pca

european journal of
postclassicalarchaeologies

volume 10/2020

SAP Società Archeologica s.r.l.

Mantova 2020

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"Post-Classical Archaeologies" is indexed in Scopus. It was approved on 2015-05-13 according to ERIH PLUS criteria for inclusion and indexed in Carhus+2018. Classified A by ANVUR (Agenzia Nazionale di Valutazione del sistema Universitario e della Ricerca).

DESIGN
Paolo Vedovetto

PUBLISHER
SAP Società Archeologica s.r.l.
Strada Fienili 39/a, 46020 Quingentole, Mantua, Italy
www.archeologica.it

Authorised by Mantua court no. 4/2011 of April 8, 2011

For subscription and all other information visit the web site www.postclassical.it.

ISSN 2039-7895

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european journal of
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BEYOND THE THEME

Colin Rynne*

Waterpower and sustainable energy in 19th-century Europe and USA. An archaeology of the water turbine

During the 19th century, many coal-poor regions of Europe and the USA had to rely on water-powered prime movers in the early years of industrialization. The development of water turbines by French engineers such as Fourneyron and Jonval, and later by Thomson in Ireland and by Howd, Francis and Pelton in America, provided a vital respite from the unavailability of coal in the drive towards industrialization. In this way, 19th-century engineers provided an important solution to the looming energy crisis of their day. As will be seen below, today's attempts to change over to sustainable energy sources can, and should, learn from their creativity. And today the Francis turbine, developed in the mid-19th century, which is still the most commonly used world-wide, provides a fitting legacy to their achievements.

Keywords: water turbine, waterwheels, industrial energy, electricity supply, energy crisis

Nel XIX secolo, gli USA e molte regioni europee povere di carbone dovettero fare affidamento a motori alimentati ad acqua nei primi anni dell'industrializzazione. Lo sviluppo delle turbine ad acqua da parte di ingegneri francesi come Fourneyron e Jonval, poi di Thomson in Irlanda e di Howd, Francis e Pelton in America, fornirono un vitale respiro dal bisogno di carbone nella corsa all'industrializzazione. Così, gli ingegneri del XIX secolo fornirono un'importante soluzione all'incombente crisi energetica dei loro tempi. Come si argomenterà, i tentativi odierni per trovare fonti energetiche sostenibili possono, e devono, imparare dalla loro creatività. E oggi la turbina Francis, sviluppata nel XIX secolo e ancora la più usata nel mondo, ci dà un'idea appropriata del retaggio dei loro traguardi.

Parole chiave: *turbina ad acqua, ruote idrauliche, energia industriale, fornitura energetica, crisi energetica*

1. Introduction

The influence of the continuing use of fossil fuels on global warming and climate change features prominently in all popular media and in general public discourse. The solution to this energy crisis, the reduction of the consumption of fossil fuels, and their replacement with forms of renew-

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Received: 15-03-2020 - Accepted: 31-03-2020 - Revised: 04-04-2020

able/sustainable energy, has long been known. But up to very recently many governments have been slow to act, or simply have paid lip-service to such concerns. The increased use of hydropower forms part of this solution. And while this is not the panacea it might appear to be –the construction of large hydropower dams can displace communities and cause long term, irreversible environmental damage – there is still enormous potential for small to medium hydroelectric schemes. Of course, we will always frame our perceptions of what constitutes an 'energy crisis' in terms of our own present-day fears, needs and expectations. The increased use of hydropower as a form of alternative energy is thus seen as 'modern' solution to a pressing existential need. Yet the development of the water turbine is very much a 19th-century technological revolution, brought about to address an energy crisis in regions where waterpower resources were in abundance, but where coal was scarce. The absence of coal to raise steam was viewed by contemporaries as a potentially crippling resource constraint on any given region or country's ability to sustain large-scale industry. The development of the water turbine was thus an important technical response to a pressing economic need: the expansion of existing renewable sources of energy so as either to minimize or completely eliminate the use of coal as a source of industrial energy. By the middle of the 19th century, as will be seen below, the technical development of water turbines was already highly advanced, while one particular type, the Francis turbine, is still the most commonly used today. Thus, what was essentially a 19th-century response to an energy crisis, continues to make an important contribution to our present concerns.

2. Improvements to the design of vertical waterwheels

In every sense the technical development of the water turbine was a triumph of theoretical observation and experiment over a looming technological imperative. Industrializing countries required larger amounts of industrial motive power but, as fossil fuels such as coal were in short supply in many industrializing regions of Europe and the USA, there was a pressing need not only to harness new sources of water power, but also to improve the prime movers used to convert these into industrial energy. Up until the second half of the 18th century almost all vertical waterwheels were constructed entirely of wood, which generally limited their diameter and thence their ability to develop in excess of 25 hp. In addition, the wood tended to warp and shrink due to the constant wetting and drying and as such wooden components needed to be replaced every 5-7 years (Reynolds 1983, p. 287). The transition from wood to metal waterwheels, however, was a relatively slow process. John Smeaton (1724-92) appears to have been the first to try out cast iron axles, and by at least 1770 he was also experimenting with iron for other waterwheel components (Wilson 1957). The first all-iron waterwheel, however, appears to have been erected at Styal, Cheshire, England, in the period 1800-7 (Hills 1970).

At the turn of the 19th century, Thomas C. Hewes (1768-1832) of Manchester was developing what was to become known as the *suspension waterwheel*. In traditional vertical waterwheels, the motion of the wheel was transmitted to the gear wheels via its wooden axle. The stresses involved required that the axle be of stout construction, made of a single balk of timber or with a number of large timbers strapped and bolted together. The *compass arms* or struts supporting the external rim of the waterwheel, or the framework of *clasp arms* introduced in eighteenth century for the same purpose also added to the weight of the waterwheel and thus increased the pressure on the axle. But on the suspension waterwheel, power transmission from the wheel was transmitted from its rim. As the principal driving wheel or *segment* was now affixed, in sections, to the outer rim of the waterwheel, it was no longer necessary for either a large axle or a heavy frame. It now became possible for the diameter of the axle and the cross-sectional area of the arms to be greatly reduced. Heavy wooden axles could now be replaced with slender cast iron ones, with internal wrought iron suspension rods providing support for the framework of the wheel. In c. 1802 Thomas Hewes erected the earliest known example of a suspension waterwheel, a 40 ft (12.19 m) and 5 ft (1.52 m) at Overton Cotton Mills, near Bandon, Co. Cork, Ireland (Rynne 2005). In 1823 the French engineer Jean Victor Poncelet (1788-1867), substantially modified the traditional undershot waterwheel by replacing its flat paddles with curved vanes and providing an angled sluice or inlet control gate, which allowed the incoming water as close to the vanes as possible. This new design successfully married the principal advantages of the traditional undershot waterwheel (low construction and maintenance costs) to the demands of increased mechanical efficiency (fig. 1, Rynne 2006).

Yet despite these advances, vertical waterwheels still operated with slow rotational speeds (Wilson 1974), while the mechanical energy generated by them (regardless of the available water supply), could only be increased by constructing wheels of larger diameters. In Britain and Ireland large diameter wheels of c. 50-80 ft (15.24-24.38m) were constructed, but the locations at which they could be used were extremely limited. At existing mill sites, where power requirements had increased, the use of large diameter waterwheels was very often simply impossible

Fig. 1. All-iron suspension waterwheel at Dyan Mills, Caledon, County Tyrone, Northern Ireland, c. 1829.

owing to the exigencies placed upon it by its available water supply. In many cases, particularly in urban areas where existing watercourses were already seriously congested at the end of the 18th century, the only alternative was to acquire steam-driven prime movers to facilitate further expansion or, indeed, to establish new industrial sites (Rynne 2006).

3. The development of the water turbine before 1850

All water turbines, past and present, fall into two categories which are loosely based on the principles that govern their motion. *Impulse* turbines utilise fluid energy in its kinetic form, where the potential energy of the water in the reservoir is converted into kinetic energy as it falls towards the turbine. A conduit or pipe, called a *penstock*, developed a jet of water which was discharged against the vanes of the turbine. In *reaction* turbines, on the other hand, the vanes of the turbine are completely submerged when it is in operation, and no water jet is formed. Only part of the potential (pressure) energy of the water is converted into kinetic energy as the water passes *through* the turbine (Rynne 2006). The word 'turbine' (from latin *turbo* meaning whirlwind) was first coined by the French engineer Claude Burdin (Smith 1977, see also below).

An early form of reaction turbine, commonly known as a *Barker's mill* (named after an Englishman, Robert Barker) whose essential mode of operation is very similar to the whirling lawn sprayers of our own era, was first described in print in 1744 (Wilson 1974). This turbine was introduced into the USA in 1791, where it was later shown that they could not achieve efficiencies of more than 40%, although they could, unlike conventional vertical waterwheels, operate when submerged (Hunter 1979, p. 302). This same basic, principle, of Barker's mill was incorporated into the *Scotch turbine*, developed and patented by the Glasgow engineer, James Whitelaw, and the first British made reaction turbine was built by Donald and Craig of Paisley in 1839 (Crocker 2000, pp. 84-85). Whitelaw's turbine operated by forming the arms of Barker's rotating jets into an S-shaped spiral, with the addition of a special speed-regulating device.

By the late 1840s water turbines could produce efficiencies equal to and often higher than the most developed vertical waterwheels, utilising falls of less than 1 ft (0.3 m) up to hundreds of feet. The equivalent range for vertical waterwheels was about 2–50 ft (0.6–15.2 m) and, whereas the vertical waterwheel could not operate efficiently when flooded, the water turbine could continue to work effectively when entirely submerged. The vertical axle of the water turbine rotated at much higher speeds than any variety of vertical waterwheel, which in practice meant that less gearing was needed to step up the speed of the axle required to power industrial machinery. Furthermore, water turbines were much more compact and could deliver more power per unit of size than a conventional waterwheel. In vertical waterwheels incoming water was only applied to one bucket or vane at a time, whereas in the water turbine the entire surface came into contact with the water flow. This latter contrast, coupled with the fact water turbines also developed considerably higher axial speeds, meant in practice that the water turbine could be much smaller than a vertical waterwheel capable of producing the same power output (Rynne 2006).

In the early 19th century, France was to become the birthplace of the modern water turbine. The *Société d'encouragement pour l'industrie nationale* offered a prize of 6,000 francs, in 1823, for the development of a horizontal wheel capable of powering large industrial concerns (Crozet-Fourneyron 1924; Smith 1976; 1977, pp. 244-246; 1980, p. 143). In 1827 Claude Burdin (1790-1873), a military engineer and instructor at the *École national supérieure des mines*, made an attempt to win it, but instead was awarded a consolation prize of 2,000 francs in acknowledgment of his important theoretical contributions (Smith 1977; 1980, pp. 140-143). The *Société*, however, did not give up on the prospect that a viable industrial water turbine might be developed, and decided to extend the competition for the 6,000 francs to the year 1832. A former student of Burdin, from St Etienne, Benôit Fourneyron (1802-1867), actually developed an experimental turbine between the years 1823-7 at Pont-sur-l'Ogne, which developed 6hp at 60rpm with an efficiency of 80% (Smith 1980, p. 143). Fourneyron moved to Besançon in 1827,

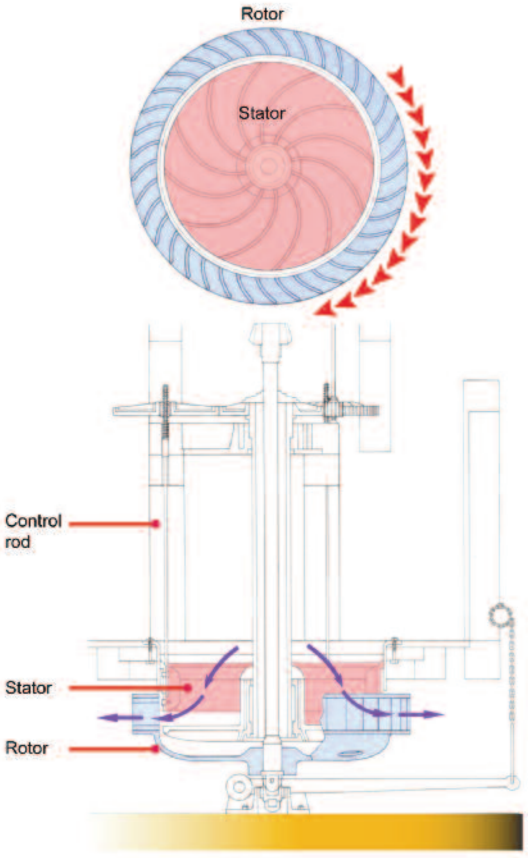


Fig. 2. Fourneyron's 50 hp turbine, built for ironworks at Fraisan in 1832. Water was admitted centrally through the *stator*, with fixed guide vanes, which then moved outwards through the rotor or wheel, transmitting its motion to the driveshaft (after Smith 1980).

and with financial support from F. Caron, an ironmaster, he developed a 10hp turbine for working Caron's blowing engine, and later a 50hp model for powering forge hammers at Fraisan (Payson Ussher 1954, p. 388; Smith 1980, p. 143).

In Fourneyron's *outward flow* turbine (fig. 2), the water was admitted via column at the centre on to a series of centrally positioned, fixed guide vanes, which directed the water, simultaneously, onto the curved blades of a rotating outer wheel (the *runner*). The outward movement of the water leaving the turbine exerted pressure on these curved buckets, and the motion created by the runner was transferred to the turbine's driveshaft. Fourneyron obtained a patent for his turbine in 1832, and his memoir on the performance of his turbines won the 6,000 francs prize in 1834 offered by the Société (Crozet-Fourneyron 1924). He then went on to install turbines at spinning mills at Inval, near Paris in 1834 and at St Blasien, in the German Black Forest (Reynolds 1983, pp. 341-342), demonstrating to his contemporaries their power, versatility and potential for use in larger industrial concerns. No less than 129 of Fourneyron's turbines were in use throughout Europe, by 1843, in regions as far-flung as Russia (Crozet-Fourneyron 1924, p. 38). By this period, it had even crossed the Atlantic, thanks to the advocacy of Ellwood Morris of Philadelphia, who had installed a number of examples in this region (Hunter 1979, p. 322). As we shall see shortly, Fourneyron's design was to greatly influence turbine development throughout the 19th-century industrialised world.

European contemporaries were unanimous in their praise for Fourneyron's achievement. Arthur Morin, the French physicist and inventor of the Morin dynamometer, demonstrated that the larger Fourneyron turbines could operate at 70-78% efficiency. By 1840, French technical literature on these new industrial water turbines had already been translated into English for publication in American scientific journals (Hunter 1979, p. 320). Moritz Rühlmann's *Allgemeine Maschinenlehre* (1842), also proved to be highly influential when it was first translated into English by the Irish scientist, Sir Robert Kane (Rühlmann 1846). Rühlmann recounted his astonishment with Fourneyron's achievement, after witnessing the St. Blasien turbine in operation: "One then feels seized with astonishment, and wonders, more than in any other place, at the greatness of human ingenuity, which knows how to render subject to it the most fearful powers of nature" (Rühlmann 1846, p. 17; Reynolds 1983, p. 342).

The success of Fourneyron's inward flow turbine, within a relatively short period of time, created enormous interest throughout Europe and the USA. As we have seen, Ellwood Morris had already produced American-made Fourneyron turbines before 1843, while other American engineers, notably Uriah A. Boyden (1804-1879) and the English-born James B. Francis (1815-1892) had installed them in large cotton mills before 1850 (Hunter 1979, p. 325). However, in the United Kingdom, similar developments, with the exception of Ireland (which had to import nearly all of its coal) occurred with noticeably less urgency. Indeed, although a Fourneyron turbines were in use in America, by at least 1843, the earliest recorded example in Britain was installed in a spinning mill at Balgonie, Fifeshire, Scotland c. 1846 (Stuart 1846). The mill's owner, Joseph Gordon Stuart has actually contacted Fourneyron but could not agree terms with him, so his turbine (as in the case of early Irish examples, see below), would appear to be a 'pirated' version (Stuart 1846, p. 6). As with many of his contemporaries, Stuart was aware of Sir Robert Kane's glowing account of Fourneyron's turbine, published in his *Industrial resources of Ireland* (1844). But as there were no British-made turbines on display at the Great Exhibition of 1851 in London (Wilson 1959), as subsequent devel-

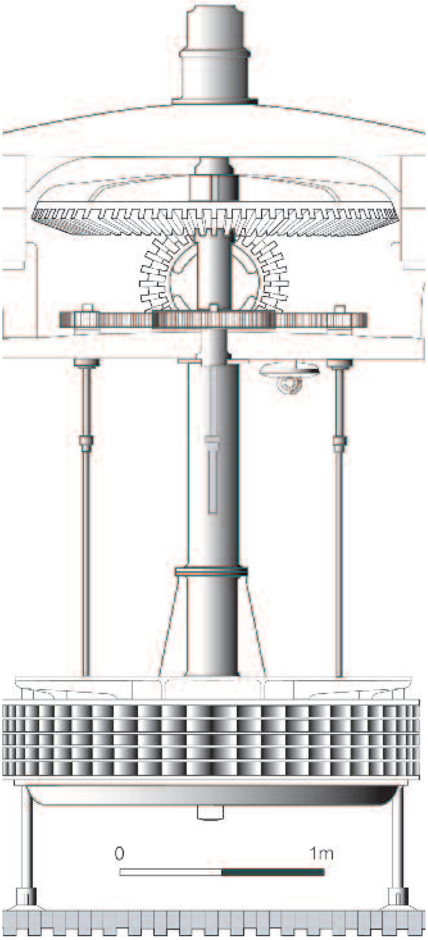


Fig. 3. Fourneyron turbine built by MacAdam's Belfast Foundry, Ireland, in the 1850s.

opments suggest, Kane's account had the most impact in his home country. In 1847, William Kirk, who owned several flax spinning and linen bleaching works in Ulster, and Samuel Gardner (owner of the Armagh Foundry) came together to install a Fourneyron-type turbine at one of Kirk's mills near Keady in County Armagh. Kirk and Gardener made contact with Fourneyron, but could not agree terms on manufacturing one under patent in Ireland. Likewise, a further Armagh millwright, William Cullen, had journeyed to France sometime between 1844 and 1848 to meet with Fourneyron, with a view to manufacturing his patent in Ireland, but again could not agree upon terms. Cullen resorted to industrial espionage. After discussions with Fourneyron's model maker, and visiting a number of sites in France at which Fourneyron's turbines had been installed, he acquired enough information on them to build a working model of one on his return to Ireland (Wilson 1959; Gribbon 1969; Crocker 2000, p. 86). Later, in association with Robert MacAdam of the Soho Foundry in Belfast (fig. 3), a Fourneyron-type turbine built to Cullen's specifications was installed in Barklie's bleach mill at Mullaghmore, near Coleraine, county Antrim in 1850 (Rynne 2006). The earliest surviving reaction turbine, built on the Fourneyron model, in either Britain or Ireland, would appear to be that installed at 'The Old Bobbin Mill', Force Forge, Satterthwaite in Cumbria around 1850, in all likelihood by an Ulster foundry such as MacAdam's or Gardner and Company of Armagh (Gribbon 1969; Crocker 2000, p. 87). An early example of a MacAdam turbine, dating to the mid-1850s, also survives *in situ* at Green's flour mill, county Cavan, and has recently been restored to full working order (Rynne 2006). Nonetheless, as European and American engineers were to discover from practical experience, Fourneyron's inward flow principle had its limitations (Smith 1975, p. 175), and they both assiduously – and often ingeniously – found ways to improve upon it. In the US, Uriah A. Boyden patented a series of important modifications to Fourneyron turbines, which included a cone-shaped flume. As a result, Boyden-Fourneyron turbines came to replace breastshot waterwheels as the prime mover of choice in the Massachusetts area (Hunter 1979, pp. 329-331).

In Germany, in 1837, Carl Anton Henschel (1780-1861) patented the first water turbine to utilise an alternative method of admitting the water into the turbine, which has become known as *downward* or *axial flow*. In axial flow turbines, water enters the turbine in the same direction as the driveshaft (i.e. vertically), passing through a series of fixed, curved guide vanes and then through the runner or wheel, exiting directly beneath the turbine and into a tailrace. Henschel and Sohn are known to have manufactured a number of these turbines, an example of which dating to 1840, is preserved in the Deutsches Museum in Munich. However, in almost all recent accounts of the development the axial flow principle, Henschel's important contribution has been completely ignored. André Koechlin (1789-1879), who operated an engineering works at Mulhouse in France, became involved in designing water turbines (presumably on Fourneyron's model) as early as 1834. In the late 1830s, Nicolas Joseph Jonval (1804-1844), who ran Koechlin's workshop, travelled to Braunschweig in Germany to meet Henschel. As a result of this, Jonval devised improvements to Henschel's design and submitted a patent to the French authorities in 1841. Jonval was clearly working in collaboration with Koechlin, but was later taken ill, leaving all subsequent design work to the latter, who submitted a new patent in 1843 (Hager 2009, p. 974). Despite this, the axial flow turbine first manufactured by Koechlin's foundry has come to be known as the Jonval turbine (fig. 4). By 1850, A. Koechlin and Company of Mulhouse, had manufactured more than 300 Jonval-type turbines for customers throughout Europe. The Jonval turbine was brought to the US in 1849 by a former employee of Koechlin's, Emile Geyelin, who had acquired the rights to the sale of Jonval- Koechlin turbines in the USA (Hunter 1979, p. 326).

Yet even before technical data on Fourneyron and Jonval turbines became available in America, Samuel B. Howd, of Ontario County, New York had patented the world's first *inward flow* turbine in 1838. This is effectively the reverse of the outward flow principle, as in Howd's turbine water was admitted from the outside of the turbine towards the centre, before being discharged at the periphery. James Francis built and experimented with three Howd-type inward flow (or what he later called *cen-*

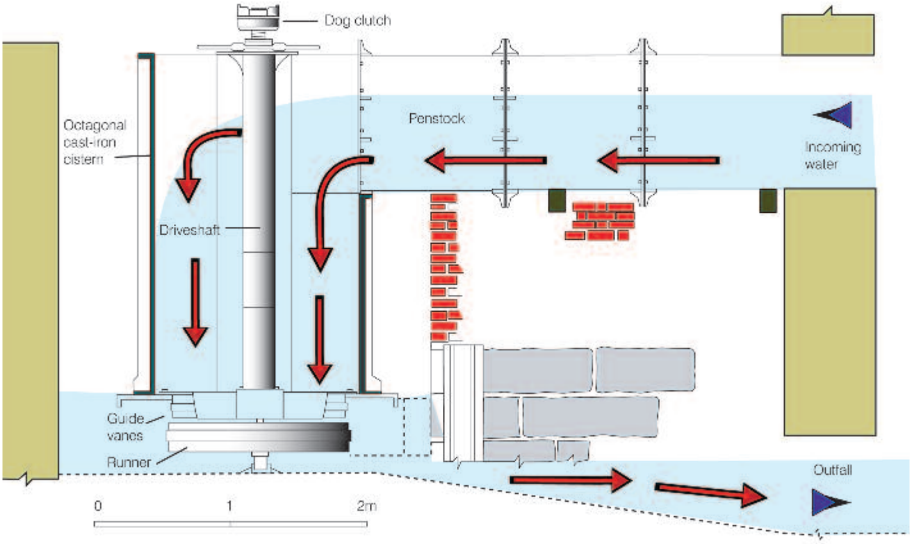


Fig. 4. Jonval turbine, built by the Hive Iron Foundry, Cork, Ireland, for the Royal Ballincollig Gunpowdermills, County Cork, Ireland, in 1855.

tre vent) turbines in the period 1847-49, and adapted these for larger industrial projects, and may be credited with important modification to Howd's original design. However, even while his contemporaries did not associate this form of inward flow turbine with him during his lifetime, it has become known as the Francis turbine: the term Howd-Francis turbine would be more accurate ((Hunter 1979, pp. 338-340).

4. Developments to 1900

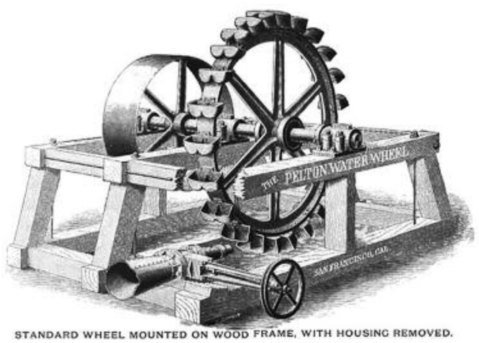
For the most part, the next wave of technical creativity associated with the design of water turbines occurred in the USA, with one notable exception. As early as 1847, and Irish engineer, James Thomson (1822-92), was developing what he termed a *vortex turbine*, for which he received a patent in 1850. James was the brother of William Thomson (later Lord Kelvin) who, on a trip to Paris in 1847, and at James' bidding, sought out an update on the most recent French research on water turbines. William had the great fortune to meet Jean Victor Poncelet and related his conversations with him to James via correspondence (Smith, Norton Wise 1989, pp. 412-413).

In Thomson's design, water was injected into either fixed or adjustable guide vanes at high pressure, creating a spiralling motion. These vanes then directed the flow on to the periphery of the runner to set it in motion (Wilson 1974, p. 13). The first vortex turbine was built in Glasgow and was later installed in a linen beetling mill at Dunadry, county Antrim in 1852, and the first to be installed in England was at James Copper's paper mill, at Cowan Head, near Kendal in Cumbria (Crocker 2000, p. 95). Operating with up to 75% efficiency, Vortex turbines were extremely versatile and could be used with heads of 1-125m. They were also amongst the first reaction turbines to be manufactured with either vertical or horizontal axles.

Fig. 5. 'Double' Leffel turbine, c. 1920, at Patterson's Spademills, Templepatrick, County Antrim.

In the United States, the next stage in the evolution of water turbines, after 1850, was the development of the American mixed flow turbine. The mixed flow concept involved a combination of the inward flow principle of the Howd-Francis turbine and the axial flow of the Jonval turbine. Both forms of water delivery were first combined by Asa Methajer Swain (1830-1980) of Lowell Massachusetts, who built his first mixed flow turbine in 1858. Stout, Mills and Temple, were to begin to manufacture their 'American turbine' shortly afterwards (fig. 5), while in 1862, James Leffel began the production of his distinctive mixed-flow turbine at Springfield, Ohio (Hunter 1979, p. 365), James Leffel & Company continues to manufacture water turbines to this day. A number of other variations were manufactured in the USA, but all shared many advantages of earlier forms- even Geyelin-Jonval wheels- including superior economy in the use of water, increased durability, low costs and being more easily adapted to any existing stream flows (Hunter 1979, p. 415). Furthermore, beginning with James Leffel, American manufacturers were the first to produce what became known as 'stock wheels' or standardized turbine sizes (Hunter 1979, p. 356).

On the Californian goldfields of the 1860s and 1870s, new varieties of impulse turbines were developed to take advantage of fast-flowing



STANDARD WHEEL MOUNTED ON WOOD FRAME, WITH HOUSING REMOVED.

Fig. 6. Pelton Wheel from early 20th-century American trade catalogue.

mountain streams and rivers, with high heads. The available sources of coal in most American metal- mining regions were scattered, and in Nevada alone industrial motive power took up 30-50% of operating costs (Hunter 1979, p. 398). Although a number of basic forms were developed, the best known and arguably most successful impulse turbine was that developed by Lester A. Pelton (1829-1908) and patented by him in 1880 (fig. 6). The Pelton wheel, which was clearly an updated, all metal version of the 'hurdy gurdy' wheel (essentially a wooden, overshot, bucket wheel, actuated by a high-pressure water jet) had a distinctive double bucket. In the centre of the bucket was a raised, dividing edge, or 'splitter', which effectively split the water jet in two and turned it through 180° (Durand 1939a). A later patent for an improved double bucket design were obtained by Abner Doble, whose company was later to merge with the Pelton Waterwheel Company in 1912 (Durand 1939b). Pelton wheels are still commonly used, worldwide, in small-scale hydro-eclectic schemes.

The second half of the 19th century, in America and Europe, witnessed the gradual substitution of water-powered prime movers with steam engines (see below). In coal-rich Britain, for example, the technical development of the water turbine experienced a precipitous decline. However, very early on in the development of electricity generation, there was a new interest in water turbines as the most practical means of actuating electricity generating sets. Many existing turbines had vertical axles, which for several decades had necessitated the use of large and expensive bevel gearing. But by placing the turbine on its side, it became possible to dispense with this and to directly drive any machinery by means of lay or lineshafting (Hunter 1979, p. 383). The high rotational speed of the turbine's axle proved ideal for driving generating sets. In 1881 at Godalming, Surrey a hydroelectric scheme using a local water mill was employed to create the world's first electric street lighting. Whilst in 1883, the Giant's Causeway, Portrush and Bush Valley Railway and Tramway Company, in the north of Ireland — while the third in the world to use electricity for traction on a commercial basis — became the first public electric railway in the world to be powered by hydro-electricity (McGuigan 1964, p. 12).

The Salmon Leap generating station was built, and still survives, on the River Bush in 1882-3, originally powered by two water turbines by Alcott and Company of New York, each generating 45 hp under a head of 8 m, these latter powered, via belting, a bi-polar Siemens generator (McGuigan 1964, pp. 84ff). A further hydro-electricity electric tramway, and the second of its type in the world, the Bessbrook and Newry, opened in 1885. This was set up by the Richardson family, owners of the local Bessbrook linen mills, and was powered by current generated at Millvale up to its closure in 1948.

5. A place apart: Ireland and the Shannon Scheme, 1925-1929

As we have seen, the work of Fourneyron had been introduced to a United Kingdom audience by Sir Robert Kane, who had also translated Rühlmann's work on water turbines into English. The critical lack of native coal in Ireland in the age of the steam engine, had placed a premium on extending and improving waterpower resources. In many of Ireland's internationally significant food processing industries, such as brewing and distilling, steam power was often employed as a supplement rather than as a complete replacement for waterpower. The scarcity of coal in the newly independent Ireland of 1922 was keenly felt. However, the potential threats that it posed for the emergent independent Irish economy actually enabled a young Irish engineer, Thomas McLaughlin (1896-1957), who had joined the German electrical engineering giant, Siemens-Schuckert, to convince the fledgling Irish Free State government to embark upon one of the most remarkable hydroelectric schemes of the modern era. Ireland, one of the least industrialised areas of Europe, and previously one of the lowest consumers of electricity, was to become the first country in the world to have a state-controlled national electricity grid. What became known as the 'Shannon Scheme' was McLaughlin's brainchild. As an engineer at Siemens, McLaughlin had been able to study German power plant design and electrical machinery at first hand. He was particularly impressed with the electrical network established in the Bavarian province of Pomerania (which was in many ways similar to Ireland) that supplied some 60 towns, 1,500 villages and upwards of 3,000 farms. Upon his return to Ireland in 1923, he was able to use his close contacts with a number of ministers in the first Free State government to have his proposals presented to the new nation's new power brokers.

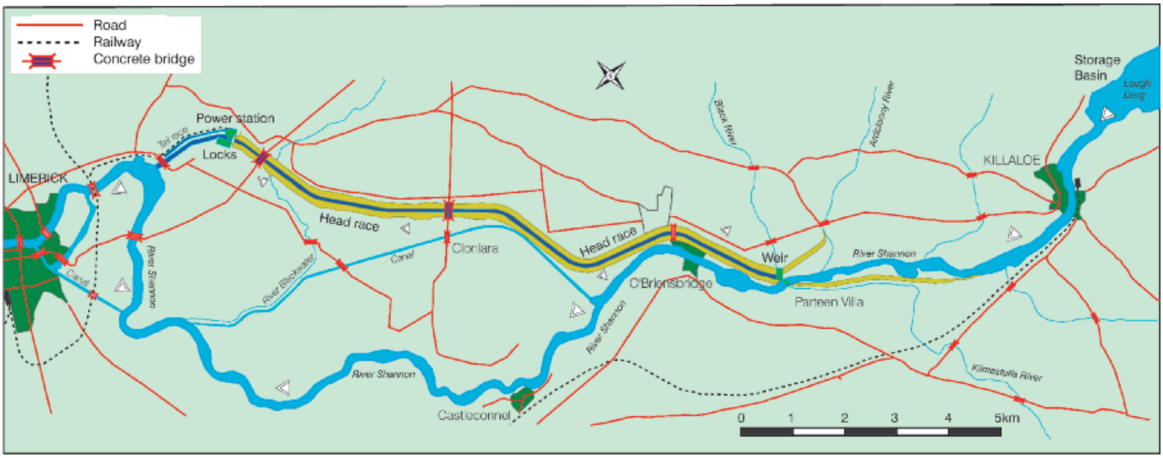


Fig. 7. The Shannon Scheme, County Clare, Ireland, showing layout of enormous headrace channels and the power station at Ardnacrusha.

The contract for the Shannon Scheme was awarded to Siemens-Schuckert in 1925, the largest foreign engineering project to be won by a German firm since the construction of the Baghdad railway. Ideally, the supply for the power station at Ardnacrusha, near Limerick, would have been created by the construction of a large dam across the River Shannon, which would have impounded a supply behind it. However, as local topography precluded this, the waters of the River Shannon – the longest river in either Britain or Ireland – were brought to the generating station site by what was, in effect, a giant mill-race. At Parteen Villa, near the village of O'Briensbridge, some 5 km to the south of the town of Killaloe, a weir was constructed on the Shannon which was designed to raise the water level by 7.55 m, the same at that of Lough Derg. The weir intake has six sluice gates and a fish pass some 190 m long, this latter the largest of its type in the world to have been constructed up to that time. From Parteen Villa, a head race channel 12.6 km long led the water to the hydro-electricity generating station at Ardnacrusha. This latter comprises an intake sluice house, penstocks, a generating building, a waste channel and navigation locks. The head race channel terminates in a 30 m high dam which supplies three 41 m long, 6 m diameter penstocks, each inclined at a slope of 31° and delivering 100 tons of water per second. Ardnacrusha began operations using three Francis turbines in 1929, to which a Kaplan turbine was added in 1934, this latter being the first of its type to utilise a head in excess of 30 m (Rynne 2006, pp. 432-434).

Fig. 8. The three Francis turbines, built by Siemens-Schuckert in 1929, in the Ardnacrusha power station, County Clare, Ireland.

6. Some conclusions

As Louis C. Hunter has observed "For the greater part of the nineteenth century, American entrepreneurs and engineers led the industrial world in the development and effective use of waterpowers of the largest capacity and on a scale unapproached elsewhere" (1979, p. 536). By any measure, the exploitation of waterpower in the United States effectively dwarfed that of Europe as a whole. Nonetheless, the transition to steam power was inexorable, given the shortage of waterpowered sites near urban locations and seaports, and the severe drop in water levels during the summer months which necessitated, in many large industries, the acquisition of backup steam engines. In the USA, as late as 1860, waterpower accounted for 56% of industrial motive power, but within a decade this had fallen to some 48% (Hunter 1979, p. 536). Even in coal-poor Ireland in 1870, waterpower only made up one fourth of the recorded industrial horsepower of 9,878 (this figure was one twentieth in Britain). However, Irish textile industries were responsible for just over 83% of Irish total waterpower in 1870 (Rynne 2006). In the Scottish linen industry there was little overall decline in the amount of power generated by waterwheels in the period between 1839 (1,495.5 hp) and 1871 (1,380 hp); indeed, in some sectors the amount of water power in use was actually on the increase (Shaw 1984, p. 523). Moreover, the adoption of iron in the construction of vertical waterwheels, along with other design improvements, meant that the decline in the use of waterpower in the period 1850–1856 was only some 9% in the UK textile industries (Von Tunzelmann 1978, p. 140).

The development of the water turbine in Europe and America provided some respite from the physical restraint that the lack of suitable mineral fuels for industrial use placed on any individual region's ability to develop heavy industries. Inevitably, perhaps, industrialists and the engineers who designed the systems providing their industrial motive power, lived in the moment and moved towards energy sources which were not location specific. The development of inland canal and railway networks with which bulky goods such as coal could be cheaply transported to industrial centres, also hastened the shift from sustainable energy sources such as waterpower to fossil fuels.

Yet only in the 20th century, with coal and oil resources rapidly running out, but with an increased demand for electrical energy, has waterpower and the water turbine received a new lease of life. Furthermore, within the last decade, with the threat of climate change and global warming becoming part of everyday public discourse, the promotion of renewable, sustainable energy sources is now an urgent matter for governments. According to the International Energy Agency, around 16% of the world's electricity, and 85% of its renewable electricity sources, continues to be generated using water turbines. The Francis turbine, or more properly, the Howd-Francis turbine, is still the most commonly used today in medium sized power plants. It is fitting, perhaps, that a technology developed by 19th century engineers to eliminate (or at least minimise) the use of fossil fuels, continues to have relevance.

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