STEAM TURBINE IMPULSE AND REACTION BLADING

R.A. Chaplin
Department of Chemical Engineering, University of New Brunswick, Canada

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Summary

Turbine blades, and hence turbines having these types of blades, are classified as impulse or reaction. When moving blades are driven entirely by the impact of an external jet impinging upon them, they are known as impulse blades. When the fluid in the moving blades accelerates and leaves the blades at a higher velocity than when it entered them, it imparts a jet reaction to the blades making these reaction blades. With reaction blades there is however always some impulse effect as the fluid enters the moving blades so such blades have only a degree of reaction which is commonly 50 percent.

Conditions in turbine blades can be conveniently visualized and analyzed by drawing vector diagrams of the fluid velocities. Such velocity diagrams corresponding to the inlet and outlet of the moving blades show clearly how the fluid kinetic energy has changed within the blades. From this change the energy transferred to the blades can be deduced. Essentially the loss in kinetic energy of the fluid is equivalent to the transfer of energy to the blades. There are however limits to the amount of energy that can be transferred. The fluid must flow away from the blades with a certain velocity to make way for more fluid so the blade efficiency can never be 100 percent. Furthermore there is always some fluid frictional loss in the blades so the stage efficiency can never be 100 percent. Nevertheless modern steam turbines are very efficient and operate with internal efficiencies within the range of 80 percent to 90 percent depending upon the steam conditions.

1. Turbine Classification

1.1. Blade Profiles

As mentioned in the introductory review, Parsons developed a steam turbine based on the reaction principle while de Laval developed one based on the impulse principle. Since then turbines based on these principles have evolved in parallel and in fact merged to some degree. Outwardly turbines of both types appear identical and, in describing different turbine configurations, it was not necessary to distinguish between the two. Even when disassembled it is not easy at first sight to say which is which. The main difference in fact is in the fixed and moving blade profiles. These profiles determine the direction and velocity of the steam which in turn governs the mode of energy transfer from the steam to the blades, namely impulse or reaction. Turbines are thus classified as being either impulse or reaction. From a practical point of view, this governs the number of stages in a turbine and the maximum steam velocities. These parameters respectively have a slight effect on the capital cost and efficiency of the machine. With this in mind, the principles of impulse and reaction need to be clarified.

1.2. Impulse and Reaction

Govanni de Branca's turbine, illustrated in Figure 1, operates on the *impulse* principle. In this machine the steam issues from a nozzle at high speed and impinges upon a series of blades which are driven and so produce work. The kinetic energy of the fluid stream is transferred to the rotating wheel by momentum transfer within the blades. The Pelton wheel using water operates on the same principle. Hero of Alexandria's turbine, shown in Figure 2, operates on the *reaction* principle. Steam issuing from the nozzles at high velocity creates a reaction in the opposite direction. This reaction drives the wheel and the energy of the fluid is transferred to the rotating wheel. The common garden rotary lawn sprinkler operates on the same principle using water. When the principles are translated to large machines the mass flows become very large relative to the machine itself and the impulse and reaction effects are very strong.

The modern space rocket operates purely on the reaction principle but it generates its working fluid on board by burning fuel. In other machines, which operate on the reaction principle but receive the working fluid from a fixed external source, provision must be made to transfer the working fluid to the moving parts. Accompanying this transfer from the fixed to moving parts is inevitably some impulse effect. It is the way in which the fluid leaves the moving parts therefore that determines whether or not the machine is based on the reaction principle. In reality a reaction machine is usually partially impulse and partially reaction but is termed reaction to distinguish it from a purely impulse machine.

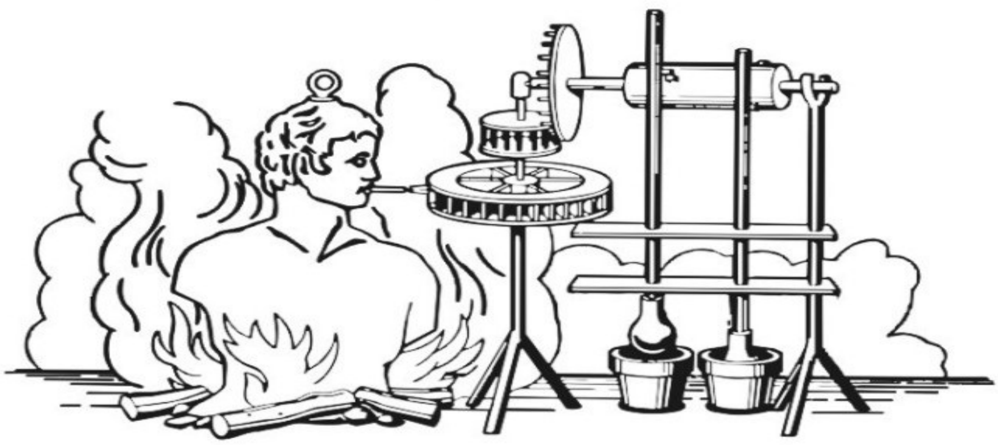

Figure 1: Govanni de Branca's turbine
(courtesy of Babcock & Wilcox)

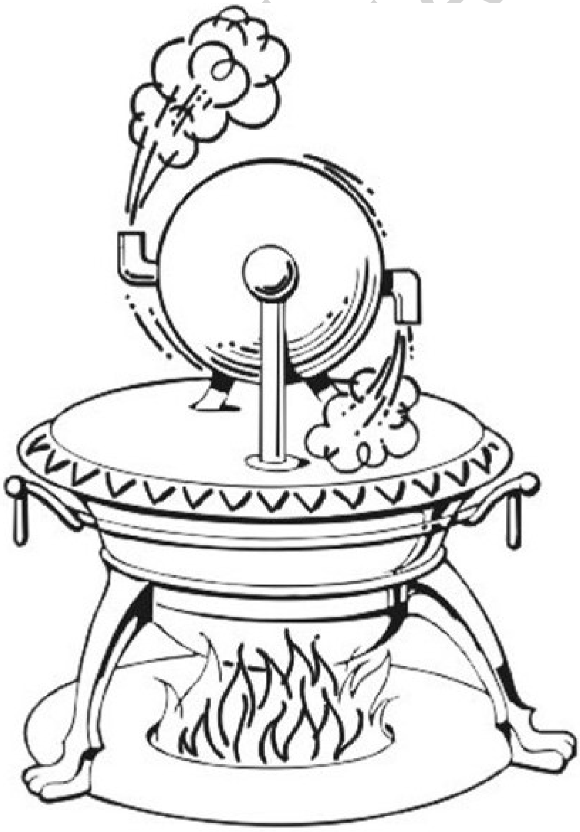

Figure 2: Hero of Alexandria's turbine
(courtesy of Babcock & Wilcox)

In distinguishing between impulse and reaction blading it is necessary to consider what happens to the steam in passing through one stage of fixed and moving blades. In the impulse turbine the entire pressure drop of the stage is concentrated across the fixed blades which act as nozzles. These nozzles accelerate the steam to a high velocity dictated by the conditions before and after the fixed blades. This high velocity steam impinges upon the moving blades and drives them at a certain velocity. Within the moving blades the steam is turned to affect the transfer of energy and leaves at a low velocity relative to the next row of fixed blades. In the reaction turbine however the stage pressure drop is spread across both the fixed and moving blades. The fixed blades act as nozzles and accelerate the steam to a moderate velocity due to the partial pressure drop. This steam then impinges upon the moving blades and imparts some energy to them. Within the moving blades the steam is turned and accelerated by the remainder of the pressure drop. The reaction effect caused by this accelerating steam imparts more energy to the moving blades. The steam leaves the stage at a low velocity relative to the next row of fixed blades. This is illustrated in Figure 3 for impulse blading and Figure 4 for reaction blading.

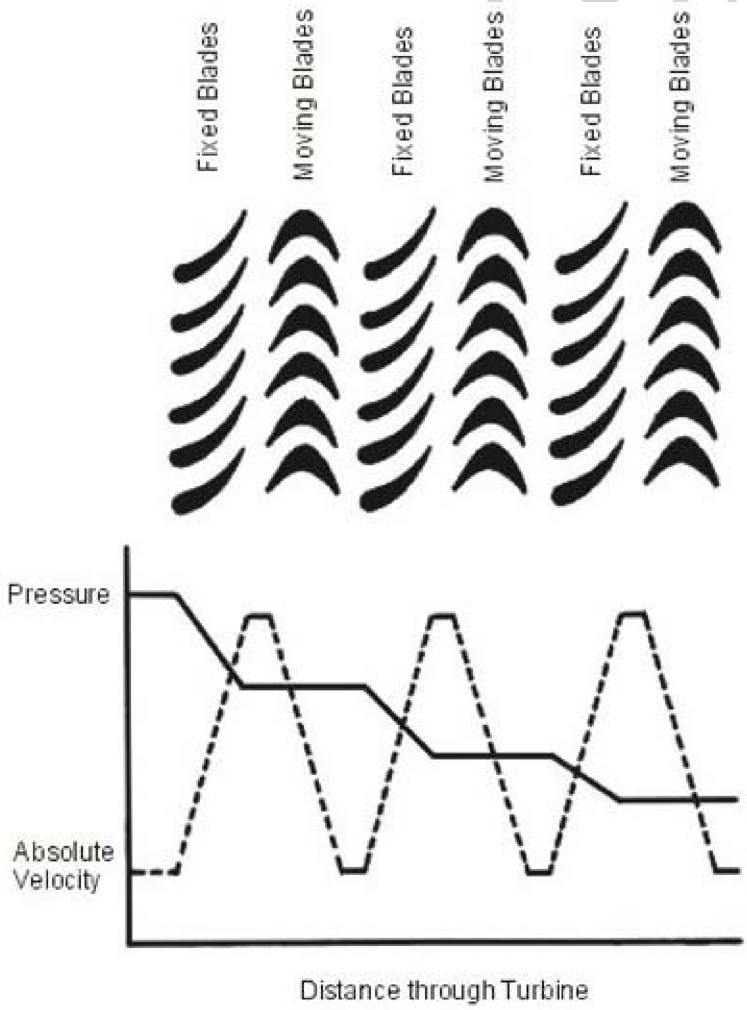

Figure 3: Impulse turbine blading and conditions

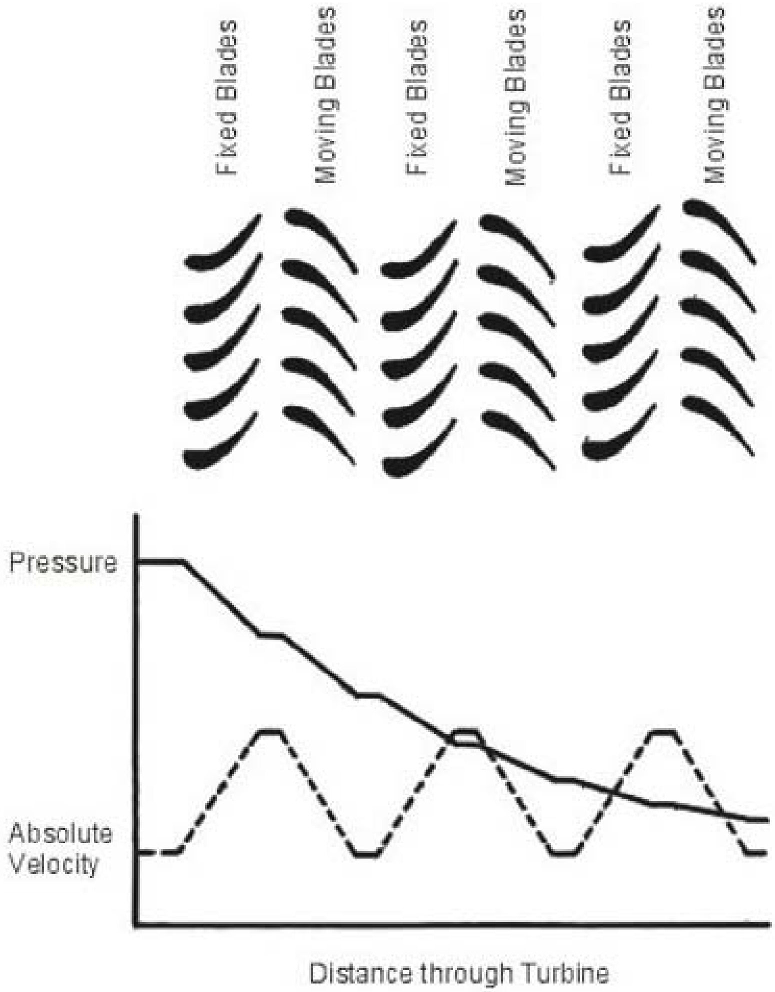

Figure 4: Reaction turbine blading and conditions

Figure 3 shows, at the top, the end view of four stages of fixed and moving blades of an impulse turbine and, at the bottom, the pressure and velocity profiles over these four stages. Since the energy in the steam is represented by the pressure (heat energy) and velocity (kinetic energy), the conversion and transfer of energy in the blading can be visualized. Initially the pressure is high representing a high energy level. In passing through the first row of fixed blades some potential energy is converted into kinetic energy as indicated by the slight drop in pressure and increase in velocity.

In passing through the mating row of moving blades the kinetic energy is transferred to the rotating wheel of the turbine as indicated by the drop in velocity. There is no change in pressure in the moving blades. It is evident that, at the exit from this first stage, the steam has given up part of its initial energy and transferred this to the rotating parts of the turbine. A similar process is repeated in the remaining three stages. Additional stages may be added to extract any remaining energy of the steam.

Figure 4 shows a similar representation of four stages of fixed and moving blades of a reaction turbine given similar boundary conditions. As before, the pressure is initially high representing a high level of energy. In passing through the first row of fixed blades some potential energy is converted into kinetic energy but not as much as in the impulse turbine. There is less of a drop in pressure and consequently a smaller increase in velocity. In passing through the mating row of moving blades there is a further drop in pressure as well as a drop in velocity.

Thus the transfer of energy is in two parts, namely the transfer of kinetic energy of the steam and the transfer of some of the potential energy of the steam to the moving blades. The net result at the exit from this stage is a low velocity and a pressure somewhat lower than the initial pressure. A similar process is repeated in the remaining three stages. Any number of stages may be added to obtain the desired pressure drop across the turbine.

The main difference between the impulse turbine and the reaction turbine is that, in the former, there is a pressure drop across the fixed blades only, whereas in the latter, there is a pressure drop across both the fixed and the moving blades. For similar boundary conditions this results in a lower velocity of the steam leaving the fixed blades in the case of the reaction turbine. This velocity leaving the fixed blades is relative to the fixed components and is therefore described as the absolute velocity.

The velocity associated with the moving blades is known as the relative velocity (relative to the moving blades). In reaction blading the increase in velocity in the moving blades is achieved by blades designed to act as nozzles to convert some pressure energy in the steam into kinetic energy.

The change in flow area in the blades governs the increase in velocity. From the continuity equation it is evident that, for small changes in density, a reduced flow area will result in an increase in velocity. The shape of the fixed blades in both impulse and reaction turbines is such as to reduce the flow area and increase the velocity.

The shape of the moving blades however is not the same for impulse and reaction turbines. The moving blades of impulse turbines do not have a change in flow area. They do not therefore change the velocity of the steam but only change its direction. The moving blades of reaction turbines do have a change in flow area. They are shaped like nozzles and act to accelerate the steam as it passes through them.

They also change its direction. The difference in the moving blades is evident from Figure 3 and Figure 4. In an impulse turbine the blades are symmetrical about the plane of the turbine wheel carrying the blades whereas in a reaction turbine they are not. Figure 5 and Figure 6 clarify the concept of flow areas and blade symmetry.

The difference between the two is easily seen when viewing the blades from the end. In the latter figure the reduction in flow area and consequent increase in velocity is clearly evident. On an actual turbine rotor however the blades invariably have circumferential shrouding over the tips and the blade profile cannot be seen.

In such cases the shape of the blade on the outlet side has to be compared with the shape on the inlet side.

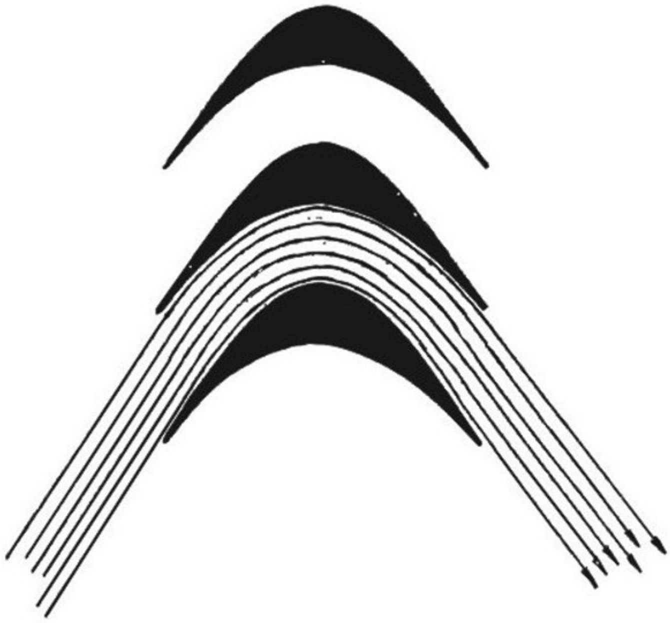

Figure 5: Impulse turbine moving blades

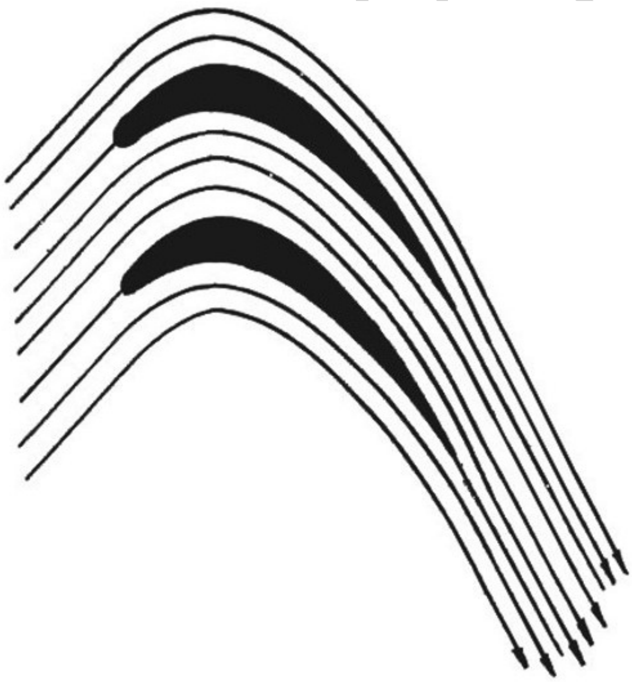

Figure 6: Reaction turbine moving blades

Shrouding on the blades stiffens and strengthens the blades and assists in tip sealing between the moving blades and the casing. In a reaction turbine, where there is a pressure drop across the moving blades, tip sealing is important to prevent steam from leaking from the upstream side around the blade tips to the downstream side. Both impulse and reaction turbines require seals where the shaft penetrates the diaphragm carrying the fixed blades to prevent steam leakage from the higher pressure side to the lower pressure side. Typical locations of these seals are shown in Figure 7.

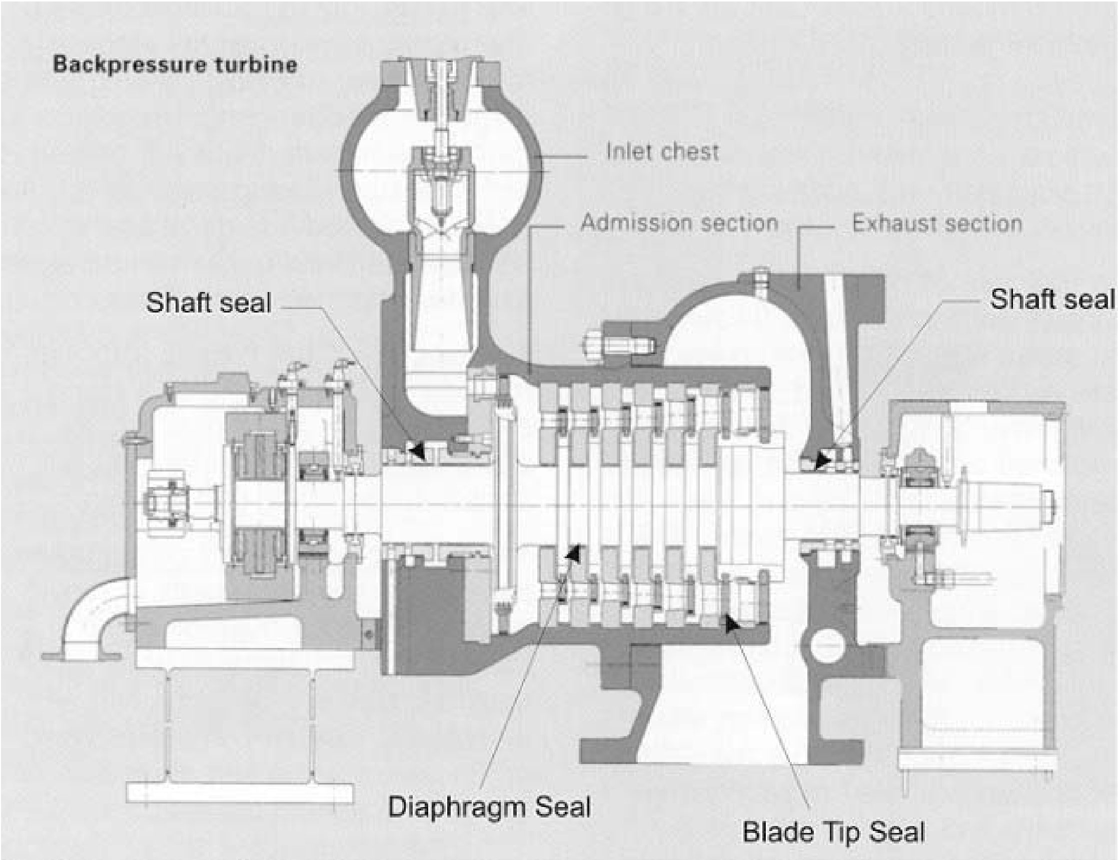

Figure 7: Turbine cross-section showing steam sealing
(courtesy of Siemens)

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Biographical Sketch

Robin Chaplin obtained a B.Sc. and M.Sc. in mechanical engineering from University of Cape Town in 1965 and 1968 respectively. Between these two periods of study he spent two years gaining experience in the operation and maintenance of coal fired power plants in South Africa. He subsequently spent a further year gaining experience on research and prototype nuclear reactors in South Africa and the United Kingdom and obtained M.Sc. in nuclear engineering from Imperial College of London University in 1971. On returning and taking up a position in the head office of Eskom he spent some twelve years initially in project management and then as head of steam turbine specialists. During this period he was involved with the construction of Ruacana Hydro Power Station in Namibia and Koeberg Nuclear Power Station in South Africa being responsible for the underground mechanical equipment and civil structures and for the mechanical balance-of-plant equipment at the respective plants. Continuing his interests in power plant modeling and simulation he obtained a Ph.D. in mechanical engineering from Queen's University in Canada in 1986 and was subsequently appointed as Chair in Power Plant Engineering at the University of New Brunswick. Here he teaches thermodynamics and fluid mechanics and specialized courses in nuclear and power plant engineering in the Department of Chemical Engineering. An important function is involvement in the plant operator and shift supervisor training programs at Point Lepreau Nuclear Generating Station. This includes the development of material and the teaching of courses in both nuclear and non-nuclear aspects of the program.