velocity head of a compressible gas at 100 meters per second (328 feet per second) differs only by 2 percent from that in a liquid. From other theoretical considerations it can be seen that the influence of the compressibility of air on the value of lift coefficient C_a of a blade profile is likewise very small. This coefficient is a very important characteristic in the design of modern turbines and pumps.

Thus the distrust professed by the hydraulician toward using air for quantitative measurements is far from being justified. The mechanical properties of this fluid for purposes of replacement remain what may be considered constant in the region of operation and even up to a velocity about 100 meters per second (328 feet per second). Is there, then, any reason to expect that the thing which varies so little has a decisive effect on the flow phenomena. on the energy exchange. and on the performance of the machine?

This conclusion has been entirely confirmed by aerodynamics studies completed during the last few years in the Escher Wyss laboratories. The same wheels operating with air and then with water have shown a perfect identity of characteristics as shown on figure 5.

An aerodynamic station can be set up in two different ways. In the first, represented schematically on figure 6, air is drawn into a closed system and finally discharged into the atmosphere. In the second, air is forced under pressure through the turbine model being tested and then through the measuring nozzle as shown in figure 7. In the set-up called variation A

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(figure 6) blower (1) sucks air through the installation and discharges it into the atmosphere. Air enters by opening (3) and is delivered by the distributor to turbine (4) and then flows into the stabilizing chamber (5). From there it passes through the measuring nozzle (6) and through blower (1). The power developed by the turbine is measured by a hydraulic or electric brake. The elements from (a) to (c) figure 6 are, properly speaking, parts of the turbine and the variation of pressure is shown schematically from (a) to (g) on the graph below.

In variation B (figure 7) is pumped by blower (1) into the volute (3) of the turbine, then passes into stabilizing chamber (5) so that discharge can be measured by nozzle (6). The letters have the same significance as on figure 7 and the graph of pressure is presented in the same manner.

In all cases it is necessary to insure that the approach of air to the turbine model be very stable. Also disturbances in the jet approaching the nozzle should be avoided because this makes for errors in measurement. The nature of the studies to be undertaken will determine the choice of variation to be used. The set-up in which air is drawn in through the installation has the advantage of entirely separating the approach of air to the model so that there is no danger of disturbance at this point. Figure 1 shows a view of the Escher Wyss testing station set-up on this principle.

The entire construction may be of light sheet iron or even wood. The suction pipe and the turbine support are readily disassembled. Figure 9 shows another view of the installation with the elements of the turbine designated by the darkened portions. The difference from figure 1 is that the turbine in this case is preceded by a scroll case. Air is drawn in downward into the spiral casing under the action of a blower located on the left in figure 1.

With a drop in pressure of about 100 millimeters (3.28 feet) of water, the turbine model with air will have a much higher peripheral speed than a hydraulic model and this allows Reynolds numbers of the same order of magnitude as in the usual hydraulic testing stations. The hydraulician accustomed to working with heads of several meters at least must naturally have to make a definite effort to adapt himself to working with only several centimeters. Here the prototype head on a turbine is replaced by a difference of pressure between the entrance to the turbine (in figure 6) the surrounding atmosphere) and the pressure in the stabilizing chamber. For the usual model scale the output is 10 to 20 ch (   ) and even more. That is to say the power can be easily measured with high precision. The measurement of very small pressure variations does not offer any difficulty in principle; those are the problems of testing that aerodynamic technique has already solved.

In addition to the measurement of power and performance which can be accomplished just as in a hydraulic testing station aerodynamic testing allows an easy and precise measurement of the pressure variation at any point in the installation. This permits the separate determination of losses in each element of the machine; scroll case, runner, suction line, etc. It has even been possible to measure accurately the distribution of pressure along the blades of a Kaplan runner during operation. Such measurements enrich our knowledge of the flow around the blades and make it possible to see what is happening when the turbine is operating. It is possible in all cases to directly observe the flow in all its particulars, its disturbances and local singularities and this observation affords a number of advantages. Figure 8 gives the results of measurements on a cylindrical section through the grill of a Kaplan propeller in motion.. The distribution of pressures is shown and the effect of the grill can be deduced.

A knowledge of the pressure distribution on the surface of the blade for all conditions of operation furnishes a new means for predicting cavitation under certain heads. It is possible from the pressures measured at an aerodynamic station to compute the pressures which will be produced in the prototype functioning with water. In the computation it is necessary to consider the speed of rotation, the model scale, and the specific gravity of the fluid. It is understood that aerodynamic tests will never completely supplant water in cavitation studies because with water the occurrence of cavitation modifies the distribution of pressure on the blade. These curves of pressure distribution nevertheless, give the engineer a very clear picture of the flow around the profile and permit him to suppress the undesirable points of low pressure by proper design.

Another advantage of aerodynamic studies is that through the use of Pitot cylinders and spheres * which give an exact

*For Pitot cylinders see: C. Keller "Nouvelles installations d'essais et travaux de recherches recents dan le domaine des turbo-compresseurs". Bulletin, Escher Wyss, 1935, p. 156.

measurement of the air velocities in magnitude and direction, it is easily possible to show the velocities at the entrance and exit of the runner or at any other point in the turbine. The formation of air bubbles and the forces exerted on the instruments by the flowing water render the use of Pitot tubes difficult and uncertain in hydraulic studies. All these inconveniences are done away with by using air in the studies. As for the measuring instruments they have been developed for experimental aerodynamics and indicate without difficulty pressures as low as a few centimeters of water.

The satisfactory experiments made in the aerodynamic station on turbines have encouraged us to extend this method to studies of hydraulic pumps. The theoretical basis for these studies is the same as for studies replacing water by air in turbines. The set-up in a closed circuit (figure 10) has been suggested by Prof. Ackeret of the Polytechnic School at Zurich and was inspired by the variable density tunnels used in aviation. The pump model (2) driven by motor (1) circulates air instead of water in a closed circuit. The air discharged by the pump is measured by means of nozzle (6). The yield and the characteristics of the test runner are determined by the increase of pressure through the pump impeller and by the power absorbed. The heat developed in the circuit is dissipated by a radiator (4). The pressure in the circuit can be established at any value up to several atmospheres. It is also possible because of the closed set-up to use gases other than air and with a different viscosity. This provides a means for varying Reynolds' number, which plays a decisive role in high specific speed wheels, between extended limits and furnishes precise figures for extrapolation formulas by which calculation of prototype performance can be made from model tests. The use of higher pressures reduces the relative importance of inevitable losses from turbulence induced by the pedestals and thus increases the accuracy of measurement.

All these perfections lead us to foresee the numerous applications of aerodynamic stations for testing hydraulic machines where studies and observations of flow phenomena under diverse conditions of operation are singularly facilitated.

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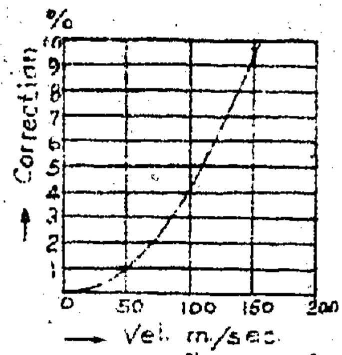


Fig. 2 — Influence of Velocity of flow on the density of air (20° l atm)

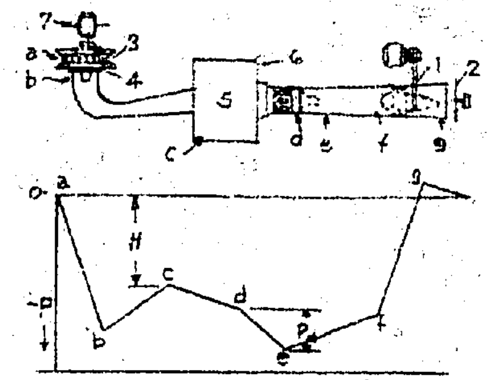


Fig 6 - Sucking in air and variation of pressure. (Var. A)

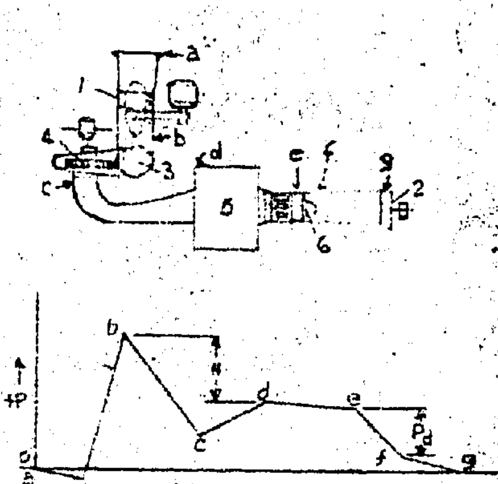


Fig. 7 - Forcing thru air and variation of pressure. (Var. B)

Fig 6+7 - Principle set-ups of aerodynamic stations for hydraulic turbine testing.

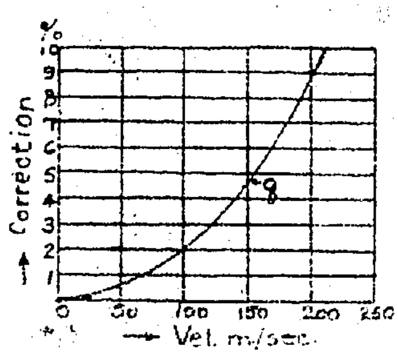


Fig. 3

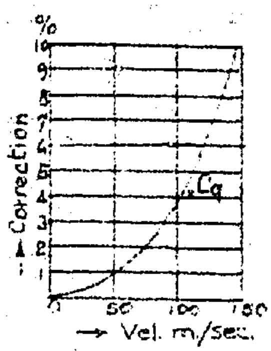


Fig. 4

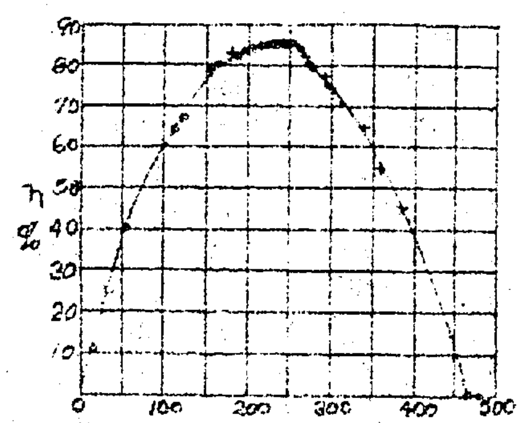


Fig. 5 – Measure of Yield in a model of a Kaplan Turbine with water (+) and with air (o).

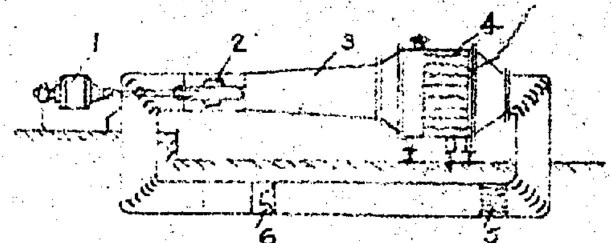
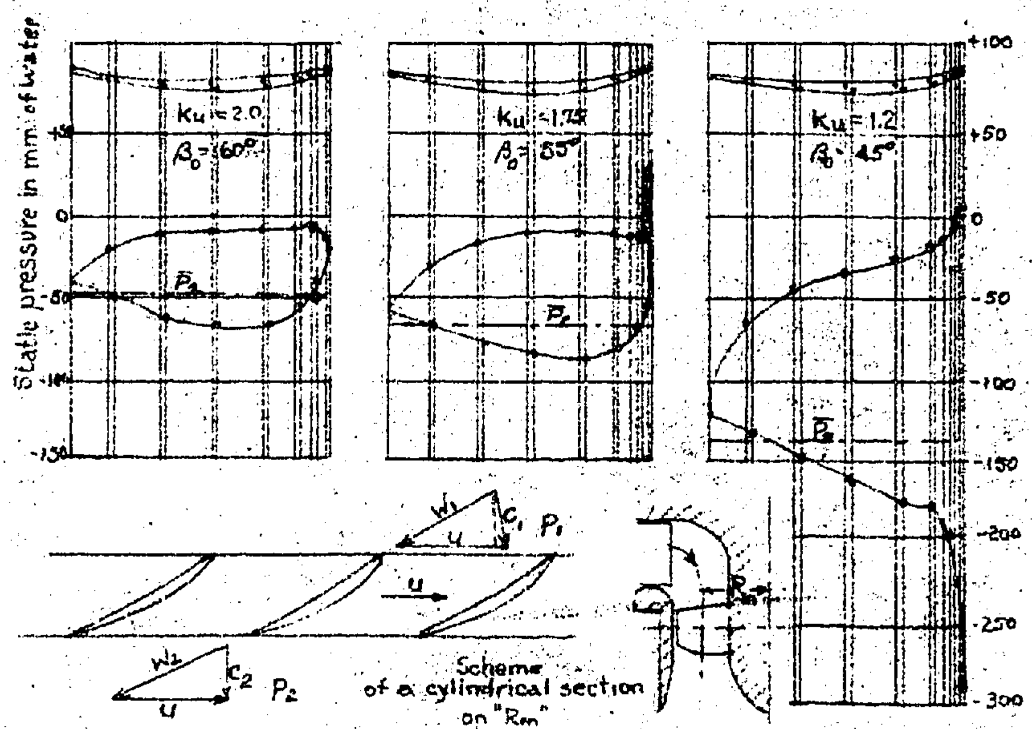


Fig 10 - Scheme of the Escher Wyss Aero-dynamic Station for testing model pumps.



<u>FIG 8</u> Measure of pressure distribution on a mean section "Rm" of a Kaplan turbine blade running under diff. heads at n = 1700 t/min.