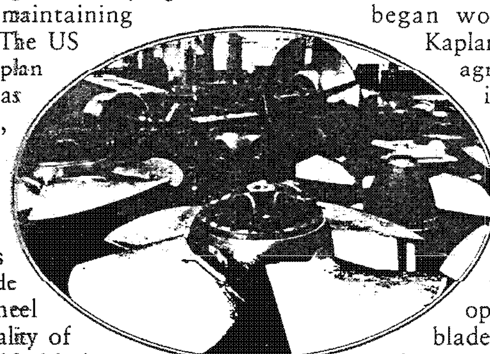
The infinite turbine

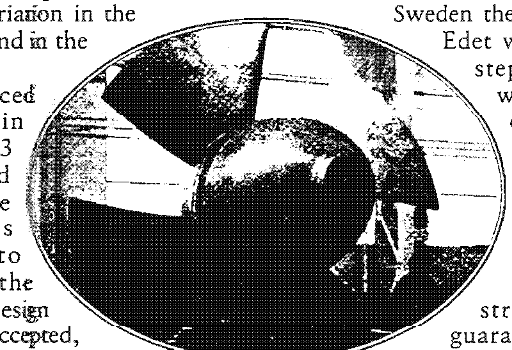
By introducing variable pitched blades, Viktor Kaplan's design made it possible for a single turbine to offer high efficiency over a range of loads, and 80 years after its debut, the Kaplan turbine still has attractive characteristics. Janet Wood reports

Packing an infinite number of turbines into a single unit may not seem like a simple idea. But in the turbine designed by Viktor Kaplan it offered an elegant solution to the problem of dealing with varying load conditions while maintaining high efficiency. The US patent for the Kaplan turbine, which was filed in 1914, describes the turbine as:

'A runner wheel for high speed water turbines provided with guide vanes, said wheel comprising a plurality of angularly adjustable blades, and means to adjust said blades while the wheel is running so as to vary not only the outlet angles and passages but also the inlet angles and passages of the wheel, to correspond to variation in the supply of water and in the power required.'



Kaplan produced his prototype in 1912, and in 1913 he approached several turbine manufacturers with a view to licensing the technology. His design was not quickly accepted, partly, it is suggested, because the models he had used relied on a runner less than 100mm in diameter operating under a head of 0.6m. Further model tests were, however, carried out by Swedish turbine manufacturer Verkstaden of Kristinehamn (KMV) in the following year using a model with a runner diameter of 700mm and a 4m head.



The first practical operation of a Kaplan turbine was in 1919, at a textile factory in Velm, Austria belonging to a yarn manufacturer called Hofbauer. This application employed a runner with a diameter of 600mm operating under a head of 2.3m, and it offered efficiencies of around 84%.

In the same year the Velm unit went into operation, the Swedish State Power Board began to consider exploiting a waterfall at Lilla Edet, and Verkstaden began work in earnest on Kaplan's designs. A licence agreement was signed in 1921 and the company began work on developing the turbine to ensure it would stand up to the stresses it would undergo in operating, and altering blade pitch, at full load.

The proposal eventually put forward for Lilla Edet was for a turbine with a four-blade runner with a diameter of 5.8m. Although by this time KMV had installed several Kaplan turbines in Sweden the proposal for Lilla Edet was a considerable step forward, and it was very carefully considered by the Power Board. The Kaplan proposal was accepted, and installation was completed in 1925. KMW had offered strict performance guarantees for the Lilla Edet application; for example an efficiency of 85-87%. In practice, the turbine efficiency was 89%, and it remained above 75% when overloaded or at part load. That these excellent figures were attested to by the Swedish Power Board went a long way towards helping the Kaplan turbine gain wide acceptance in Europe.

Cavitation and other concerns

The problem of cavitation is a characteristic of Kaplan turbines and it was identified very quickly after the first

Viktor Kaplan

Born in Murzzuschlag, Austria on 27 November 1876, Viktor Kaplan was educated at Realschule in Vienna and went to Technischule Hochschule in Brno (now in the Czech Republic) to study machine construction, gaining an engineer's diploma in 1900. He spent a year in voluntary service in the Navy before entering Ganzt Company at Lebersdorf where he worked for two years on designing and building diesel engines.

In 1903 Kaplan started a professorship in kinematics, theoretical machinery studies and construction at the Technischule Hochschule. He soon developed an interest in hydraulic turbine design and construction, and his first book, on the design and construction of the Francis turbine rotor, was published in 1908. This work formed the basis of his doctorate, which was granted by the Vienna Polytechnic University in 1909.

During the period 1908-11, Kaplan worked with colleagues on multi-dimensional fluid flow and started experimenting with small-scale turbine models. This research led to the first of 260 worldwide patents for the Kaplan turbine. The first was issued in Austria on 28 December 1912 (patent number 74,388) but the patent for what is now recognised as the Kaplan turbine was issued in Austria on 7 August 1913 (patent number 74,244).

In 1918 Kaplan became Professor of Water Turbine Construction at the Technischule Hochschule and he continued working there until he was forced to retire due to ill health in 1931. Kaplan's achievements in hydraulic engineering were acknowledged by the Society of Austrian Engineers and Architects who awarded him with the Society's gold medal in 1932.

Two years later, on 23 August 1934, the inventor of the Kaplan turbine died suddenly at the age of 58.

After his death the Austrian Research Institute for the History of Technology honoured his memory by setting up a memorial plaque on the house where he was born, and arranged memorial exhibits in the Technisches Museum in Vienna and the Deutsches Museum in Munich. The Institute also arranged publication of a biography of Viktor Kaplan (Viktor Kaplan, by Alfred Lechner, Julius Springer Verlag, Vienna 1936).

In 1937 Kaplan's wife Fray Margarethe Kaplan donated a collection of experimental runners from Viktor Kaplan's laboratory to the Tekniska Museet in Stockholm, Sweden.

turbine was put into operation. While the first unit at Velm showed 84% efficiency in its first year, in later years the efficiency fell to around 60% and the runners were seen to be damaged. The cause was cavitation: in reducing friction losses and increasing optimum speeds Kaplan had reduced the blade surfaces too much.

The problem caused some hesitation on the part of Kaplan developers, but was the spur for some interesting research at KMV. Before completing the Lilla Edet design KWV's chief designer, Elov Englesson, built a dedicated cavitation test stand — the first in the world — to establish the cavitation characteristics of the Lilla Edet turbine. In the event, after four years of operation the runner blades at Lilla Edet revealed only minor pitting near the edge of the suction side of the blade. Later, stainless steel plates were inserted in vulnerable areas to reduce the possibility of further damage.

Some other aspects of Kaplan turbine design caused initial concern, particularly to engineers in the US:

- There was scepticism that the mechanism for adjusting the blades would prove robust in long term operation.
- Kaplan turbines cost more than comparable fixed blade turbines.
- Kaplan turbines were more complex than other options and used more oil.

By 1929, however, some 150 Kaplan units were in operation in Europe and it was becoming obvious that the design was reliable and robust, and what is more the increased costs of the turbine were outweighed by other cost savings. In that year the first US Kaplan turbine was installed, a 1900hp unit operating under a 10m head, sited on Devil's river, Texas, at the Central Power & Light Co's Lake Walk plant.

Acknowledgements

With thanks to Kvaerner, Boving, Kvaerner House, Ten Pound Walk, Doncaster, UK, and Voith Hydro, D-89509 Heidenheim, Germany.

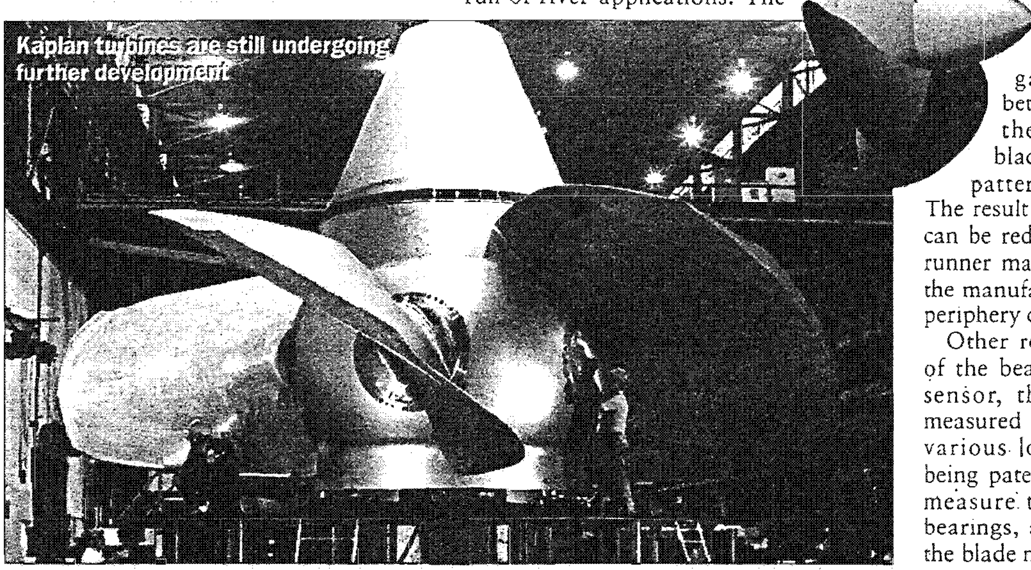
Further reading:
The Kaplan Turbine - Design and Trends. Transactions of the ASME, by J Fisch, Transactions of the ASME, July 1954, p765.
Kaplan Turbines, Design Trends in the Last Decade, A Lugaresi and A Massa, International Water Power & Dam Construction, May 1988, p12
Development of the Kaplan Turbine, by Hans G Hansson

Recent developments

Between the 1950s and 1990s, development of the Kaplan turbine improved efficiency by 4-5%, from a typical 89.5% in 1952, up to 93.5% in recent years. The advent of tools such as computational fluid dynamics has been of help, although the type of flow seen in Kaplan turbines limits the usefulness of CFD. Nevertheless, flow modelling has helped make improvements in the hydraulic design of runners and of water passages, particularly the draft tube, and CFD has been particularly useful in modelling and controlling cavitation. At the same time, the evolution of the spherical hub design and better-controlled blade-to-hub and tip clearances has significantly reduced losses across the runner.

Increasingly, Kaplan turbines are being used at higher heads. Using smaller, high-speed machines, with more runner blades has been associated with a trend towards a reduced hub diameter. This has increased the flow area available, and reduced the capital cost of the turbine, but has brought its own requirements in ensuring that stress in the hub and blades is understood and managed adequately. Further changes in hub design have been required to accommodate additional parts. These developments have gone hand in hand with improvements in steel design and a tendency to use new materials, such as stainless steel for runner blades.

A direct development from the 1950s version of the turbine has been the advent of horizontal bulb and pit turbines for low head or run-of-river applications. The use of geared units with either Kaplan or semi-Kaplan turbines allows the water passage to be optimised and a smaller high speed generator to be used. Heads of under 3m have been utilised for such bulb units, using runner diameters greater than 8m.



Kaplan turbines are still undergoing further development

Environmental developments

At the present time, much of the development of the Kaplan turbine is directed towards improving its environmental profile. At Kvaerner's research centre in Porjus, Sweden, for example, one route for development is aimed at reducing or removing oil from the turbine hub.

In its original form, the hub of a Kaplan turbine was completely oil-filled, and it was preferred that oil leak out, rather than water leaking in — protecting the hub at the expense of the environment. Work at Porjus is now directed toward minimising the volume of oil required and ensuring it is carefully controlled. In this new design all bearings have permanent lubrication. While the turbine is operating at its normal speed oil is taken from the hydraulic system via a magnetic constant-flow valve. Two tubes in the shaft direct the oil to the motor, located in the hub cone, and pump returned oil, which also lubricates the runner bearings. The oil channels are connected via hoses so that the unit can be removed and maintained. The total amount of oil in this system can be monitored accurately, and any leak can be quickly detected. In effect this reverses the original philosophy of lubricating the turbine, in that water is permitted to enter between the sealings on the pressure side of the runner blade. Pressure here is higher than it is inside the hub, where it is at atmospheric pressure, so water leaks into the hub in preference to oil leaking out. If water leaks in it is detected at an early stage and repairs can be quickly effected.

Several other areas are under development at Porjus. One example is the periphery gap: by adjusting the gap between the blade periphery and the runner chamber, until the blade can touch the chamber, the pattern of wear can be examined. The result will be that the size of the gap can be reduced, reducing losses, and that runner manufacture will be simplified, as the manufacturing tolerance of the runner periphery can be less demanding.

Other research includes measurement of the bearing play. Using an inductive sensor, the position of the blade is measured relative to a fixed point under various loads. The technique — now being patented — will make it simple to measure the play in the runner blade bearings, and will help anticipate when the blade needs to be repaired.