Development of the Turgo turbine

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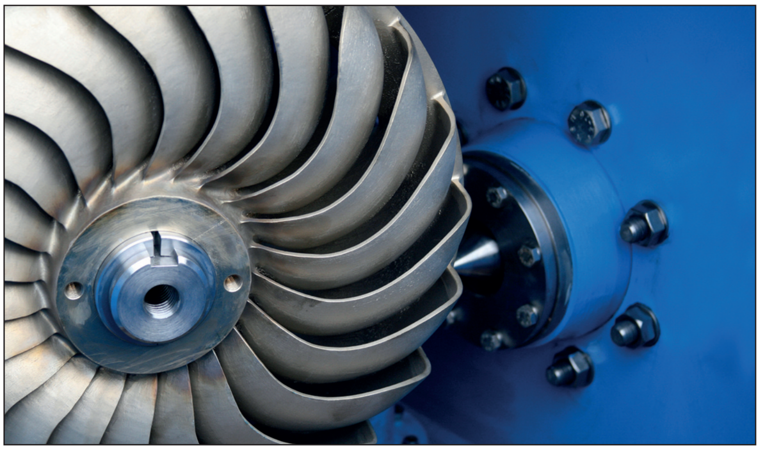
The Turgo impulse turbine is a simple and robust design that generates power from a high velocity jet of water. As a result of its ability to maintain its original efficiency, the Turgo turbine is particularly well suited for run-of-river schemes with large flow variation. Problems that are experienced by other turbines are not typically a concern for a Turgo turbine. For example, the Francis turbine stops generating at lower flows while the Turgo continues to supply power. This characteristic becomes more pronounced as the performance of the susceptible Francis turbine starts to suffer from wear, while the Turgo maintains its original efficiency. This paper presents recent research and development to improve the Turgo turbine.

Turbine selection is a critical element of any hydroelectric project, and the choice of turbine available to today's developer is very wide. It is clear that developers of schemes with a low head will generally opt for Kaplan or Archimedes screw machines, and Francis units are popular for medium head opportunities and schemes that benefit from storage. Pelton turbines, as a result of their low specific speed, are generally the optimum solution for schemes with a high available head. In between all of these is the less well known Turgo turbine, see Photo (a). Originally patented by Gilkes, UK, in 1919, the Turgo has been generating around the world for nearly 100 years and is currently undergoing a process of development and innovation.

The simplicity of the Turgo turbines means that there are minimal service and maintenance requirements, making it particularly appealing in regions of the world where good, long-term operation and maintenance capabilities can be unreliable or difficult to procure.

There have been 1000 Turgo turbine installations worldwide, ranging from 25 kW to 7.5 MW. However, to make the Turgo turbine attractive in an increasingly competitive market, it is vital that it continues to be developed to meet modern demands. During the past five years, this improvement process has been driven by significant investment in research and development capabilities, with the aim of producing new designs and gaining greater understanding of current ones. To minimize risk and benefit from existing resources, initial research was done in collaboration with Lancaster University, UK. As the benefits of this initial work became clear, Gilkes invested in in-house capabilities, which are now complemented by new test facilities at the National Technical University in Athens (NTUA), Greece, where selected designs can be tested to IEC standards. Work on the Turgo turbine has been a major focus of this research, involving both analysis of the runner itself and the design of the jet injector.

(a) A 10.5 in (27 cm) Turgo runner with spear and nozzle design in the background.



Developing a new Turgo runner

Unlike the Pelton turbine, the Turgo has few theoretical design guidelines. Development of a new design using a test rig alone would be a time-consuming and above all very expensive process of trial and error. Instead, computational fluid dynamics (CFD) has enabled the rapid evaluation of numerous designs allowing a greater understanding of the factors affecting turbine performance.

Fig. 1 shows a visualization from the CFD model of a Turgo runner. The CFD process is invariably a compromise between accuracy and computation time. To reduce the complexity of the model, the CFD simulation included the passage of just two blades of the runner through a single idealized jet. Even so, the level of detail that can be captured is limited by the resolution of the mesh (shown in Fig. 1), which is in turn limited by the available computer power. Choices such as how to capture turbulence effects and how to model the air-water interface add further uncertainty to the final results. Nevertheless CFD provides an excellent tool for assessing the effect of design modifications (the CFD simulations were performed in ANSYS Fluent using a moving mesh, VOF multiphase model with the k-epsilon realizable turbulence scheme. A single Turgo runner model comprises around 5×10^6 cells and takes 12 hours to solve on a 32 CPU (central processing unit) workstation.

As an impulse turbine, the Turgo shares many similarities with the more common Pelton turbine, but provides some crossover with lower-head reaction machines such as the Francis turbine. In contrast to the Pelton runner in which the water jets impact in the plane of rotation and water exits to both side of the runner, the Turgo jets are typically angled at 20-

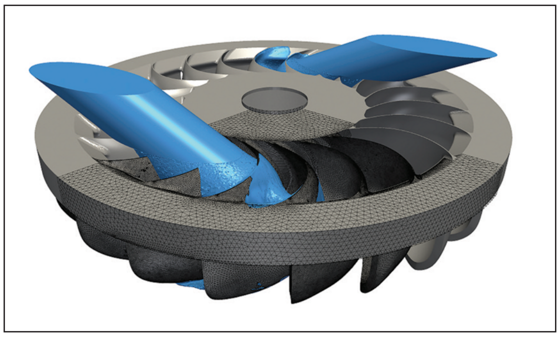
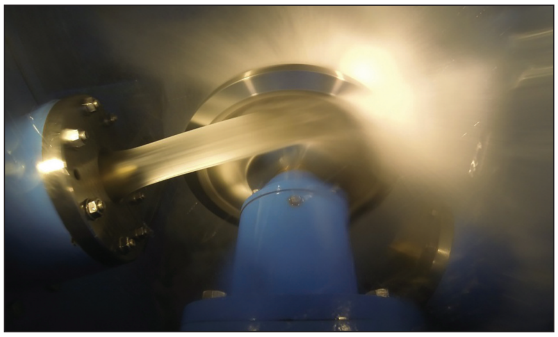


Fig. 1. CFD model of the Turgo runner showing water jet interaction and surface mesh.



(b) A Turgo unit in action showing a single water jet impacting on a rotating runner.

30 degrees from the front face of the runner and water exits from the rear of the runner, see Photo (b).

As seen in Fig. 1, the CFD model predicts the way the water interacts with the runner as it passes through the jet. In particular the CFD model predicts the pressure on the surface of the blades and hence the torque transmitted to the shaft. By integrating the torque over time, and over the number of runner blades, the overall power output can be predicted.

In keeping with its operating range between Pelton and Francis machines, the Turgo runner generates torque from both the impulse of the water jet on the blades (buckets) and from suction on the rear of the blades. At higher flow rates, the passage between the runner blades may be entirely filled with water and suction on the back of the buckets can contribute 5-10 per cent of the total power generated. Without CFD analysis none of this detailed knowledge would be available.

Having created a baseline CFD model, Gilkes' R&D department used CFD to attempt to optimize the runner design. The complex three-dimensional curvature of the runner blades provides numerous possible geometric parameters. Factors such as the width, depth and length of the blades, the blade entry and exit angles, the number of blades and the jet inclination were all evaluated through changes to the underlying CAD model (see Fig. 2). More than 100 designs were simulated in CFD before taking the two most promising designs were taken for final verification on Gilkes Turgo test rig, see Photo (c).

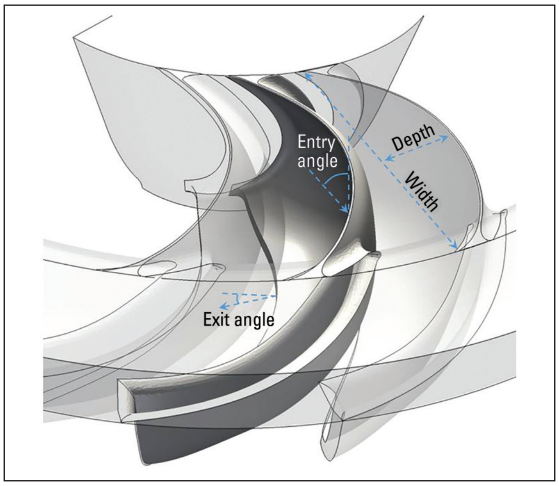
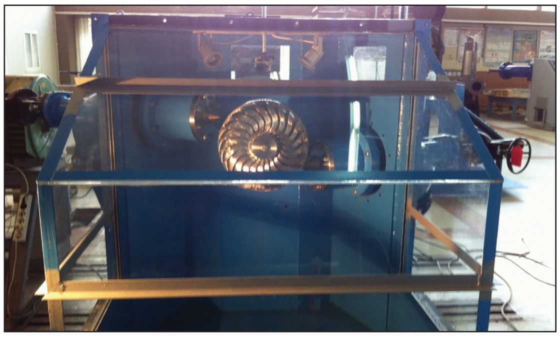


Fig. 2. Some of the design parameters used in optimization of the Turgo runner blades.



(c) Gilkes Turgo test rig at NTUA, Athens.

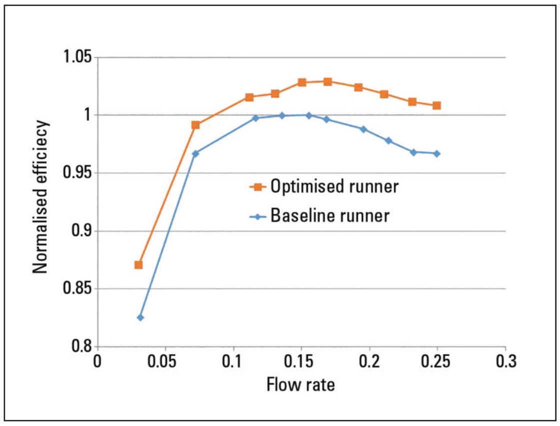


Fig. 3. Test values of efficiency for the baseline and optimized Turgo runners.

Performance testing correlated well with the CFD results confirming expected gains over the full range of operation. The optimized runner shows a 2 per cent increase in maximum efficiency over the baseline with larger gains at higher flow rates (see Fig. 3).

The final stage in the development process was to confirm the durability of the new design. Structural analysis (FEA) of the strength and fatigue life of the optimized design was done using forces taken directly from the CFD simulations. This analysis provided the confidence to release the optimized runner and it is now being used as the new standard for Turgo turbines.

Injector design

In parallel to the runner development, extensive work has been undertaken on upgrading the design of the spear-and-nozzle injectors that deliver the water jet to both the Turgo and Pelton turbines, see Photo (b) and Fig. 4.

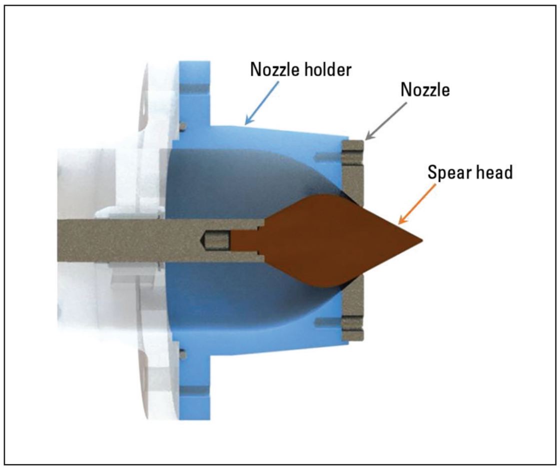


Fig. 4. Cutaway view of a typical Turgo or Pelton injector.

The size and speed of the jet are largely determined by the available head, H and flow, Q:

$$Jet\ velocity, V = C_d\sqrt{2gH} \quad \text{... (1)}$$

$$Jet\ area, A = Q/V \quad \text{... (2)}$$

The one unknown in these equations is the loss coefficient, C_d. Typical values for C_d are between 0.97-0.99 depending on the spear opening and the design of the injector.

Losses arise primarily from surface friction with the walls of the injector and swirl (secondary flows) as a result of asymmetry in the pipework. The CFD model of a jet issuing from a Turgo injector shows a truer picture of the jet (see Fig. 5). In contrast with the idealized jets assumed for the runner development study, the true jet is neither circular nor of uniform velocity. The branchpipe bend generates counter rotating vortices in the flow resulting in a rib on the surface of the jet. Further deformation can also be seen caused by interference with the spear-rod support. Meanwhile, friction with the spear head and nozzle results in a small reduction in velocity both around the perimeter of the jet and at its core.

An additional loss of velocity, which is not seen in Fig. 5, occurs as the jet surface breaks down into droplets as it travels away from the nozzle. The mechanism for this is surface tension effects at the microscopic scale, enabling the growth of minute imperfections. The CFD model does not attempt to capture this level of detail; suffice to say that to minimize jet breakdown, the injector exit should be situated as close to the runner as is practical.

The ultimate effect of all these factors is to reduce the energy in the jet and hence to reduce the power available for extraction by the runner. Therefore, while potential gains are relatively small, minimizing these losses should yield a clear performance improvement.

CFD analysis has been used to test many factors governing the injector design: spear head diameter; spear tip shape and angle; nozzle diameter and nozzle angle; spear rod support geometry; and, branchpipe design. By focusing on the injector in isolation from the runner, the CFD models were able to capture the fine detail of flow within the injector, picking out both the friction losses and secondary flow. In addition, some CFD models ignored the geometry upstream of the spear head and took advantage of the rotational symmetry of the injector to simulate a simple 2D axi-symmetric slice (see Fig. 6). The friction losses are proportional to the square of the water velocity and therefore become most critical as the jet accelerates towards the exit of the nozzle. The losses as a result of interaction with the spear can be seen as a dip in the velocity in the centre of the jet in Fig. 6.

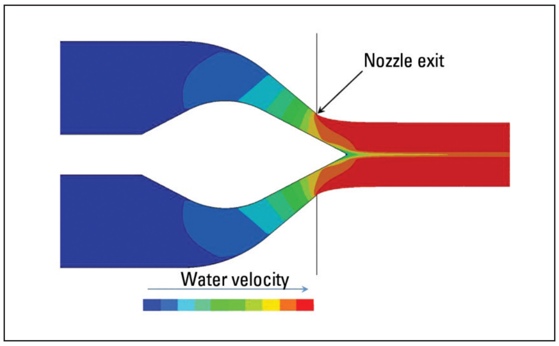


Fig. 6. Detailed 2D CFD simulation of flow between the spear tip and nozzle.

In a similar process to the runner development study, CFD was used to evaluate numerous designs without the need for manufacturing. More than 50 injectors were simulated at various heads and flow rates. The CFD results predicted that by careful design of the injector, around a 1 per cent increase could be achieved in the energy of the jet.

Based on this work, new injectors were manufactured and tested on Gilkes' Turgo test rig. As expected, the improved injector design translated to an increase in output both from the baseline and optimized runners.

The future of the Turgo turbine

The simplicity of the Turgo, and its ability to operate efficiently in dry seasons, means that minimal supervision is required on site, with many schemes being unmanned. This has proven to be a real attribute of the Turgo in remote parts of Zimbabwe and further afield throughout Africa.

It was the Turgo's simplicity that was particularly appealing to Nyangani Renewable Energy (NRE). NRE is the developer of a number of hydropower projects in Africa. The Pungwe B plant in Zimbabwe, see

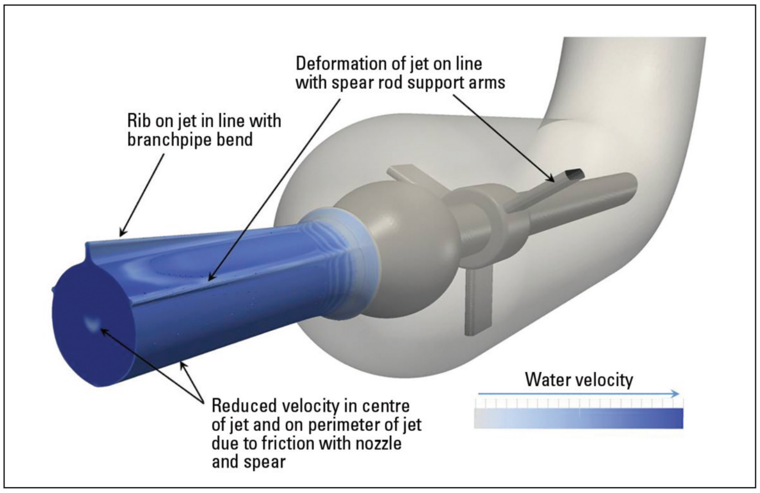


Fig. 5. 3D CFD simulation of the water jet issuing from a Turgo injector.

(d) Twin jet Turgo turbines at the Pungwe B powerhouse in Zimbabwe.

Photo (d), is the largest Turgo installation on the continent and uses four identical Turgo turbines. Each twin jet turbine uses a 28 in (71 cm) mean diameter runner and operates on a head of 176 m. Combined, the four turbines generate more than 16 MW of power.

Like the Pungwe B scheme, many hydroelectric plants in Africa are in remote areas meaning access and terrain can be challenging and often a critical factor. An advantage of the Turgo, with a higher specific speed than the Pelton, means that a smaller runner operating at a higher speed can often be used. This brings the weight of the turbine components and generator down considerably often resulting in this being the decisive factor.

While river water quality is not too bad in Zimbabwe, there are a number of turbine installations in Africa where the Turgo was specifically chosen for its ability to maintain efficiency even in abrasive conditions where turbine wear is inevitable. Gilkes has even replaced Francis turbines with Turgos because of high annual maintenance expenditure being incurred with the Francis units.

One criticism of the Turgo is its lower peak efficiency when compared with other turbines. The efficiency gains mentioned within this paper significantly reduce that gap and, the fact these improvements are retrofitable means existing schemes can benefit from the same significant efficiency improvements as any new Turgo installation. Following on from the research and development work undertaken by Gilkes, the optimized Turgo runner and injector will be introduced as standard to all new turbines and can also be included in plant modernization upgrades. ◊

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Alan Robinson has a degree in Engineering. As the Research and Development Manager for Gilbert Gilkes & Gordon Limited, he oversees a broad portfolio of projects from product analyses, product improvement, and software development. He has worked in many countries and on projects across several continents.

Jo Scott is a CFD engineer with more than 20 years experience of fluid flow modelling across a wide range of industries. Starting out in the oil and gas business, he then spent many years working in motorsport aerodynamics before branching out into CFD consultancy on products as diverse as coffee machines, asthma inhalers and Olympic cycling helmets. During this time he has seen CFD analysis develop from a niche application to a widely used engineering design tool. He joined Gilkes in 2013 and has been instrumental in building the research and development group that is now working on all aspects of Gilkes hydro business.

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