The Technology of Wire Making at Tintern, Gwent, 1566–c.1880

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INTRODUCTION

The industrial archaeology[1] and general history[2,3] of the metal-working complex of the Angidy Valley near Tintern, Monmouthshire (now Gwent) have been reported upon, but little has so far been published on the technical processes used over the centuries following the opening of the first works in 1566. Indeed, little is known of most of the processes used, the evidence relating specifically to Tintern being very sparse and fragmentary. It is our purpose here to examine this evidence, and by relating it to known developments of technology elsewhere, to speculate on what processes were used at Tintern (and, of course, at its branch at Whitebrook), and to pose some questions to which answers are not at present forthcoming.

The great novelty involved at Tintern, so far as Britain was concerned, was the use of water power in the drawing operation. Before the Angidy wire-mills were established in 1566, men's bodily power alone was employed, although as will be seen, water power was a familiar adjunct in other countries.

BEFORE TINTERN

The primitive method of making wire was by hammering it manually;[4,5] we can also accept that use of the draw-plate or dies was of ancient origin.[6] More efficient man-powered machines had been developed by the early part of the 16th century. Judging by the relative sophistication, the earliest of these was of the form described by John Evelyn in 1675[7] as follows:–

"In this parish [Wotton, Surrey] were set up the first brass-mills, for the casting, hammering into plates, cutting, and drawing it into wire, that were made in England; first they drew the wire by men sitting harnessed in certain swings, taking hold of the brass thongs fitted to the holes, with pincers fasten'd to a girdle which went about them; and then with stretching forth their feet against a stump, they shot their bodies from it, closing with the plate again . . . "

This method of wire-drawing is illustrated by a woodcut showing a man sitting on a swinging seat, in front of a stump on which is mounted a multi-holed draw-plate; he is gripping the wire with hand-held tongs. No means of securing the operator to his seat is shown, but Evelyn states that he was "harnessed".[8]

Another means of using bodily power was a bench fitted with a die-plate at one end and a windlass at the other, with a belt, the free end of which was attached to tongs which gripped the wire; operation of the windlass wound the belt onto the shaft, and thus the wire was pulled through the die. Schubert discusses these early methods at some length.[9] He notes that the windlass bench was known as a brake, and its operators brakemen. (We have adopted the name "brake" for this type of machine and its derivatives, whether manually or water powered, although it was also called a draw-bench). "Compared with the brake, the girdle was a definite advance, as power was more advantageously distributed. The method did not compare favourably however with that of . . . the Tintern works, as the pincers used with the girdle as well as with the brake left impressions on the wire produced." There appear to be two objections to this statement: the girdle seems to have been a more primitive device altogether than the brake, and we feel that its use was confined to brass wire, as in Evelyn's description Furthermore (as will be shown later) one of the early objections to Tintern wire was that the pincers marked it.

A technical treatise published in 1540 by Biringuccio in Venice[10] illustrates and describes three methods of wire-drawing (see Figs 1 and 2) which may be summarised as follows:–

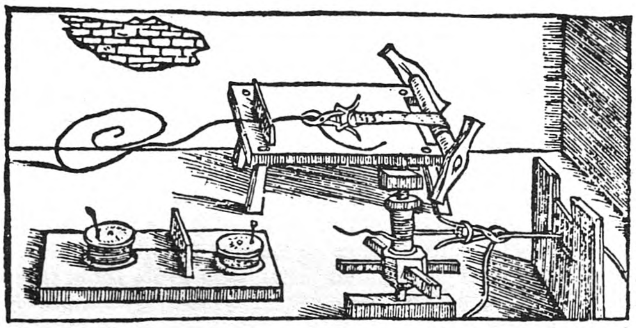

Figure 1 Three types of hand-operated wire-drawing machines, viz. the brake, the windlass, and the drum types, as shown by Biringuccio in 1540.

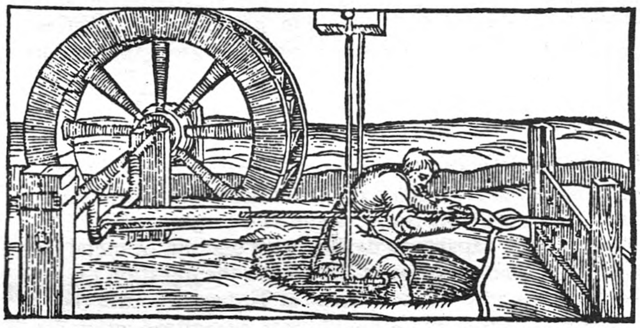

Figure 2 Water-powered machine for drawing iron wire, as shown by Biringuccio in 1540.

1 Bench windlass as described above. A similar mechanism, but with a capstan shaft arranged vertically between bearings at floor and roof is also shown.

2 Two drums mounted on vertical spindles on a base-plate, with a drawplate in between them. The wire was wound by hand off one drum and on to the other via the draw-plate.

3 A water-powered crankshaft, the throw of the crank pulling the wire through a draw-plate by means of

tongs moved by a driving band. The operator sat on a swing, 'his only care is to seize with the jaws of the tongs the end of the wire that issues from the draw-plate with every return that he makes". He moved with the work, and a pit was provided for his legs, which enabled the draw-plate to be floor-mounted, and kept short the bearing pedestals for the shaft.

Methods (1) and (2), and another not illustrated in which the force was applied by a screw device, were hand-operated. The drums were used for fine-drawing. The water-powered machine was stated to be for drawing 'heavy iron', and the author added that he had also seen iron wire drawn on horizontally-mounted drums, but then it had to be greatly thinned and well annealed; he added that this mechanism could be operated by water wheel, or by horse- or man-operated wheel.

It is probable that these methods described in 1540 were then by no means new, since 'the drawing of wire by the labour of wheels' is ascribed to Rudolf of Nuremberg in 1350[11]. An early industrial historian, Beckmann,[12] writing c.1800, states that the greatest improvement in the art of wire-drawing was undoubtedly 'the invention of the large drawing machine which is driven by water, and in which the axletree, by means of a lever, moves a pair of pincers that open as they fall against the drawing-plate, lay hold of the wire, which is guided through a hole in the plate, shut as they are drawn back, and in that manner pull the wire along with them . . . It is . . more than probable that it was first constructed at Nuremburg by a person named Rudolph, who kept it long a secret. . . Conrad Celtes, who wrote about the year 1491, is the only author known at present who confirms this information . . . '

It would appear that the old manual methods were not immediately superseded by the establishment of the works at Tintern in 1566, even in their immediate vicinity, for at Soudley, in the neighbouring Forest of Dean, 'here, as early as 1565, iron wire is said to have been made, being drawn by the strength of hand',[13] and in 1608 a list of able-bodied men in the Forest includes one wire-drawer at Newnham and one at Tidenham.[14]

TINTERN

The first wire works in the Angidy Valley at Tintern were being erected in November 1566, furnished with four water wheels, two annealing furnaces and two forges, and reckoned to be capable of dealing with one ton of metal per week: iron, steel, or brass.[15] This raises the question of whether brass wire was ever made at Tintern, because the original proprietors undoubtedly were authorised, inter alia, to make wire from brass, iron and steel.[16] In December, Schutz, the technical partner, was promising a weekly production of 25 cwt (1270 kg) of wire, and also latten (brass) wire at a rate sufficient to repay the building charges speedily.[17]

Humfrey, the commercial partner, reported on 23 July 1567 that the works were ready to start[18] and on 1 February 1568 he announced the production of latten at Tintern.[19] Yet on 11 July he wrote that the hammer house for latten, the foundry, the forge for Osmond iron, the rollers, and the casting stones for the brass were still to be made or obtained.[20] Moreover, a statement of expenditure at Tintern in its first five years (ie to 1570) mentions, so far as brass is concerned, only searching and mining for calamine (zinc carbonate ore), burning, and making pots for trials of latten;[21] and John Brode, in 1596, said that when he visited Tintern he was told that one Hinckens and his sons had built furnaces for making brass, their product being of the right colour but incapable of being rendered malleable; the small amount of calamine stone remaining was eventually used for repairing a fishing weir.[22] As to copper, the other constituent of brass, the arrival at Tintern of five tons is recorded by Humfrey, but apparently more of an embarrassment than anything else because it had to be paid for.[23]

Regarding brass at Tintern we may therefore repeat in part Hamilton's findings[24] that " . . . failure and disappointment are writ large over their efforts with brass . . . The Company was concerned with two different projects – the manufacture of iron wire and the making of brass, and the initial success of the former appears to have led to the neglect of the latter". From the facts known, the closing down of the brass-making experiments, far from being due to the success of the iron wire manufacture, was due to the failure of the experiments themselves, coupled with the great difficulty encountered in the making of iron wire, upon which all available resources had to be concentrated. It is safe to conclude that no brass wire was ever made at Tintern.

There is no doubt that iron wire was drawn in the Angidy Valley from the earliest period, but with limited success at first due to unsuitable iron and unskilled labour according to the list of expenditure already mentioned; this period would be from September 1565 (since the cost of the Letters Patent giving the necessary privileges is included) to 1570. We have no specific contemporary description of the wire-drawing machinery used in this early period (or indeed for the next century), save that it involved the use of water power by means of wheels. It is also safe to assume that tongs were used to grip the wire, as in 1596 there were complaints as to the quality of Tintern wire, centred upon bad smithing under the hammers, oversizing, and pinching with the drawing tongs.[25] According to Hamilton, the main reason was that the works had been let on lease since 1570 and the lessees had tried to maximise profits by raising prices and lowering quality.[26]

Whatever the details, within the first five years it was necessary to bring over from Germany Barnes Keyser, who 'caused all the engines in the house for drawing of wire to be altered into a new forme' and spent two and a half years in training operators.[27] It is probably significant that Keyser was described specifically as the only wire drawer there, whereas there must be considerable doubt about the talents of Christopher Schutz, if only by the very slow progress in the early years. Owen[28] describes him as an 'engineer and inventor, who claimed to possess the sécret to the modernisation and enhanced efficiency of the wire industry . . . (he) had conducted experiments in the extraction and utilisation of iron ore in Saxony, and had discovered a revolutionary technique in the use of calamine for mixing metals, and in rendering iron more malleable for industrial purposes'. Rees is much more cautious,[29] saying that 'neither Schutz nor Humfrey were fully competent in iron work'. Humfrey was a goldsmith, and assay master of the Royal Mint,[30] while Schutz was most likely as Grey-Davies[31] says, 'skilled in the smelting and extraction of non-ferrous metals, but knew nothing of the vagaries of iron working and smelting'. Hamilton describes him as the manager of the zinc mining company of St Annenberg, Saxony.[32] Certainly the early correspondence between Humfrey and Cecil (Secretary of State) spoke much of calamine, and little or not at all of iron, and if Schutz had real mechanical skills in wire drawing it is indeed strange that Keyser had to be brought over, and had to spend so much time rebuilding the new machinery; there is also some reason for believing that another German, Corslett, played the major role in establishing production of Osmond iron, essential for the production of good iron wire.[33]

It is reasonable to speculate upon the necessity for modifying the original machinery. It seems unlikely that the equipment was obsolescent or needed major repairs, and it could be concluded that it was in fact unsuitable for its purpose; it is tempting to think that it was intended for the drawing of brass wire, and had proved unsuitable for iron, a less ductile material of greater tensile strength. It may be, indeed, that Schutz, with his bias towards non-ferrous metals, had installed drums, which would probably not have been suitable for drawing iron wire in its heavier gauges.

We suggest that the means first used for drawing wire at Tintern were twofold: a modified form of Biringuccio's water-wheel machine for heavy-gauge drawing, and drums for fine gauges. The evidence which follows is circumstantial and slender, but not without weight. These two methods were clearly well-established on the Continent twenty-five years before Tintern, and it was from the Continent that Tintern's first mechanics came; moreover, 25 years was a very short time in the history of technical advance in the 16th century, and the rate of advance in the wire industry seems to have been notably slow. Apart from this, there is another reason for believing that Biringuccio's water wheels were used at Tintern, although the evidence does not appear until 1803, when Charles Heath of Monmouth published a description of the then old method of wire drawing at Tintern, which he said was based upon a handed-down description, all those who had practised it having passed away.[34] The full text is reproduced in Appendix 1, but the essentials were a long beam carrying the operators, who were secured by girdles to seats in pairs facing one another with the draw-plate between them, the wire being gripped with pincers and the beam being reciprocated by a water wheel. This is simply what we may term the 'Biringuccio machine', enlarged to accommodate several men. Whilst the first wireworks building was under construction in 1566 it was described as about 50ft x 30ft in size, and 'in the same cometh as many works as four wheels can drive'; it appears that if such a small building needed four wheels to power its machinery, that machinery was probably of a ponderous nature, which description would appear to fit Heath's swinging beams very well.

As to our contention that drums, almost certainly mounted on vertical spindles on each side of the draw-plate, were also used, clearly the full power of the water wheel would not have been needed for drawing fine wire, and again Biringuccio shows that these drums were well-known by the time the Tintern works were started. In 1569 Humfrey Cole, a die-engraver at the Royal Mint, was sent to Tintern for 'justifyinge the rolars'.[35] This has been interpreted by Rees[36] as indicating the presence of a rolling machine for flattening the plates prior to cutting them into rods by means of shears, but this is contrary to the generally-understood history of rolling mills. Rhys Jenkins has said[37] of Plot's reference (1686) to 'the new invention of slitting mills'[38] that this is 'the earliest indication that we have of the use of rolling mills in the English iron industry'; and the earliest reference he finds to the water-powered cutting of iron into rods is the patent granted to Bevis Bulmer in 1588, itself apparently unused for many years. Of the Saugus ironworks in Massachusetts, established in 1646, it is said that it embodied the most advanced iron-making technology of its day, and its rolling and slitting mill was one of the few then existing in the world.[39] So the 'rolars' were unlikely to be part of a rolling mill.

There is, however, another possible explanation of the rollers of 1569, because the term roller was also applied to the small hand-operated drums described by Biringuccio,[40] and it seems most likely that such machines were used at Tintern from the beginning, as the finer wires could not have been made with the heavier machines, whilst equally the converse was true. The relationship of the rollers on their spindles with the draw-plate and with one another was clearly fairly critical if breakage of the wire was to be minimised, and the choice of a toolmaker rather than a millwright to remedy their defects suggests that the equipment concerned was of a relatively delicate nature, which could hardly be said of even a small rolling mill.

The virtues of wire drawing on drums were, according to Abraham Rees (1819),[41] that they eliminated the marks left by the tongs, and being small and cheap they could be used by out-workers in their cottages, or by small craftsmen who bought relatively coarse grades and reduced them to the finer sizes they required in their own premises. Biringuccio says that for iron-drawing such drums could be worked by water or other power, although he does not say that this had actually been done. There is no evidence of out-working at Tintern, and as water-power was the feature which distinguished Tintern wire-making from previous English operations, it is likely that the drums there were water-powered. Abraham Rees illustrates multiple-drum units arranged for power drive, although he also shows hand-operated drums, and it is known that such equipment was still in existence in Yorkshire in 1913.[42]

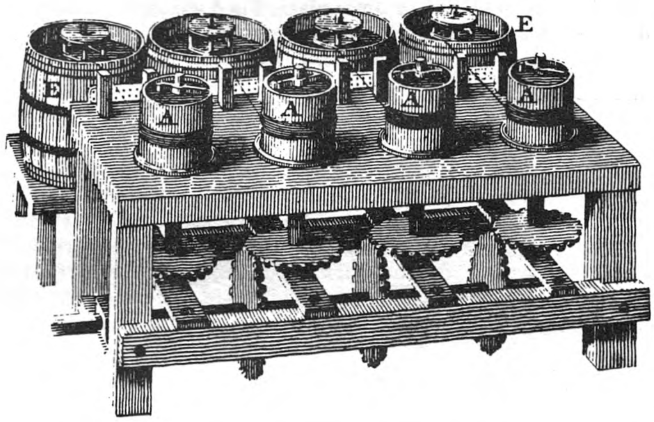

Figure 3 A battery of powered drums for wire-drawing, as shown by Abraham Rees in 1819.

RAY'S BARRELS

The first description of one type of machine used at Tintern was published in 1674 by John Ray, FRS, son of an Essex village blacksmith and later to be dubbed the Father of Natural History. The description[43] is reproduced in Appendix 2, but briefly the equipment consisted of a barrel mounted horizontally on an eccentric axis, rotatable by water power through a quadrant, after which the offset of its centre of gravity returned it to its original position; during its working cycle the barrel drew back a pair of tongs which gripped the wire and pulled it through the draw-plate. This was a major advance upon Heath's beam method, using the power more economically because the heavy beam was eliminated, and the operators themselves were no longer moved to and fro, but stood beside the machine as minders, feeding the wire into the die and adjusting the tongs as required.

Ray was born in 1627 and went to Trinity College in 1644; assuming that he saw the machinery for himself, as seems likely from his description of it, and assuming that he had little or no opportunity for travel before completing his studies, it can be taken that he visited Tintern at some time between say 1650 and 1674. There has been some tendency to assume that 'Ray's barrels' were the original machines employed at Tintern, but they embody mechanical sophistication so far advanced beyond that of Biringuccio that they appear to us to be more credible as a development near 1674 than of 1566.

We find no mention or illustration of a machine resembling 'Ray's barrels' in any of the other literature examined, which suggests that it may have been peculiar to Tintern. However, apart from the eccentric barrel, there is little real departure from the brake in its power-operated form, of which several illustrations exist (see Appendix 3), except that in the latter, the return of the tongs to the gripping position was achieved by an overhead spring beam linked to the operating lever, and possibly by sloping the work-table downwards to the draw-plate as appears in several illustrations,whereas the swing of the barrel re-positioned the tongs positively. The 'lazy-tongs' linkage described by Ray is illustrated in use on a sloping-table type of brake, with water pov er, in a work of 1839.[44]

It is, we feel, highly likely that the barrels of the machines described by Ray were weighted internally, to give the return stroke more impetus, and also that the working tables were sloped down towards the draw-plate. Fig 4 shows our reconstruction of the method.

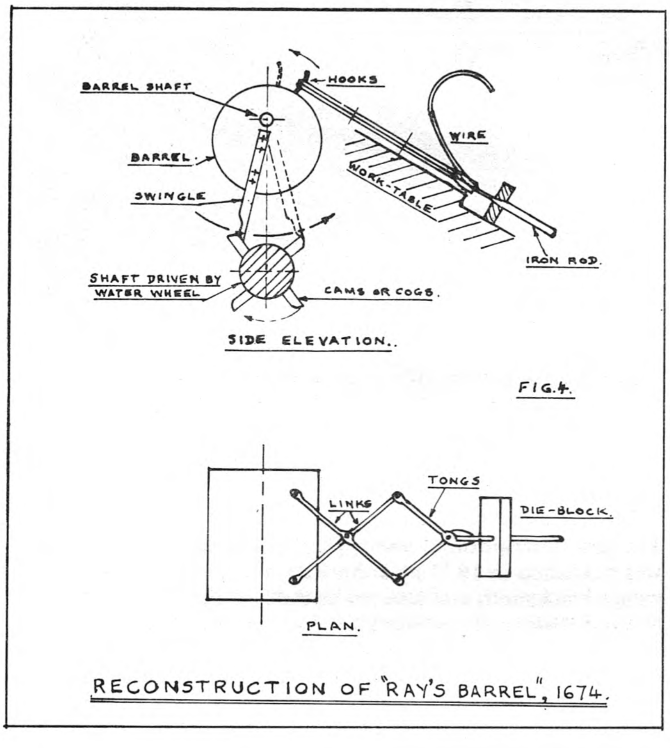

Figure 4 Authors' reconstruction of eccentric barrel type of wire-drawing machine, based on John Ray's description of 1674.

THE OVER–HOUSE MEN

Ray refers to another mill, for fine-drawing, having three floors with a driving shaft on each floor, driven by one water wheel, the wire-drawers being called 'over-house men', probably because they worked in an upper room. It appears that here the machinery was of relatively light weight, as it could be placed on upper floors, and it probably took the form of drums. The Schedule of 1821[45] includes a building named 'Gig Mill' in which one wheel worked three 'blocks' in the lower loft and five in the upper loft. This was the only building listed as having upper floors (and clearly two of them), so that there is no reasonable doubt that this was the single mill of that type mentioned by Ray, and the fact that 'blocks' was another name for 'drums' reinforces our belief that the fine-wire drums at Tintern were water-powered.

THE AGREEMENT OF 1747

In 1747 Rowland Pytt proposed to introduce new machinery at the Tintern wireworks, and it was such a fundamental departure from that in use before that he had to negotiate new rates of pay with his workmen.[46] The Agreement gives no indication of the nature of the innovation; Llewellin says that 'the ingenious apparatus employed at other establishments had placed their proprietors in a position to diminish the cost of production, and enabled them to undersell . . . Tintern'.[47] It was ostensibly to rectify this position that the Agreement was made.

There is a remarkable paucity of information available about what went on at Tintern in the 18th and 19th centuries, but there is certainly support for Llewellin's view that the Tintern wireworks, after their initial success under monopoly conditions in the 16th and early 17th centuries, had failed to respond to the growing competition from other works, and were backward and unsuccessful. The account books[48,49] for the last part of the 17th century, when the works were, for a time, under Foley management, show a surprisingly small scale of operation, with only about 30 men in total at Tintern (ie. including all trades, not merely wire-drawers), and even fewer at Whitebrook. Holland[50] says that 'in the 17th century the wire-drawing business . . . took deep root in the neighbourhood of Barnsley [Yorkshire] . . . the first workmen, it is supposed, came thither from Wales' [from Tintern?]. So there may have been an exodus of skilled men from Tintern to join competing organisations. Holland goes on to say, of wire-drawing generally, that 'grooved rollers' (ie. rolls) superseded hammering for making the iron rods, and referring to the brake with lazy tongs (which he illustrates) describes it as 'now [1839] rarely to be seen in the large wire-mills of this country . . . still to be met with in some of those old establishments where expensiveness, or want of convenience, preclude the adoption of rollers, and where the rippers . . . care little about modern improvements'.

Could a rolling mill with grooved rolls have been the new machinery which was being discussed in 1747? This would have replaced either the old process of tilting (ie. hammering) the bars into rods or the old processes of ripping and slipping the rods into wire – or both. However, if it had been the former, the 'hammermen' or 'handmen' would have been included in the 1747 Agreement, and they were not; had it been the latter, the rates for ripping and slipping (see p.24) would have been reduced or might even have disappeared; but in fact they were hardly changed. The rate for ripping was increased 12% as compared with 1698–9, and slipping was decreased 14%, so that the changes here were quite insignificant. It was indeed the rates for 'upperhouse wire', as the finer grades were called at the end of the 17th century, which were decreased by the 1747 Agreement, thus:–

Size	Rate per stone 1698–9	1747	% Reduction	
Reevin	3d	2d	33	(this size called Kleven in 1747)
Clavant	4d	3d	25	
Bastard	7d	4d	42	
Coarse fine	10d	5d	50	
Fine fine	12d	6d	50	
Super fine	18d	9d	50	

These very substantial decreases indicate that it was in this area that the great increase in efficiency was expected to take place. Heath (1803)[51] says that with the new methods 'less than one half the former number of hands became necessary'. But drums were still the normal system for fine-wire drawing in the 19th century, so it is hard to see what the great improvement could have been.

There is one possible explanation of the situation which appeals to us, namely, that the changes in machinery envisaged by the 1747 Agreement,did not, in fact, take place. Prior to the Agreement, the workmen had guaranteed security of employment; the real purpose, or at any rate, the real effect, of the Agreement may have been to change this situation by giving the employers greater freedom in deploying their workers at more suitable rates of pay. There is really no firm evidence that new methods were actually introduced within some decades after 1747; Heath's actual words were 'when the *present* method of making wire was introduced . . . less than one half . . . ' [Heath's italics]. As he was writing in 1803, the 'present' method may have been introduced quite late in the 18th century, or even in the first year or two of the 19th. We know that a rolling mill existed at Tintern in 1821,[52] situated at the Lower Works, although none was mentioned in an admittedly rather abbreviated description of 1798,[53] which did, however, include three tilt hammers. It is thus very possible that Heath's '*present* method' referred to the introduction of rolls without any implication that rolls were associated with the 1747 Agreement.

It may be presumed that the three hammers just mentioned were housed in the tilting mill which, by the evidence of surveys of 1763 and 1821, was built between those years. Tilt hammers had been used from the beginning of the wireworks for 'straining' or drawing down the iron bar into rods. (In 1583 reference was made to the straining of iron rods in the hammer houses built by Christopher Schutz,[54] and earlier, in 1580, when Richard Martin took a lease of the works, he promised to erect two hammers in addition to the four already there.[55]) The construction of new tilt hammers between 1763 and 1798 infers that no great changes had been made in this part of the wire-making process at that time, thus supporting our suggestion above.

TONGS AND BLOCKS

In the two descriptions of the wireworks dated 1798 and 1821, the wire-drawing machinery is described partly by the term 'tongs' and partly by the term 'blocks'. The following numbers of each were recorded:–

	1798	1821
Tongs	10	12
Blocks	10	23

In the period concerned, capacity had been increased by a total of two tongs and 13 blocks, yet in this period New Tongs Mill was built at Pont-y-Saeson, housing 11 tongs, one more than the total in 1798. The tongs were evidently still a well-established and indispensible means of production which had been concentrated in new premises rather than expanded, perhaps to make room for the considerable increase in the number of blocks. We are certain that the blocks were drums or developments thereof. The tongs would have been for relatively heavy drawing, where marking did not matter; they were probably still of the 'Ray's barrels' type, or possibly of the type of brake illustrated by Abraham Rees (see Fig 5) in 1819.[56] They were certainly not Heath's beams, pronounced long-extinct in 1803.

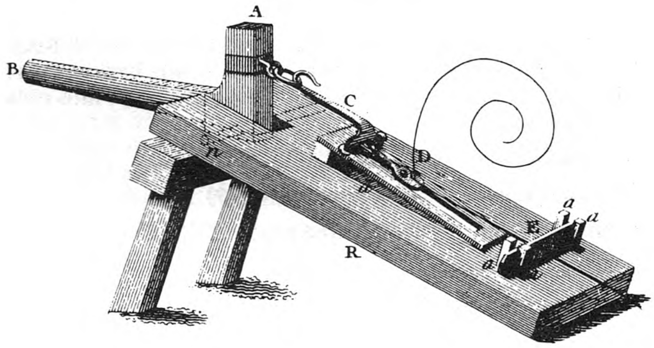

Figure 5 A brake for wire-drawing, as shown by Abraham Rees in 1819; the water-powered drive and spring-beam return are not shown, but are mentioned in Rees's text.

The fact that a great increase in the number of blocks was not accompanied by a corresponding increase in the number of tongs, coupled with the provision of a rolling mill which we have already mentioned, suggests that an increased demand for wire was being met by the substitution of rolling (with grooved rolls) for part of the wire rod making process. That the rolls were not plain rollers for rolling iron plate is indicated by the fact that we have found no record of slitting mills ever being used at Tintern, and without such mills to make bars from the plate, there could have been no purpose in making plate there.

We have discovered no technical information concerning the equipment used at Tintern in the 19th century; it is surprising that, limited though the accounts of earlier centuries are, they are generous compared with those for the most recent period. After the first quarter of the 19th century, the works appear to have been generally on the decline, and it is unlikely that any technical innovations were made after the installation of the rolling mill.

Considering wire making generally, not just at Tintern, an examination of available illustrations through the years indicates remarkably little change in the mechanics of wire production. We believe that this is partly attributable to the separation of the processes into the two quite distinct parts: (a) the production of wire rod (ripping, or 'rumpling' in some places), and (b) the drawing of this into fine wire. It is the second part that receives attention in most accounts, and changes in the first part may have escaped note.

The known illustrations are listed in Appendix 3.

OTHER ASPECTS OF THE WIRE–MAKING PROCESSES AT TINTERN

We have concentrated attention on the wire-drawing methods because these embodied the more refined and novel mechanical equipment; but the whole wire-making process involved other operations, and these will now be noticed.

Given the billet of Osmond iron, it was necessary to heat it, work it under a hammer to a thickness suitable for the wire contemplated, take off the four corners or edges, and bring each rod to a taper at one end so that it could be offered into the die with sufficient protrusion for it to be gripped by the tongs. During these operations, it was necessary to place the iron in water for varying periods (see below).

In the earliest period, a list of labour and material charges at Tintern taken in 1574 records the following operations:—[57]

Straining the iron into rods (under a power-hammer; W Rees states[58] that 'straining' was rounding under the hammer, but John Ray[59] equates straining with elongation only, into rods of square section).

Ripping (drawing of wire rod)

Slipping (drawing of square-section wire?)

Rounding (removing the squared edges of slip wire?)

Drawing of the wire

Scouring of the wire (cleaning off the scale).

The trades employed, apart from the wire drawers themselves and a carpenter and labourers (maintenance workers), comprised two smiths and their two strikers, nealers, and 'one to scale'. The definitions above are those given by W Rees, Schubert, and others, and which can be deduced from Ray's work. The sizes of wire made were given distinctive names, as listed in Appendix 4. There is some suggestion, as from the distinction between 'round' and 'slip' wire, that some was of square section.

The raw materials mentioned, apart from the iron, are given as train (oil), tallow, candles, 'sea coal and wood to neal', and steel and iron to mend tools and make new ones. The first two were clearly lubricants (Ray mentions train oil as such).

THE WATERING PROCESS

The immersion of the wire in water at various stages of drawing, detailed by Ray, has been the subject of some speculation in recent years. Ray offers no explanation of it, and Rogers, quoting the workmen's terminology in 1857,[60] says it was intended to 'purge and purify away the sulphur', and that the indication that the process was complete was a thin scum rising to the surface of the water.

The other contention is that the object of the watering process was to promote the formation of a rust coating, which acted as a carrier for the lubricant, thus permitting easy and continuous drawing. The formation of this coat, and its preservation by dipping into slaked lime, was described in 1913,[61] but the writers were silent as to its purpose. Professor Hugh O'Neill has briefly described this process, adding that the reason, according to the 'Steel Wire Handbook' (USA) of 1965 was that the calcium hydroxide acts as a solid lubricant carrier.[62] Mr K Gale adds that rusting also helped to break up hot-rolling scale which, being very hard, would quickly damage the dies.

It appears to us that even the early practitioners must have known that they did not need to water the iron for weeks and even months, simply to produce a coating of rust, also that total immersion in water was not the best way to achieve this. The presence of air would hasten the matter, so that far from making special 'water-holes' like tan-pits for the purpose, as Rogers states, it would have served better to have put the wire into a flowing stream, with its better aeration. We suggest that the original purpose of the watering was as Rogers states; that the formation of a rust coating used to carry lubricant was a useful by-product of the process; and that in later years, with the use of improved annealing methods in a sulphur-free environment, only the coating was required, and was obtained following tumbling in the scouring barrels, to which we can now turn our attention.

SCOURING BARRELS

These items of equipment were in use at Tintern in 1798[63] and the fact that they were not mentioned by Ray, coupled with Rogers's note of 1857 to the effect that the traditional watering process was regularly practised at Tintern more than fifty years before to his own knowledge, suggests that their introduction can be placed in the last quarter of the 18th century. The barrels were used for removing the scale produced by air-cooling following annealing, and their use was probably the same as described for works at Thurgoland, Yorkshire, as follows:—[64] The charge, ranging from 5 to 10 cwt, was packed with broken blast-furnace slag into a barrel, the end of which was removed for loading and then screwed into position. The barrel was set in motion (using water power at Tintern,[65] and no doubt at other places also) in a trough of running water, and it was rotated at about 30 rev/min for a period of 12 to 24 hours. The wire was removed wet, and stood until a coat had formed, which was preserved by dipping into lime, after which the wire was dried before a fire. The wire was then drawn through the first two holes, but in later stages of drawing it was sometimes cleaned with a mixture of vitriol and brewery grounds. Later stages of drawing were known as common-drawing or jigging.

There were ten scouring barrels at Tintern in 1798[66] and 16 in 1821,[67] disposed among four different sites, at three of which the barrels were driven by their own water wheel, while at the Tilting Mill site two barrels were driven from the same wheel as the hammer.

ANNEALING

Each time the metal is drawn through a die it hardens, and after each few drawings it is necessary to anneal it, ie. to heat it (usually to red heat) and to allow it to cool slowly, when its ductility is restored. This was a common and well-known process, in early days done in an open fire of some sort. The iron (or other metal) was thereby exposed (a) to the undesirable elements, such as sulphur, in the flames, and (b) to the oxygen in the air on cooling, thus causing scaling. No doubt this simple process was what was used at Tintern at least up to the end of the 17th century.

Improved annealing furnaces came into use elsewhere in the 18th century. Those used in the Bristol brass industry,[68] for example, were tall towers (around 30 ft high, or 10m) tapering from a base about 10 ft (3m) square. Inside the base was a smaller oven of refractory material, with a fireclay door which could be raised by means of a lever and counterweight. The metal to be annealed was put in this. The fire was outside it, and the flames and hot gases were caused to circulate in the gap between the oven and the tower itself. Thus the metal was protected from both the flames and the air. More efficient arrangements used in France are described by Abraham Rees[69] whereby the container or oven (made of iron) could be removed after heating in order to allow another to be put into the furnace while it was still hot.

No information is available as to what kind of annealing furnaces were used at Tintern up to about 1800. However, there are still a few remains extant of the new tongs and annealing mill at Pont-y-Saeson, built in 1803, and these indicate that the annealing furnace then provided had a square base very similar to those used in the Bristol brass works, and it is a not unreasonable assumption that the whole furnace was of the same general design.

PRODUCTIVITY

The object of introducing technical change must be either to improve the quality of the product or to increase productivity per unit cost. It is clear from the 1747 Agreement, whether it resulted in technical change or not, that it was the latter consideration which applied at Tintern. It is therefore worthwhile to determine what the productivity was at various periods. Unfortunately the account books which have so far been discovered[70] cover only the period from 1672 to 1700 – ie. the 'Ray' period. We record some conclusions from them in the hope that the data can eventually be used for comparison.

Analysis of the accounts shows an overall productivity of finished wire of about 1.8 tons per year per man employed at the wireworks, or about 4.5 tons per year per upperhouse wire-drawer. 62 tons of Osmond iron, purchased at £18 per ton, was dealt with by the hammermen at the wireworks in 1699 to produce 42½ tons of wire selling at an average of about £40 per ton, plus some miscellaneous iron selling at about £200.

CONCLUSIONS

It will have been seen how difficult it is to be certain about the processes used at Tintern. There are a few certainties, however:–

1 Water power was used from the beginning in 1566–8, and this was the first time it was so used in Britain, although an established practice on the Continent.

2 A detailed description of a water-powered mechanism for the Ripper's stage of wire-drawing was given by John Ray in 1674. The tongs had to be applied to the wire by the operator, or ripper, at each pull.

3 Finer stages of wire-drawing were also water-powered by 1674, according to Ray, being done in a 3-storey building powered by one water wheel driving shafting on each floor.

4 The accounts for 1699 show that bar iron was 'drawn' at the forge (not part of the wireworks, but associated with them) at the rate of 160 tons/year and that 62 tons of iron were dealt with by 'hammermen' at the wireworks. So the preliminary preparation of rod was done by hammering.

5 Radical changes in technique were proposed in 1747, the new rates of payment per cwt showing an increase for rippers but decreased payment to all other wire-drawers.

6 A rolling mill was provided around 1800, and by then the number of men required had been drastically reduced.

Apart from these facts, we have had to speculate; some of our suggestions are:–

i. Wire-drawing at Tintern had started using men in swing seats, moved to and fro by the water wheel, as described from tradition by Charles Heath around 1800. The men fastened tongs onto the wire each time they moved backwards and so drew the wire through the die. This is more or less the system described by Biringuccio in 1540.

ii. The radical changes of technique implied by the 1747 Agreement were never made.

iii. The rolling mill of c.1800 had grooved rolls, and was used for the preliminary forming of bar into rods, and thus reduced the work required from the rippers.

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APPENDIX 1

WIRE–DRAWING AT TINTERN, c.1600, ACCORDING TO CHARLES HEATH
(reference 34)

"The assistance of the mechanic powers to the operations of labour, appear to have been in a very infantile state at that period, if an opinion may be formed from the process of their work, of which tradition has preserved a feint recollection. A large beam was erected across the building where they carried on their trade, to which were affixed as many seats (in the form of large wood scales), as there were men employed, who were fastened in them by means of a girdle, that went round their bodies. The men were placed opposite each other, while between them stood a piece of iron, filled with holes of different bores, for reducing the wire to the various sizes. When the iron to be worked was heated, the beam was put in motion by means of a water wheel, that moved it, with the workmen in their seats, regularly backwards and forwards, who, with a large pair of tongs, passed and repassed the iron through the holes, till by force they reduced it to the sizes required. The motion was as regular as the pendulum of a clock; and if any one of the men missed seizing the iron with his tongs, he suffered a considerable shock in the return of the beam."

APPENDIX 2

WIRE–DRAWING AT TINTERN, c.1674, ACCORDING TO JOHN RAY
(reference 43)

"They take little square Bars, made like Bars of Steel, which they call **Osborn–Iron**, wrought on purpose for this manufacture; and strain ie. draw them at a Furnace with a Hammer moved by water (like those at the Iron Forges, but lesser) into square Rods of about the bigness of ones little Finger, or less, and bow them round. When that is done they put them into a Furnace, and neal them with a pretty strong Fire for about twelve hours: after they are nealed they lay them in water for a month or two (the longer the better) then the Rippers take them and draw them into Wire through two or three holes.

Then they neal them again for six hours or more, and water them the second time about a Week, then they are carried to the Rippers who draw them to a two-bond Wire, as big as a great Packthread.

Then again they are nealed the third time, and watered about a Week as before, and delivered to the small Wire Drawers, whom there they call Overhouse-men, I suppose only because they work in an upper Room.

In the Mill, where the Rippers work, the Wheel moves several Engins like little Barrels, which they also call Barrels, hooped with Iron. The Barrel hath two Hooks on the upper side, upon each whereof hang two Links standing a-cross, and fastened to the two ends of the Tongs, which catch hold of the Wire and draw it through the hole. The Axis on which the Barrel moves, runs not through the Center, but is placed towards one side, viz that on which the Hooks are. Underneath is fastened to the Barrel a Spoke of Wood, which they call a Swingle, which is drawn back a good way by the Calms or Cogs in the Axis of the Wheel, and draws back the Barrel, which falls to again by its own weight. The Tongs, hanging on the hooks of the Barrel, are by the Workmen fastened on the Wire, and by the force of the Wheel the Hooks being drawn back, draw the Wire through the holes.

They anoint the Wire with Train-Oil, to make it run the easier. The Plate, wherein the holes are, is on the outside Iron, on the inside Steel.

The holes are bigger on the Iron side, because the Wire finds more resistance from the Steel, and is streightened by degrees.

There is another Mill where the small Wire is drawn, which with one Wheel moves three Axes that run the length of the House on three Floors one above another.

The Description whereof would be tedious and difficult to understand without a Scheme, and therefore I shall omit it."

APPENDIX 3

PUBLISHED ILLUSTRATIONS OF EARLY WIRE–DRAWING EQUIPMENT

Date	Equipment illustrated and source	
1540	1	Brake, hand-operated, horizontal table
	2	Vertical-shaft capstan
	3	Drums, hand-operated
	4	Water-powered hand-held tongs (Biringuccio, our reference 10)
1768	Brake, power-operated, horizontal table, with spring-beam return. For brass wire. (D. Diderot, **Encyclopédie**, Vol. 6)	
1786	1	Brake, water-powered, sloping table, spring-beam return
	2	Brake, hand-operated, sloping table, leaf-spring return
	3	Drum-brake; wire wound through die by a drum, rotated by hand; sloping table
	4	Drums, hand-operated (Diderot & d'Alembert, **Encycl. Methodique**, Vol. 3 of plates)
c.1800	Brake, hand-operated, horizontal table (reproduced by Schubert, our reference 9, from D H Döhner, **Geschichte der Eisendrahtenindustrie**, Springer, Berlin, 1925)	
1819	1	Brake, hand-operated, windlass, sloping table
	2	Ditto, geared, horizontal table
	3	Brake, water-powered, sloping table, spring beam

	4	Multiple drums, power-driven
	5	Drums, hand-operated
	6	Ditto, geared (Abraham Rees, our reference 41)
1839	1	Brake, power-operated, sloping table, lazy tongs
	2	Single drum, hand-operated
	3	Drums, power-operated (John Holland, our reference 44)
1853, 1869, 1873		Drum method, power-driven (C. Tomlinson, **Encyclopedia . . .**; W Crookes & E Röhrig, **Pract. Treat. on Mety.**, Vol. 2; G H Makins, **Manual of Mety.**)

APPENDIX 4

WIRE SIZES, RATES OF PAY, AND TRADES AT TINTERN AT VARIOUS TIMES

Note: No source examined so far enables the actual wire size to be determined for any of the traditional names listed here. Most sources, including John Ray (see Appendix 2) agree that when the osmund iron left the tilt hammers, it was about the thickness of one's little finger and square in section. When a wire size or trade is mentioned in a particular year, it is named below. The payment for drawing one stone (14 lb or 6.35 kg) is given in pence (d) where recorded.

1574 (ref. 2)	1672/3 (ref. 48)	1698/9 (ref. 49)	1739 (ref. 71)	1747 (ref. 34)
	Boltack	Boltack	Bolttack	
	Buckle	Buckle		
	Two band	Two band		
	Round wire	Round wire	Round wire	
Riving 2d	Reeven 3d	Reevin 3d	Revin	Kleven 2d
Clavant 4d	Clavant 4d	Clavant 4d	Clavant	Clavant 3d
Northern 4½d	Northern 5d			
Bastard 6d	Bastard 7d	Bastard 7d	Bastard	Bastard 4d
	Course fine 10d	Coarse fine 10d	Corse fine	Coarse fine 5d
Fine 10d				
Fine fine 12d	Fine fine 12d	Fine fine 12d	Fine fine	Fine fine 6d
	Super fine 18d	Super fine 18d	Super fine	Super fine 9d
				Big Nogg 14d
				Small Nogg 16½d
Straining	Handmen (for drawing out Osmund, iron)	Hammermen		
Ripping	Rippers (for round wire)	Rippers		Ripping
Slipping	Slippers (for two band wire)	Slippers		Slipping
Scouring(of slip wire, of round wire)	Scourers (for round wire, for two band wire)	Scourers		Scouring of two-band
	Scallers (for round wire)	Scalers		Scaling of ripp wire
	Swager	Swager		
	Smiths	Smiths		
	Nealers	Nealers		
	Carpenter	Carpenter		
	Sawyer			
				Breaking of round wire
Rounding				Rounding