The Engine Indicator

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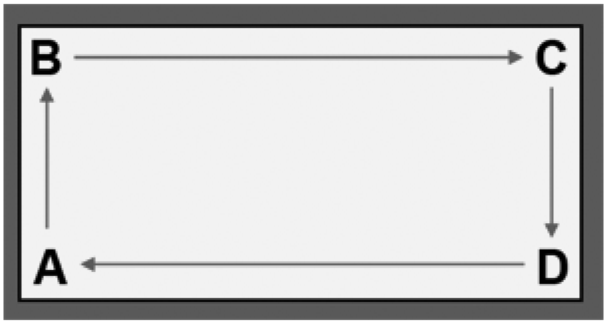
What is an indicator?

An indicator is a small, originally mechanically-operated instrument that gives an insight into the operation of a range of pressure-operated machines — steam engines, gas and oil engines, compressors, condensers, even guns — by comparing the rise and fall of pressure during the operating cycle. The use of an oscillating drum allows variations in pressure to be recorded on both the outward stroke and the return journey. Excepting some of the continuously-recording instruments and virtually all maximum-pressure recorders, indicators usually give a trace in the form of a closed loop.

A steam engine works by allowing steam to enter a cylinder behind a piston, then pushing the piston along to the opposite (far) end of the cylinder. The piston is connected to a crank, and the crank is often connected to a heavy flywheel. If the engine is single acting, the steam would be exhausted at the end of the piston stroke and the momentum of the flywheel, once the engine was running, would return the piston passively to its original position. Steam would be introduced, and the cycle would recommence. Most engines are double-acting, however. When the steam is exhausted from the head side of the piston at the end of the outward stroke, another charge of steam is introduced on the crank side of the piston to actively push the piston back again. This results in continual motion as steam is admitted and exhausted on both sides of the piston alternately.

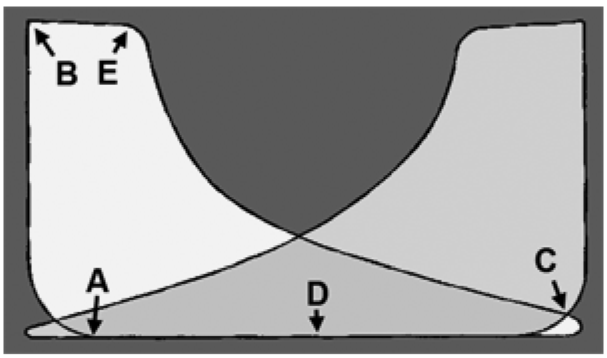


The sides of this near-rectangle illustrate the steam cycle in graphical form. The steam valve opens at **A**, allowing the pressure to rise instantaneously to its maximum level, shown at **B**. The piston starts to move forward, propelled by steam that is admitted until the piston reaches the far end of the cylinder at **C**. The exhaust valve then opens, releasing all the steam, and the pressure drops to**D**. At this point, the admission of steam to the other side of the piston (or the momentum in the flywheel) pushes the piston back to its original position **A**.

But this is a very simplistic case, and no engine could ever work exactly in this way. This is due to several factors, ranging from a desire to economise, using the ability of steam to expand within the cylinder ('expansive working'), to the inability of valves to admit or exhaust steam instantly and the inadvisability of pistons slamming into the end faces of cylinders. It is standard practice, therefore, to shut the inlet valve long before the piston has travelled the length of the cylinder, allowing steam to provide impetus by continuing to expand even though pressure drops as volume increases. Opening the exhaust valve shortly before the end of the piston stroke allows pressure to fall quickly, but smoothly enough to cushion the last few inches of piston-travel.

As the piston travels back to its start position, propelled by a fresh admission of steam on the crank side, it does so against a certain amount of back pressure (a residue of steam remains after the exhaust valve has closed) that rises far enough to prevent the piston slamming against the inner face of the cylinder head. The inlet valve admits steam shortly before the end of this return stroke, pressure climbs rapidly to its maximum value, and the cycle begins again.

The diagram is no longer a horizontal rectangle, but more like a vertical rectangle (where steam is admitted at full pressure) joined to a truncated right-angle triangle representing the part of the cycle where the expensive properties of steam are being used to promote economy. Rounded corners show the point at which the admission of full-pressure steam has been cut off, where admission or exhaust occurs, and where the cushioning effects of residual steam prevent unnecessary damage to the piston and cylinder.

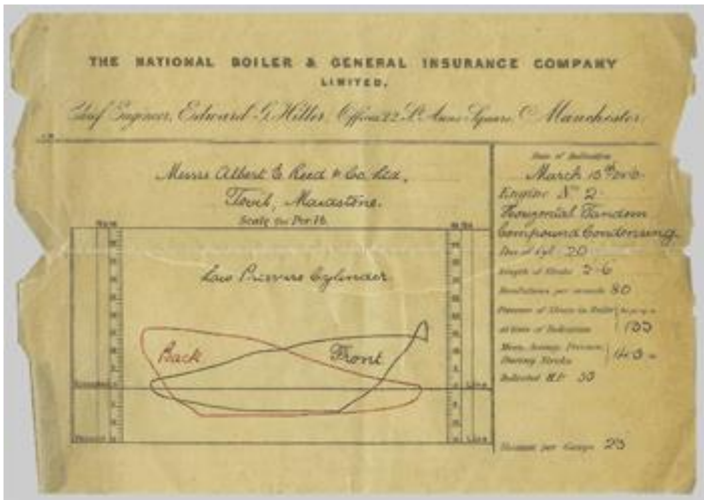


This diagram is to be expected from a well-regulated engine of Corliss type, showing the traces obtained from the outward or head stroke (left) and the return or crank stroke (right). The admission of steam during the head stroke is 'cut-off' at **E**, allowing the remainder of the piston stroke to be powered simply by the additional expansion of the steam that is already in the cylinder.

The position of the base of the trace in relation to an atmospheric line will show the levels of back pressure, and whether the engine is fitted with a condenser (when the baseline of the trace will lie below the atmospheric line and indicate the presence of a vacuum).

Diagrams may be taken from one end of the cylinder only, though, with the aid of multi-way cocks, they will often be taken from both ends in sequence and present the mirror-image appearance shown above. The greater the symmetry of the mirroring, the more consistently an engine is performing. There can be good reasons why the power developed on each stroke is not identical, but this balancing is nevertheless an ideal if often theoretical goal. To guard against a single indicator card being untypical, several traces would sometimes be run on a single card; in most cases, assuming the engine was working reliably without any change in load, the lines would usually reinforce each other. The so-called 'limiting' indicators achieved a similar goal by building up a single trace of narrow horizontal slices taken from as many as fifty sequential strokes.

An indicator diagram could draw attention to a wide range of problems with an individual engine, which had often escaped the attention of its minder. On many occasions, the diagram revealed that the setting that was claimed to be perfect 'by ear' or 'by eye' was anything but ideal, and changes could often be made to improve economy or reduce the strain on the components. Some engines, of course, could have a number of faults simultaneously; those that were due to poor design or bad construction were much more difficult to address than a simple case of bad valve timing.



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This was copied from a diagram taken in 1906 by a boiler inspector employed to check that the steam plant insured by his employers was working satisfactorily. An Elliott-Richards indicator was used.

The diagram show above, taken from a real double-acting engine, makes these points eloquently. The shape of the 'Back' (head) trace, in red, shows that the engine is not working particularly hard, and that the cut-off — the point at which the admission of steam ceases — is too early. The pressure of steam behind the piston then falls so far that there is virtually no additional drop as the exhaust valve opens. In addition, the long sweeping upward curve at the bottom left-hand corner shows that there is too much steam left in the cylinder when the inlet valve opens and the cycle begins again. The trace of the 'Front' or crank end, however, is worse. The steam-admission pressure is lower, cut-off is even shorter, the decline of pressure too protracted, and there is almost no cushioning effect on the piston as it returns.

A few simple alterations could greatly improve the smooth-running and general efficiency of this particular engine. Different types of engine, of course, gave characteristically different diagrams; though the design of the intervening pipes played an important part in ensuring that as much of the boiler pressure as possible was preserved when the steam reached the cylinder, there is little doubt that the valve gear made the greatest difference. This is particularly true of 'detaching gear' such as the American Corliss design, which (at its best) gave very precise admission and exhaust phases.

Indicators could be used with anything in which pressure changed over a period of time -- steam engines, pumps, compressors, refrigeration equipment, internal-combustion engines, and even guns.

The perfection of the gas and oil engines was due partly to trial-and-error experimentation, but many of the leading experimenters explored operation in great detail. At first, the pressures and running speeds were quite low: nothing, indeed, that would have seemed remarkable to a steam engineer. This allowed investigative work to be undertaken with conventional spring-and-piston indicators. However, the diagrams obtained from the earliest internal-combustion engines were not as satisfactory as those from a steam engine. This was partly due to the exceptionally rapid rise of pressure, which not only placed a great strain on the components of the indicator but also highlighted inherent problems of vibration and inertia. In addition, working temperatures rose far higher than those encountered in steam engines made prior to the introduction of superheating. The worst feature was undoubtedly the unreliability of an individual diagram as a guide to performance. Internal-combustion engines often ran erratically and were prone to misfire; individual cycles, therefore, were not as consistent or predictable as those of a steam engine. Many experimenters became convinced that a better method of indicating internal-combustion engines could be found, and appropriate patents were granted from the late 1880s onwards.

In the Provisional Specification of his 1900 British patent, Rodolphe Mathot observed that: '…indicators are at present used in connection with the testing and verifying of the work of thermal engines, but they generally prove insufficient for controlling the said work in explosion engines, such as gas and petroleum engines. The diagrams taken on these afford only indications or data on each explosion taken separately and from the stand-point of the initial pressure at the time of same, etc. Now, all the explosions which succeed each other, whether successive or distant on account of misses, differ from one another in their importance, their efficiency, the time of ignition of the mixture, etc. For controlling the complex phenomenons [sic] which take place during the motion in explosion engines, it is accordingly important to note during the proper time, all the explosions and misses which succeed each other under the various conditions of work or regulation…'

The search for better designs had begun.

The first steps

Watt, *c*. 1793

The first of Watt's pressure-indicating gauges had been tried by December 1793. It consisted of a small cylinder, no more than an inch in diameter with a bore six inches long, which contained a solid-head piston made with the greatest accuracy that could be obtained. The cylinder terminated in a small cone-tipped pipe, which could be inserted in a hole bored in the cylinder or condenser covers. Communication between gauge and receptacle was controlled by a system of cocks.

A long spiral spring connected the piston rod with the supporting frame, and a pointer attached to the rod-tail lay against a graduated scale allowing the pressure within the cylinder (or, alternatively, the vacuum in the condenser) to be determined. Calibration was undertaken by referring to a mercury barometer.

Watt's primitive gauge worked well enough to enable the operating characteristics of individual engines to be determined, but had an important drawback: pressures could be observed only by watching the movements of the pointer during the piston stroke and then simply writing the results down. This process was open to error, even though the ponderous movements of the early beam engine were slow enough to facilitate observation.

Indicating devices of this type soon proved so useful that refinements were made. The Science Museum in London still has a machine in the form of a small beam engine, with the piston on one side of the supporting column and the spiral spring on the other, taking the place of the connecting rod or pump rodding on the full-size engines.

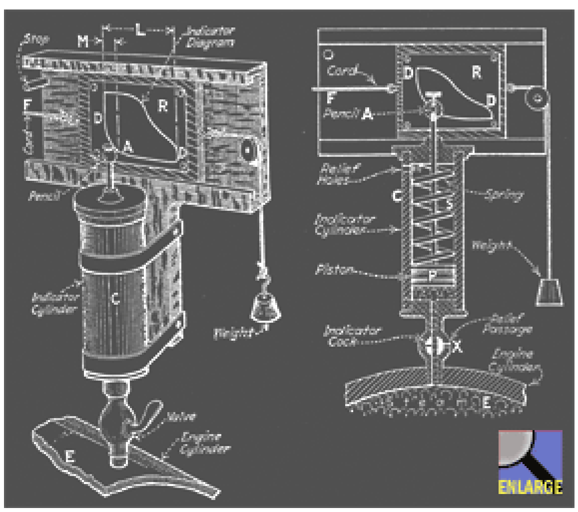
The minuscule beam, with two small arch heads, supports an elongated metal rod running upward to serve as a pointer. A graduated scale could be attached to a board attached to the vertical arm of the frame, which in its entirety resembled a large slender round-headed 'T' on a low four-leg stool.

Elongating the pointer rod magnified the movement of the pointer against the scale, facilitating observation, but the process still demanded great care if the fluctuating pressures within the cylinder were to be recorded accurately. Exactly when this instrument was made remains in dispute, though the Boulton & Watt Papers, now in the care of the Birmingham Museum of Science & Industry, contain a variety of references dating back to 1794.

Watt & Southern, *c*. 1796

The indicator was soon adapted to provide a written record of each individual application instead of merely a transient observation. This was a tremendous analytical breakthrough, allowing, as it did, an accurate picture to be formed of the pressure of steam at any time during the movement of the piston. The inspiration was due to John Southern (1758-1815), Watt's draughtsman, who recorded in a letter dated 14th March 1796 that he had 'contrived an instrument that shall tell accurately what power any engine exerts'.

By August 1796, Southern was expressing doubts that diagrams that had been supplied from the Salford Cotton Mill engine were accurate. He went on to note that 'It would be better if instead of drawing the board uniformly forward, a pair of wheels was applied so as to make one revolution for a double stroke of the engine and crank fixt [sic] upon one end of such a length as to give the stroke you wish for the board to move. The exactness of the beginning and ending might be ascertained very nicely, and as the pencil would go over and over again the same track or nearly, the mean might be taken with some precision'. The 'closed loop' was obtained by fitting a tablet that reciprocated in phase with the piston.



ABOVE
Genuine Watt indicators are exceptionally rare. This replica built by Bruce Babcock of Amanda, Ohio, on the basis of information supplied by the Science Museum in London, has been shown at many steam fairs in the USA. The drawing, taken from Terrell Croft's *Steam Engine Principles and Practices* (1922), shows a typical Watt-type indicator of the 1820s.

Watt moving-tablet indicators were made only in small numbers, though construction and design often differed greatly in detail; for example, a long spiral spring was often substituted for the cord and weight. Many of them were still being used in the 1850s. They were invaluable to the engineers of their day, even though excessive friction in the moving parts promoted inefficiency. Consequently, the moving-tablet indicators were eclipsed first by the McNaught instruments and then by the many 'high speed' designs deriving from the Richards pattern.

However, there were many who mistrusted the ability of the spring-driven reciprocating cylinder to provide accurate diagrams, pointing to the dependence on inherently elastic driving cords and on the assumption that the performance of the spring in the recording cylinder would be consistent throughout the entire range of movement.

One of the earliest attempts to resurrect moving-tablet systems was reported by John E. Sweet to a meeting of the American Institute of Mining Engineers held in Chattanooga, Tennessee, in the summer of 1879. Even at this early stage in the development of high-speed engines, a need had been identified, said Sweet, for efficient indicators that dispensed entirely with parallel motion. The Thompson indicator (then regarded as the most modern design) had dramatically reduced the weight of the parts in the pointer linkage, but engineers were already predicting that running speeds of 1000rpm would be achieved. No indicator available in 1879 could provide legible diagrams at this speed.

Sweet claimed that the indicator made by Fred Halsey, one of his students, had worked very well, providing diagrams as good at 330rpm as they had been with the Thompson instrument at 270rpm and the original Richards machine at only 220rpm — though the rigid connection between the reducing gear and the sliding tablet undoubtedly explained part of the improved performance.

The most sophisticated moving-tablet indicator to be introduced prior to 1914 was patented in 1893 by an Englishman, Moses Wayne, who acknowledged the prior existence of instruments working on similar principles. A lightweight moving tablet was combined with a rotary piston controlled by an externally-mounted helical spring.

Steam from the engine cylinder entered by two channels through diametrically opposed admission ports, twisting the piston by its vanes against the pressure of the control spring. The steam or water that leaked past the piston simply dissipated through two escape ports. The pointer was a radial arm attached directly to an extension of the piston spindle, drawing its trace on a piece of paper attached to a concave mounting plate on the tablet. This was moved forward and then back by the connection with the crosshead (or suitable reducing gear), producing a conventional indicator diagram.

However, the Wayne instrument could also be fitted with a detachable limiting mechanism (later known as a 'liner'), enabling it to be used in circumstances — e.g., on railway locomotives — where vibration hindered the creation of a single diagram. The limiting mechanism allowed the operator to produce a continuous line-by-line summary of performance as the tablet reciprocated. The movement applied to the piston by the worm gear ensured that each line was drawn at slightly greater pressure than its predecessor.

The piston could be moved from its 'off' position (when the cylinder pressure was less than that the opposing spring) to 'on' when the pressure finally overcame the spring. Though the absolute pressure was not shown, the point at which it rose above the controlling spring was clearly marked on each line and allowed the points to be joined to provide continuity. Experience soon taught the operator how fast to turn the limiter crank-handle, until the individual lines were no more than a twentieth of an inch apart. At this spacing, the pressure line became all but continuous.

Elliott Brothers made Wayne moving-tablet indicators until 1900 or later, though the quantities involved were probably small. The simplicity of rival rotating-drum patterns relegated the Wayne pattern largely to experimental or laboratory use, even though the ease with which legible 'lined' traces could be obtained from engines running at 600rpm (or more) was greatly in its favour. Elliott turned instead to the equally short-lived Simplex drum instrument, with its detachable 'tong' springs.

McNaught, c. 1827

The first major advance in design was made by replacing the reciprocating tablet with a revolving drum, which was much more compact, easier to manage, and offered less frictional resistance to the recording stroke. The instigator of this system is generally believed to have been John McNaught, who began trading on his own account in Glasgow in the 1820s having previously made Watt-type indicators for (possibly among others) the engineer John Farey.

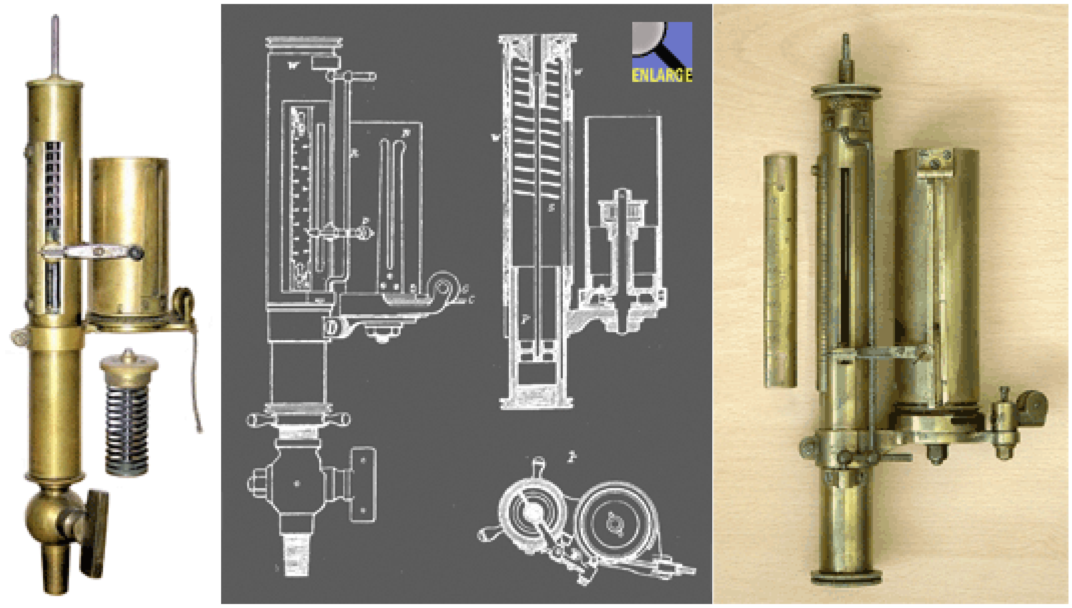
McNaught relied on the piston stroke to make half a rotation of the drum and a spring within the drum to enforce a return. The date of this advance has not been satisfactorily determined, though some evidence was laid by McNaught before the Society of Arts for Scotland in 1829, including a pamphlet entitled *Description and Use of Macnaughts Improved Indicator for Steam Engines*, published anonymously in Glasgow in 1828 but almost certainly McNaught's own work. There were also several testimonials, including one from 'Mr Alexander', who claimed to have been using a McNaught indicator for 'more than two years'. This suggests that the development had been completed by, at the latest, the winter of 1827.

The original McNaught indicators were of the 'co-axial' or 'in-line' design, with the paper drum around the cylinder. They were suitable only for low-power engines, the scales usually ranging a vacuum of 15lb/sq.in to a pressure of 15lb/sq.in above atmospheric level. Soon, perhaps inspired by an ever-increasing enthusiasm for compounding (and undoubtedly also the introduction of railway locomotives), a high-pressure 'parallel axis' variation had appeared. The recording drum had been moved to a bracket projecting at right angles from the cylinder.

A catalogue published in Glasgow in 1831 shows both patterns. By 1842, however, McNaught had abandoned the co-axial indicator, and the distinction between pressure ranges was being addressed with differing pistons. The high-pressure and low-pressure patterns had areas of 1/8sq.in and 1/4sq.in. respectively. Pressures ranged as high as 130lb/sq.in, which had advanced only to 140lb/sq.in by the mid 1850s. Some, if not all high-pressure McNaught instruments were also apparently capable of indicating a vacuum; however, it is suspected that most would have been used in conjunction with non-condensing locomotive engines. The pressures were far too high for the stationary engines of the day.

By 1856, and the final version of McNaught's promotional leaflet (which had become a book), the separate-cylinder indicator was being offered for pressures of 60, 100 and 140lb/sq.in. In addition, a specially enlarged version was being offered, capable of giving a six-inch diagram instead of the customary 3.75in version.

McNaught indicators—and the copies that they inspired—came from a variety of sources. Some may have been made for McNaught by Joseph Chadburn and Chadburn Bros. of Sheffield; many were made by the Novelty Iron Works of New York (apparently from 1847); and others came from Joseph Hopkinson of Britannia Works, Huddersfield. One example in the Science Museum collection bears the mark of John Hannan of Glasgow.



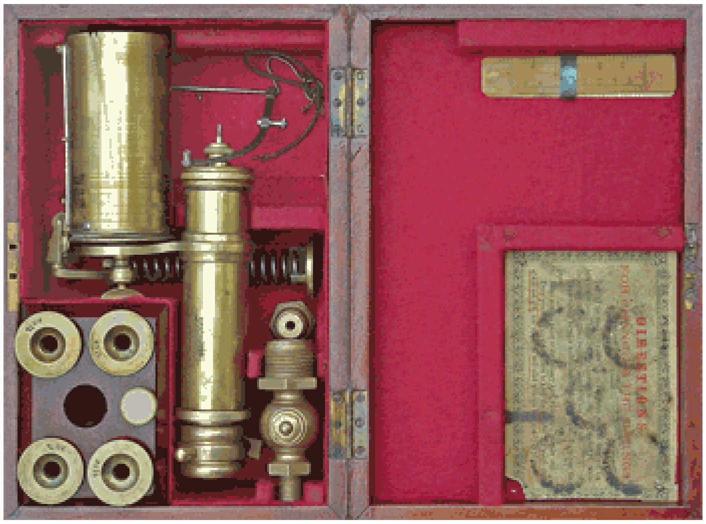
ABOVE, LEFT TO RIGHT
A McNaught parallel-axis indicator, probably dating from the 1840s, with a replacement spring. *Photograph by courtesy of Bruce Babcock, Amanda, Ohio, USA*. Drawings taken from *Indicator Diagrams and Engine and Boiler Testing* by Charles Day, published in 1898. A later indicator, made by J. McNaught & Son of Glasgow. This large example, with replaceable pressure-graduation plates, may date from about 1858 and is believed to have been used in a military factory in India. *Museum of Making collection.*

McNaught indicators were successful, particularly for use with slow-running engines, and set a trend that lasted for more than thirty years. They were still regarded as standard in the Royal Navy (where boiler pressures had remained exceptionally conservative) as late as 1882; the advent of compounding then had an effect, and McNaughts were soon being preferred only 'for general use on ordinary service'—the Richards design was used 'for the records of steam trials and other special services'.

The indicator promoted from the early 1850s onward by Joseph Hopkinson of 'J. Hopkinson & Co., Engineers of Huddersfield and London', was the most interesting variant of the McNaught system. Hopkinson's indicators returned to the co-axial design, which he considered to be more resistant to vibration. The operating cord ran around the base of the drum, and around a pulley attached to an arm held to the base of the tube by a collar-and-thumbscrew assembly. The pencil pointer lay on a spring-steel arm, attached directly to the piston tail rod to work directly on the trace-paper. Additional springs could be supplied, each suited to differing pressure ranges. Unlike virtually every other design, however, these springs were added to the piston rod above the cylindrical casing, where they were retained by a locking nut.

Hopkinson's design was simple and compact, remaining in vogue even after the first Elliott-made Richards instruments had been distributed in Britain in the 1860s. However, it soon lost favour once high-speed engines became common, as the inertia of the heavy spring/piston unit contributed to excessive vibration and irregular trace lines. The original axial or 'in-line' design was discontinued in the mid 1870s.

Hopkinson had attempted to make a parallel-axis indicator, protected by British Patents granted in 1869-70, but this fragile-looking design offered little improvement on the axial pattern. The inventor was still championing the direct-reading system, and a flimsy curved arm, with a slender cylindrical tail rod, was simply slipped on to the piston-rod extension and clamped in place with a small threaded nut. The tail rod was supposed to steady the assembly by passing down through a small horizontal plate protruding above the cylinder cap, which allowed the whole tracer unit to turn until the pointer was brought to bear on the paper.



LEFT
The new-pattern Hopkinson indicator, clearly inspired by the Richards design but lacking an amplifying trace mechanism, was made in small numbers in the early 1870s. This example is numbered '209'. *Museum of Making collection*

Play in the tracer mechanism and the use of springs that were unnecessarily large, owing to the absence of amplification, were too much of a handicap to allow accurate readings to be taken. Consequently, the parallel-axis Hopkinson indicator was in vogue only for a very few years. For a long time, none had been identified; then, in the space of as many weeks, two examples were found.

Hopkinson indicators retained their popularity in northern England into the 1880s, losing ground there only as the mill and factory engines increased in size, speed and power, and there is circumstantial evidence to show that they were also popular in Cornwall.

Internal-spring type

The continuously-recording machine proposed by Daniel Gooch (1816–89) was not only the first indicator to be used successfully on a railway locomotive at speed, but also the first to incorporate an amplifying recorder: a pencil bar, attached at one end to the piston rod was mounted so that the movement of the piston was magnified approximately fourfold

Richards, 1862

The next great advance occurred in the USA, owing to the interest shown in engine design by Charles Talbot Porter (1824–1910). The success of the Porter Governor, which improved the performance of many a steam engine from the 1850s onwards, led to an association with a mechanic named John Allen. Allen had designed what he felt was a better way of controlling a steam engine than the classical adjustable slide valve. Porter not only persuaded Allen that his design was worthwhile, but also suggested that a high-speed engine could result from a marriage of the Allen 'liberating gear' and Porter's flyball governor.

The first high-speed Porter-Allen engine was built in 1861, ran successfully, and inspired the creation of a larger machine shown at the International Exhibition in London in 1862. There it aroused great controversy, as many observers opined that high speeds posed a real threat to life and limb. The running speed was so great, indeed, that only the indicator supplied with the machine could produce useful pressure/time diagrams.

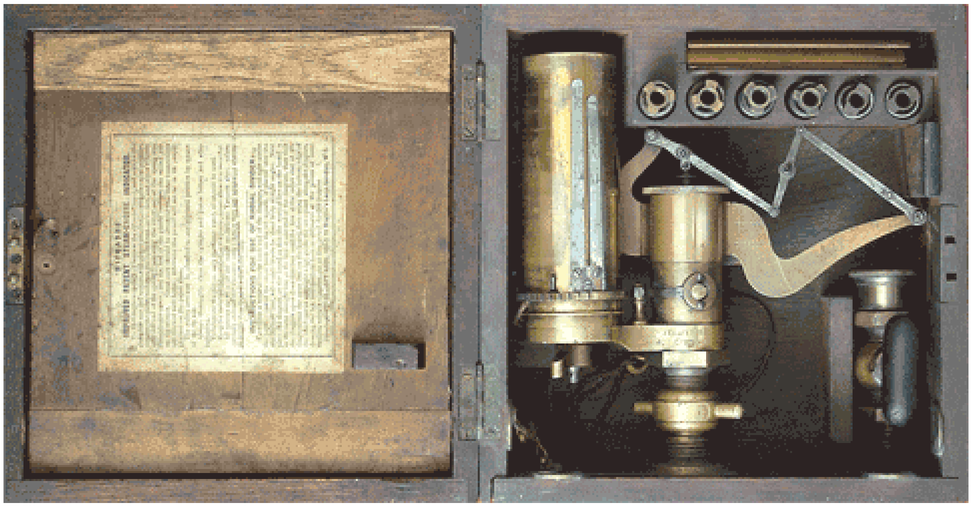
The designer of the indicator was Charles Brinkerhoff Richards (1833–1919), a successful Brooklyn-born consulting engineer with whom Porter had previously had contact. Richards declined to patent the indicator, leaving the task to Porter in return for a $100 fee and a ten per cent royalty on each instrument. Porter subsequently obtained patents in many countries in 1862–3, including British Patent 1450/62 and US Patent 37980. The principal claim to novelty concerned the parallel-motion type amplifying mechanism, which ensured that the pencil that traced the diagram moved in a straight line.

The Richards Indicator amazed onlookers in the Crystal Palace by recording perfect diagrams at an unprecedented 150rpm. No other indicator of the day would have coped in such circumstances, owing to the inertia of their heavy moving parts and the effects of vibration on their feeble springs. The *Record of the International Exhibition, 1862* described the improvements as the substitution of "very light moving parts, attached to a short, and therefore stiff spring, instead of the comparatively heavy moving parts, attached to a long, weak, and therefore tremulous spring. The motion is multiplied by a lever of the third order, and a parallel motion is employed to guide the recoil spring in a straight line... It is very little more complex than the [common] M'Naught instrument". It attracted so much attention that it was used to test all but two of the British-made engines that were present.

Porter stayed in England after the 1862 International Exhibition finished, keen to promote not just the Porter-Allen engine but also the Richards indicator. His experiences with the engine were unhappy, as the initial contractor (Oswald, Grierson & Company of Manchester) failed in 1866 and a subsequent liaison with the autocratic Joseph Whitworth was equally unproductive. Conversely, the indicator was successfully licensed to in the winter of 1862/3 to Elliott Brothers of London.

Elliott-Richards indicators had improved recording units, with the parallel-motion components made in the form of two thin bars instead of a single flimsy rod. A better method of connecting the piston rod to the parallel motion with a swivel is usually attributed to an employee of Elliott, Edward Darke, and the provision of exchangeable springs was also a helpful novelty: in 1874, the range of springs extended from 15lb/sq.in to 175lb/sq.in. To allow such flexibility in a single instrument, Elliott instruments had a piston-area of 1/2sq.in, double that of the Richards prototype.

Elliott Brothers made 'Improved Richards' indicators into the early years of the twentieth century. Though production was slowed by the introduction of better designs (Elliott also made Simplex and Wayne indicators), at least 23,000 Richards-type instruments had been made in a variety of sizes. Most of the 'Improved Richards' indicators had detents of a type patented in 1875 by Edward Darke, which allowed the drum to be stopped without disconnecting the driving cord.



ABOVE
The perfected post-1875 Elliott-made Richards indicator, fitted with a Darke-patent detent. This particular example dates from about 1890. Note the full complement of six springs, three of which match the surviving rulers. There is little doubt that this instrument was the property of a consulting engineer or an insurance inspector. *Museum of Making collection.*

The Richards Indicator required careful manufacture and accurate assembly to work efficiently and was also surprisingly expensive. However, as steam pressures and engine speeds rose dramatically in the 1860s and 1870s, so the need for its sophisticated analytical capabilities grew commensurately. Richards-type indicators were still being advertised by many suppliers of steam accessories (e.g., W.F. Stanley & Co. Ltd of London) in the 1920s. For slow-speed installations, they were as reliable as any of the later, lighter and usually more delicate designs, and were eminently suited to the comparatively ill-trained engineers to whom many manufactories, waterworks and similar installations entrusted them. They were also commonly used at sea.

Charles Richards made one final, if short-lived contribution to the design of the indicator. A pantograph-type instrument was apparently made for exhibition in Paris in 1878 on the general lines of an Elliott-Richards instrument, but in steel instead of brass. The new amplifying mechanism was inspired, no doubt, by the emergence in the USA of the Thompson and Tabor indicators.

This particular instrument is still in the museum collection in Paris, inventory no. 09416. It was donated after the exhibition had ended and is marked appropriately 'Presented/to the/Conservatoire/des/Arts et Métiers' and 'C.B. Richards' over '1878' on the body. The amplifying mechanism is a simple pantograph system comprising a link, pivoted on the serpentine standard protruding from the body, which is connected at its tip with the elongated pencil arm. A link from the top of the piston rod to the pencil arm is connected to the rear link, at approximately its mid-point, by a short double-pivoting bar. This maintains a proper straight-line motion, but the undoubted efficiency of the design was never matched by commercial exploitation; indeed, perhaps only the prototype was ever made. Jacques Buchetti, in his book *Guide pour l'Essai des Machines à Vapeur et la Production Économique de la Vapeur* (1887?), gives a diagram.

RICHARDS COPIES. Many Richards-type indicators were made prior to the First World War, most of them being advertised as 'improved'. The principal alterations concerned the drum spring, which was often changed from a coil in the drum-base to a coil around a vertical post, and in the design of the piston. Novelty was sometimes introduced into the cord pulley or the indicating-pointer linkage, though the basis of the instrument almost always remained unchanged.

Classifying these instruments is complicated by the involvement of a variety of manufacturers in the USA, Britain and Europe. These included Casartelli of Market Street, Manchester, who made sold standard Richards-style indicators in Britain before proceeding to a modified version with a lighter double-bar parallel motion system 'somewhat like the pentagraph'; Hannan and Hannan & Buchanan made them in Glasgow; and Martin-Garnier of Paris and Duvergier of Lyon made them in France. Many of the Duvergier-made examples had a patented integral reducing wheel, which was fitted to a bracket beneath the drum-support part of the frame.

The status of the Richards indicator in the USA has often been questioned, and it is widely believed that the initial needs were satisfied with Elliott-made instruments imported from Britain—indeed, several indicators of this type, with low serial numbers suggesting production in 1863–4, have been found in the USA. It is now known that the American Steam Gauge Company of Boston, Massachusetts, made Richards indicators before progressing to the better-known Thompson design. One of these Richards instruments (pictured below) is owned by the Knox County Historical Society of Mount Vernon, Ohio, and may be seen on display in the local museum. It appears to be numbered '599' and also bears an acknowledgement of the design—C. B. RICHARDS' PAT. MAR. 24, 63 in two lines on the rear link bracket. This suggests that it dates prior to the expiry of the patent, placing manufacture in the mid 1870s.

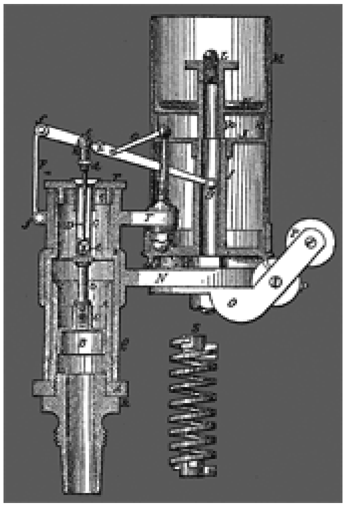
Though Richards-style instruments have been identified as the work of Rosenkranz of Hannover, the principal German manufacturer was Schaeffer & Budenberg of Buckau bei Magdeburg — though production (possibly never excessive) had ceased in favour of Thompson indicators by the late 1870s.

Thompson, 1875

The Richards indicator reigned supreme until the master patent expired in the mid 1870s, allowing a stampede to develop a better design. Though the Richards-type instruments were robust and reliable, tests often showed that oscillations began to affect the accuracy of its diagrams above 200 rpm, and rival promoters considered that many details of the basic pattern—e.g., the pointer linkage—could be improved to reduce both friction and inertia. This left the field open to speculation, and a variety of 'improved' designs appeared.

The first improvement is credited to an American, Joseph W. Thompson of Salem, Ohio, whose US Patent was granted in August 1875. The Watt-type or *lemniscoid* parallel motion used by Richards did not entirely ensure that the pen moved in a straight line. Once the central range of the lemniscoid curve had been exceeded, the pen began to trace an arc, and although the error was comparatively small, reckoned to be about 0.8 per cent for a standard 'large' example, many reasoned that it was avoidable. The Thompson system made use of the mathematically superior "Evans' Parallelogram", also known as the 'Scott Russell', 'Grasshopper' or *ellipsoid* method.

The instruments are readily identified by the design of the recording mechanism, as the serpentine linkage and robust supports of the Richards design were replaced by much lighter components taking the general form of the letter 'M'. The piston-rod extension often incorporated a universal joint, not only to allow proper movement of the parallel motion but also to combat wear. The piston-rod extension pushed upward on the pointer bar, which was attached to one link attached to a fixed post and another pivoted on the cylinder body.



LEFT
A sectional drawing of the first or Buckeye-type Thompson indicator, dating from the late 1870s. The illustration was taken from the British periodical *Engineering* of 19th October 1877.

Thompson indicators generally performed better with high-speed engines than the Richards pattern. The first instruments were probably made on behalf of the assignee of the patent, the Buckeye Engine Company of Salem, Ohio, by the American Steam Gauge Company. Later, once licenses had been obtained or after the patent had expired, Thompson-type indicators were made by Schaeffer & Budenberg of Buckau bei Magdeburg, Rosenkranz of Hannover in Germany and Kraft & Sohn of Vienna in Austria-Hungary; Victor Lefebvre in France; and Hall-Brown, Buttery & Company of Glasgow, Scotland.

Changes made as a result of intensive scrutiny, largely undertaken in Germany in the 1880s, led to the 'Improved Thompson' instruments made by the American Steam Gauge Company, Schaeffer & Budenberg, and Dreyer, Rosenkranz & Droop. Essentially similar examples were made by Star, Lippincott and others.

The indicator designed by Ebenezer Hall-Brown of Hartlepool, patented in Britain in 1889, was among the most interesting Thompson derivatives. Though the distinctive linkage was retained, Hall-Brown devised a method of detaching the pointer mechanism, cylinder cap and piston/spring assembly simply by aligning the bayonet joint and a supplementary locking collar running around the cylinder body. The spring in this design is exceptionally easy to change, but the Hall-Brown system does not seem to have survived into the twentieth century; the readily detachable cylinder cap would have contributed to accidents if the engineer forgot to rotate the collar back to its locked position before opening the steam cock. However, a substantial number of indicators were made by Hall-Brown, Buttery & Company of Glasgow. There is no doubt that they were intended for use at sea, something the original indicator cards made clear.

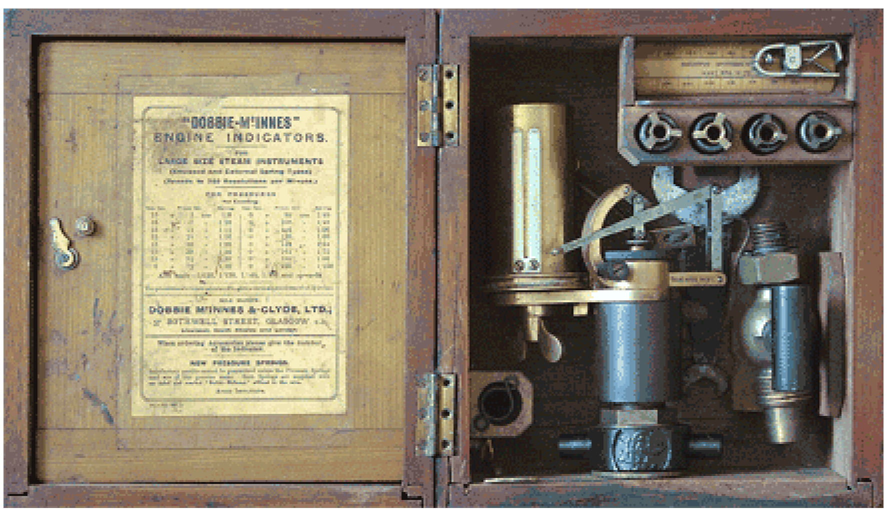
Another of the interesting variations on the Thompson theme was that of Joseph Bachelder of Manchester, New York, who received a US Patent in 1887 to protect a Thompson-type indicator linkage working in conjunction with a unique adjustable-pressure riband spring placed horizontally beneath the drum. This was intended to avoid changing springs to suit differing engine characteristics and exploited the ease with which the effective length of the spring could be changed to provide an 'adjustable' indicator. The Bachelder instruments were made in small quantities by Thompson & Bushnell of New York City, but may not have been successful; they are now exceptionally rare.

Other American-made indicators included the Buffalo; the Calkins, perhaps made only in small numbers; the Robertson-Thompson, which became the Trill early in the twentieth century; the Lippincott; the Lyne; and the Star. (See 'Sources of information')

The most popular variation of the Thompson linkage to be found in Britain in 1900 was based on a patent granted in November 1887 to Thomas McInnes (or M'Innes) of Glasgow. An instrument maker by profession, McInnes eschewed the minimalist approach and accepted that his new indicator would inevitably contain more parts than some of his better-established rivals. McInnes sought to reduce friction whilst simultaneously improving the response of the pointer linkage to changing pressures, but the greatest claim to novelty, however, lay in the adoption of vulcanite sheathing to protect the operator's hand from heat absorbed by the piston-cylinder body.

The earliest instruments may have been made by a short-lived partnership of McInnes & Cairns (allegedly in Edinburgh). By 1889, however, McInnes was trading as 'T.S. McInnes & Co.' from 56 Waterloo Street, Glasgow. A limited-liability company had been formed by 1894, manufacturing facilities moving from Waterloo Street to Clyde Place.

These first-pattern McInnes indicators were made until the end of the nineteenth century. In May 1898, however, a British Patent had been granted to John Clark Dobbie, a partner in A. Dobbie & Son. Dobbie was making clocks and watches in premises virtually adjoining McInnes' premises in Clyde Place, and it was a logical step for McInnes to make the new Dobbie-patent indicator.



ABOVE
McInnes-patent 'Large Size' indicator no. 637, made by 'T.S. McInnes & Co.' of Glasgow, *c.* 1893. Note the trademark moulded into the vulcanite sheath of the threaded union (at the bottom of the body) that couples the indicator to the steam cock. The label pasted in the lid of the case replaced the original at some time after 1928. *Museum of Making collection.*

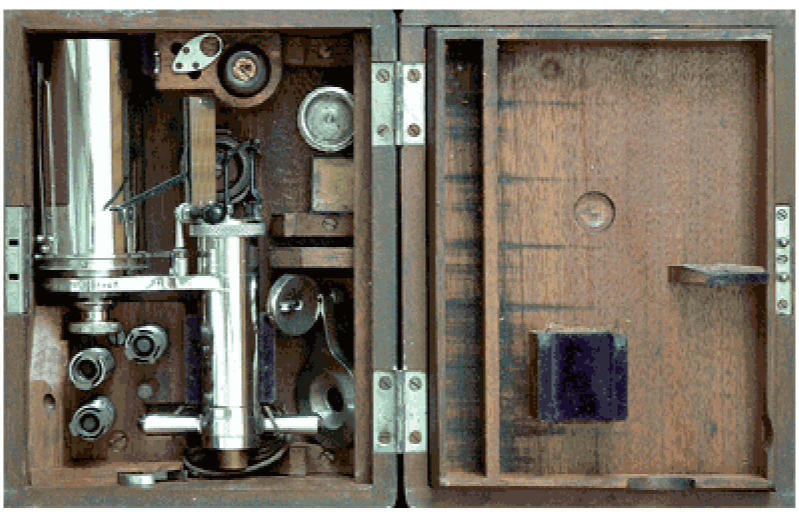
The new instrument offered an external-spring system and a modified mechanism with the pointer directly above the supporting bar instead of alongside. These changes were incorporated on the McInnes-type closed-cylinder indicators made after c. 1900, though production was slow. All Dobbie-patent instruments had 'D'-prefix serial numbers, and most post-1903 examples bore the marks of Dobbie McInnes Ltd. Perfected McInnes-Dobbie internal spring indicators were still being made in the 1920s, but were eventually superseded by efficient outside-spring types patented in 1898-9.

Thompson-type indicators were also made by Whyte, Thomson & Company of Glasgow. Their history is remains obscure; though their existence is mentioned in several pre-1914 sources, only one could be located for examination—'Model I' no. 305, which is somewhat similar to the contemporaneous McInnes pattern. However, comparing the design and construction of individual components reveals a total lack of similarity, and any theories that Whyte, Thomson indicators were simply McInnes or Dobbie McInnes instruments being marketed under another name can be discounted.

Schaeffer & Budenberg made several versions of the Thompson indicator, with internal and external springs. There was also an instrument that allowed a simultaneous combined diagram to be taken from a double action engine. It was otherwise necessary to use two indicators, or throw a three-way cock to indicate first one side of the piston and then the other—but not on the same stroke.

Tabor, 1878

The indicator patented in the USA by Harris Tabor in 1878 was the result of a prototype shown to Charles Porter that could run efficiently at 450rpm. This had interested the Ashcroft Mfg Co., which was soon making Tabor indicators in quantity. The first few hundred of these, despite the statements that have been made to the contrary, were made in close accord with the patent drawings. The essence of these Tabors — which were being made in quantity by 1883—is a small cam-plate elevator attached directly to the piston-rod extension. In 1886, however, after at least 413 of the first-type indicators had been made, Ashcroft replaced the flimsy elevator with the more familiar amplifying mechanism: a sturdy standard, attached to the cylinder cap, containing a curved track to ensure that the pencil arm moved vertically. Links pivoted at both ends joined the pointer bar to the piston-rod extension and the cylinder body. Series production of the new-pattern Tabor indicator began in 1887, and continued for many years.



ABOVE
A boxed Tabor indicator, no. 1951 dating from 1889 or 1890. Note the design of the guide pulley for the drum cord; later examples replaced the knurled fairlead retainer with a large hexagonal-headed nut. This particular set is lacking the steam cocks. *John Walter collection.*

Tests conducted by the U.S. Navy in Brooklyn Navy Yard, in 1886, with Richards, Thompson, Tabor and other indicators, revealed that the moving parts of the Tabor instrument were thirty per cent lighter than the nearest rival and had 24·3 per cent less friction. One of the most popular systems of indication in the 1890s, the basic Tabor pattern was extensively marketed in Europe. Among the British distributors were the Globe Engineering Works and John Musgrave & Sons Ltd of Bolton, who began work in 1889. Engravings accompanying a short descriptive article published in *Engineering* in June 1889 depict an Ashcroft-made indicator no. 915, but the printing blocks may have been several years old.

Darke, 1879

The simplicity of the Tabor system influenced Edward Darke of London, whose minimalist design was patented in Britain in 1879. Made exclusively by Elliott Brothers in 'small pattern', the Darke Patent High Speed Indicator had only one fixed pivot and a swivelling link connecting the piston-rod extension to the pointer bar. The role of the other fixed pivot was taken by a vertical slot cut in a plate on the cylinder body.

The pointer was allowed to slide back along its bar as a guide pin rose in the slot. However, though this was claimed to promote accuracy—the Darke and a properly regulated Tabor were among the few indicators to be mathematically perfect—it was also susceptible to excessive friction in the slider unit. Darke claimed the improvements in his system as 'an invention for giving motion to the paper drum by means of rods, &c, in rigid communication with the engine, with means of stopping and start-ing the paper drum in a very simple and effective way': a sprung pawl-type detent (patented in 1874) could be activated at will by engaging a spring-steel plate that slid horizontally around the cylinder body. This allowed the operator to stop the movement of the drum whilst the indicator card was removed.

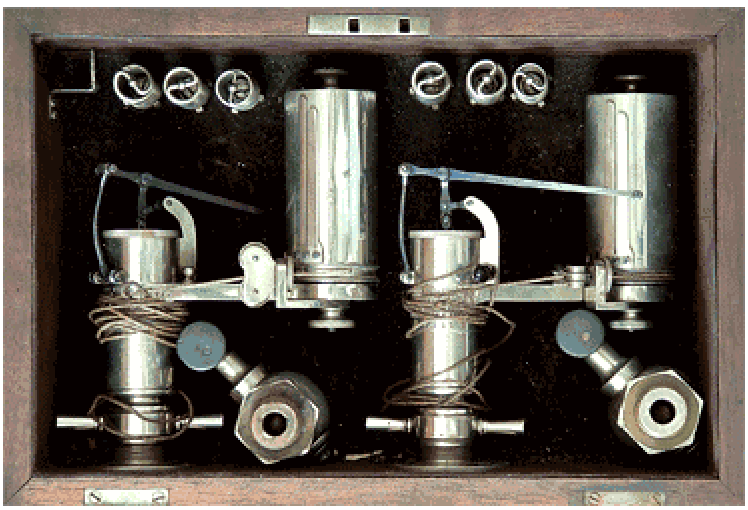
ABOVE
A typical small-size Darke indicator, made by Elliott Bros.of London. This particular example, no. 565, dates from the mid 1880s. Many rival promoters were scathing about the accuracy of the Darke mechanism; though defensible mathematically, there is little doubt that there was far too much friction between the slide and its track. *Museum of Making collection.*

Darke-patent indicators generally had a coil-type spring in the base of the drum, freeing the interior for a continuous roll of paper. The paper clip was often a hinged two-bar pattern instead of the customary Richards spring fingers. Instruments of this type were made in large numbers, but had been overtaken by better designs by 1900.

Crosby, 1882

Very few indicators have embodied a pantograph amplifying mechanism, excepting a prototype exhibited in Paris in 1878 by Charles Richards and the Simplex, made in quantity in the late 1890s by Elliott Bros. Ltd of London. The only other pantograph-like indicator was the Crosby, though sufficient change had been made to the geometry of the links to compromise the mathematical certainty of 'straight line' rivals. Perhaps the most successful of the late nineteenth-century designs, made in Boston, Massachusetts, by the Crosby Steam Gage & Valve Company, the Crosby Indicator was the subject of patents granted in the USA in 1879, 1882 and 1885. The perfected pencil motion, an ultra-light pseudo-pantograph, was just one of several alternatives proposed in the master patent of 1882. This mechanism bore some resemblance to the 1875-vintage Thompson type, though the short anchor link was pivoted to the piston-rod extension link instead of the pointer arm.

The Crosby indicator was exceptionally successful, particularly after changes in the geometry of the links were made after intensive scrutiny by experimenters in Germany suggested that the original design was not as efficient as it should be. Post-1895 Crosby indicators, therefore, have a sturdier straight rear link than their predecessors, which relied on a very slender link with a noticeable curve.



ABOVE
A matched pair of Crosby enclosed-spring indicators, one left-hand and one right-hand (note the positions of the trace arm). These instruments are believed to have been the property of the Municipal Technical College in Brighton (England), opened in 1897, but were already several years old and may have come from School of Art & Science. They represent the first type of Crosby, with a curved rear link in the amplifying mechanism. The quality of the nickel plating is extremely good, and the blueing of the steel links is exemplary.

The perfected Crosby Indicator may have been the first to incorporate a spiral rotating spring within the drum body, which was soon accepted as an improvement over the conventional coil spring within the drum base. This feature was widely copied once Crosby's patents lapsed. Crosby was also known for the counter-wound spring, but was responsible for a variety of other relevant innovations.

The Crosby instrument was very popular, allowing its manufacturer to maintain offices in Boston, New York and Chicago. A branch was also operated for many years at 147 Queen Victoria Street, London. These indicators were made in several styles, and were often supplied in a single box as matched pairs, triples or even quadruples. Crosby-type linkages were used by a variety of external-spring rivals, including Maihak in Germany, and are still evident on the Leutert instruments being made today.

Casartelli, c. 1883

Another Tabor-like design was the Casartelli High-Speed Steam Engine Indicator, made in Manchester, which was exhibited at the Engineering and Metal Trades Exhibition staged in London in 1883. This offered a vertically slotted plate to guide the pointer, but had an additional moving pivot. The cylinder body had a screwed joint at its mid-point, while the piston rod (in the form of a tube) was attached to the piston with a universal joint. The total weight of the working parts was claimed to be less than one ounce, which may explain why indicators of this type are rarely seen; they may well have been too lightly built to withstand hard use.

External-spring type

The identity of the designer of the first successful indicator to isolate the spring from the effects of heat (usually by removing it from the piston chanber) is still disputed. Experiments undertaken by the Royal Navy in the 1840s, summarised in the book by Main & Brown, were assisted by an indicator made by Maudslay & Field. The engraving prepared for the book shows a suprisingly sophisticated instrument with a rotating drum and the spring carried externally on two standards.

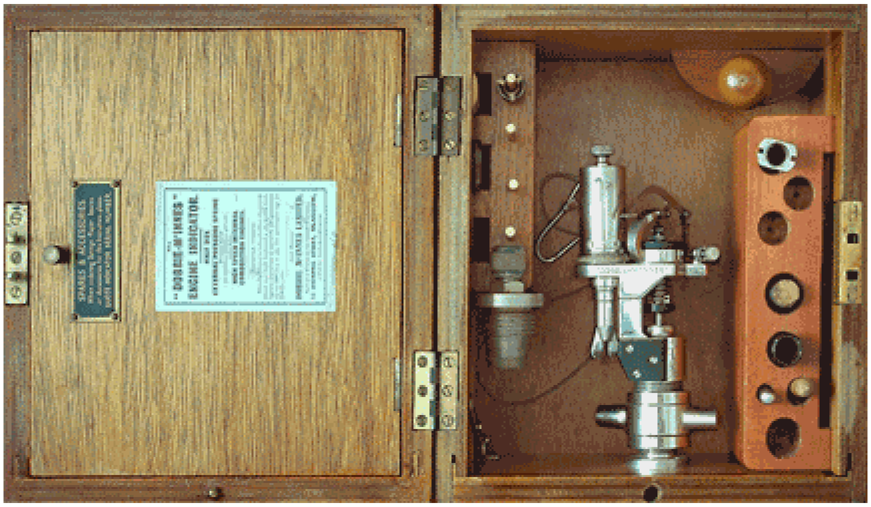
Attempts have been made to date this design as early as 1822, but evidence is sketchy. If such an early date can be proven, however, there would be little doubt not only that the Maudslay & Field design was the first to mount the piston spring internally, but also that the rotating drum customarily associated with McNaught may have originated elsewhere.

Credit has also been given to the Scotsmen McKinnell and Buchanan, whose alteration of a basic Richards-type indicator was patented in Britain in November 1892. The spring, carried on top of two standards, acted on an extension of the piston rod; a rounded abutment on the otherwise conventional Richards amplifying linkage was actuated by a collar on the piston rod to move the trace point. It is assumed that a few of these indicators were made by Hannan & Buchanan of Glasgow, makers of Richards, improved Richards (including a small-scale 'high speed' pattern) and Thompson-type instruments prior to 1914.

Dobbie, 1898

A derivative of the basic Thompson linkage was the subject of a patent granted in Britain in 1898 to John Clark Dobbie, a 'Nautical Instrument Maker' of '45, Clyde Place, in the City of Glasgow'. The indicator was based on the proven McInnes pattern—which was little surprise, as Dobbie & Son traded next door to T.S. McInnes & Co. Ltd. The principal claims to novelty included a readily removable piston spring, exposed to the air, and a 'pencil-carrying arm curved at its forward end and having a downwardly projecting knee or branch'. Changes were also made to the drum. A patent granted in December 1899 then allowed claims for a lightweight pointer assembly made of aluminium 'or similar light metal or alloy' and a lightweight piston consisting of two hollowed discs. The lower disc was steam-tight, but the upper one was perforated to allow grit to pass through.

The Dobbie indicator was initially made by T.S. McInnes & Co. Ltd, but then by a new partnership of McInnes and Alexander Dobbie & Son, known as 'Dobbie McInnes Ltd'. Too few indicators have been examined to deduce exactly when the first instruments were made, though *Engineering* of June 1900 contained a brief review of the new external spring McInnes-Dobbie design. Concurrently, the pointer of the concealed-spring McInnes indicator was changed to the new Dobbie 'over-bar' layout.



ABOVE

A compact half size Dobbie-McInnes external-spring indicator, D1C-32988, dating from 1944 or 1945, used to indicate 'explosion' (internal-combustion) engines. Similar indicators were made in 'Large' and 'Small' versions for use with steam engines. *Museum of Making collection.*

The design of the pointer linkage identifies all Improved McInnes, McInnes-Dobbie and Dobbie McInnes indicators made since the beginning of the twentieth century. The improvement concerned the ease with which the spring could be changed. It was simply necessary to unscrew the top cap (carrying the pointer linkage) and lift it clear of the indicator body; the vulcanite locking collar could then be unscrewed and the spring removed. McInnes-Dobbie indicators were very successful, and are still commonly encountered. They had been renamed 'Dobbie McInnes' by 1909, though many instruments continued to be marked MCINNES-DOBBIE and misleadingly marked printing blocks (already some years old) continued to be used for some time.

Thompson, 1899

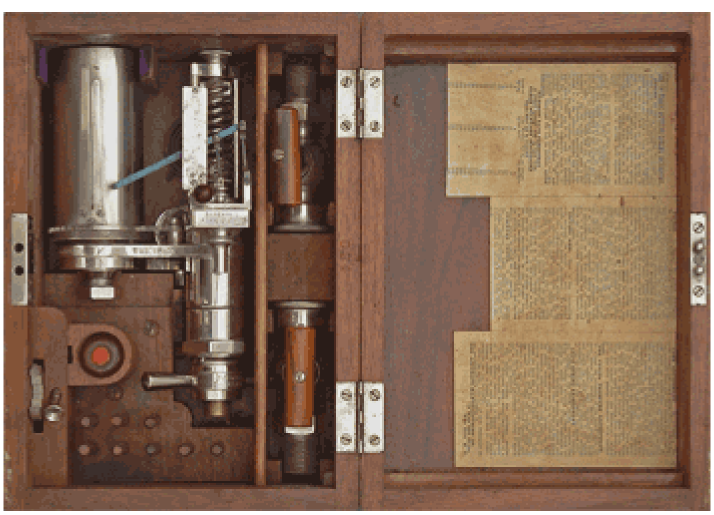
Among the first of the American exposed indicators seems to have been a modified Thompson type, patented in 1899 and introduced commercially by the American Steam Gage Mfg Co. by 1902-3. The spring was mounted on top of the platform, held in a threaded collar supported by a bar across two pillars. The two-leaf pointer lever was bent so that the piston rod could pass through a central aperture.

Similar indicators were also made by Schaeffer & Budenberg in Magdeburg (though often marked 'Manchester', where a limited company had been registered). The first type had the spring beneath the platform, connected to the piston by a bifurcated arm with prominent lightening holes. The piston housing was connected with the platform by three pierced steel straps. Instruments of this type were only made in small numbers, and had been replaced by 1908 by an improved design with the spring supported above the platform by a two-strap bracket. The side links were duplicated to allow the piston rod to pass between the stirrup-shape pencil arm. German-made Thompson derivatives were more successful than their American counterparts, which, with the exception of the Trill, lost so much ground to the Crosby type that manufacture had apparently ceased by 1917.

LEFT
A German '1902 Model' external-spring indicator made by Dreyer, Rosenkranz & Droop of Hannover, probably in about 1907. Extremely well made and beautifully finished (though a cumbersome variant of the Thompson amplifying mechanism), this particular example has a wide range of accessories. *Museum of Making collection.*

Houghtaling-Tabor, 1900

An exposed-spring version of the Tabor indicator was introduced in 1900 on the basis of a patent granted to William Houghtaling, retaining the basic curved-track-and-roller amplifying system of the perfected internal-spring design. However, two cylindrical standards protruding vertically from the platform supported a bridge, and the spring was clamped between the bridge and the platform by tightening a screwed collar. The amplifying mechanism was offset in an auxiliary chamber alongside the piston cylinder, allowing the pointer to be activated by a 'lifter' on the piston rod. Much of the existing production tooling could be used and the springs could be changed exceptionally easily, but the unconstrained springs were prone to flex laterally; accuracy may not have been exceptional. In addition, the clumsiness of the design—which had much in common with the American-Thompson and the first Dreyer, Rosenkranz & Droop or Maihak patterns in Germany—suggests that the Ashcroft Manufacturing Company rushed the external-spring Tabor into production prematurely.



ABOVE
The external-spring Tabor indicator had a vertical plate alongside the spring standards, containing the cam-track regulating the pointer. *Museum of Making collection.*

Crosby

The introduction of exposed-spring indicators by the Ashcroft Manufacturing Company (Houghtaling-Tabor type) and the American Steam Gauge Company ('Improved Thompson') persuaded Crosby that a competing design was needed. Neither of the rival designs were particularly efficient, and it must have seemed that a better instrument was easily developed. For this Crosby turned to a design by Theodore Davidson of Salem, Massachusetts. Assigned to the Crosby Steam Gage & Valve Company, U.S. Patent 713611—sought on 10th May 1901 and granted on 18th November 1902 — protected a variation of the standard Crosby indicator with the spring moved to encircle an extension of the piston rod carried above a bridge supported on two cylindrical standards. The central portion of the rod was split to allow the linkage to pass. Unscrewing and removing the threaded piston-rod cap allowed the spring to be changed in an instant.

The Davidson patent provided the basis for a number of Crosby indicators. The first, the 'Crosby New Engine Indicator', seems to have appeared about 1904. It followed the patent in virtually all respects, embodying traditional Crosby practice in the design of the amplifying mechanism and the 'spherical piston' associated with the earlier enclosed-spring designs. This was claimed never to jam or bind. The New Indicator was customarily supplied for use with steam engines, and had a piston diameter of 1.128 inches. The paper drum usually had a diameter of two inches, but a version could be supplied for use with high-speed steam and gas engines: this had a piston offering half the surface area of the steam-engine type—one half of a square inch instead of one square inch—and a stronger tracer mechanism. An all-steel indicator could be supplied for refrigeration machinery in which ammonia was used (the standard versions were nickel-plated brass).

By 1910, the standard New Indicator had been joined by the 'New No. 2 Indicator', a smaller and somewhat cheaper version of the original instrument intended for use with high-speed steam and gas engines. This was made with a piston diameter of 0.7979 inches (giving a piston face of one-half of a square inch) and had a slimmer body than the New Indicator; it also had a drum with a diameter of 1.5 inches, and could be supplied for use with gas engines with a piston-face area of only a quarter of a square inch (piston diameter: 0.564 inches). A minor variation allowed either 'steam' or 'gas' pistons to be used by providing exchangeable pistons and liners; it could be identified by a prominent hexagonal shoulder at the base of the body. Pistols with a face as small as one-twentieth of a square inch could be obtained to special order.

The 1910 handbook may have been the first to illustrate the 'Crosby [New] Indicator with Drum for Taking Continuous Diagrams'. Some years earlier, Crosby had experimented with two versions of the continuous recorder. Similar in principle but differing in detail, both patented in the U.S.A. in October 1907, they were the work of Theodore Davidson and Frank Wolfe. The Davidson version was preferred, as it allowed the space between successive diagrams to be altered by a ratchet-and-pawl mechanism.

ABOVE
The Crosby 'New Model' indicator was a distinctive design, made in accordance with a patent granted in 1902. This photograph shows a pre-1914 example in the Museum of Making collection, number 01393.

Production of enclosed-spring Crosby indicators seems to have ceased at the end of the First World War, though existing inventory allowed them to be sold 'as new' for several years thereafter. By 1927, however, only the exposed-spring 'New' and 'New No. 2' were being marketed (the former only in the guise of the continuous-diagram pattern). A rationalisation of Crosby's inventory system had gained them 'B'-prefix designations. The standard steam version was 'BC-101', the gas/oil-engine version was 'BC-201', and the all-steel ammonia instrument was 'BC-701'. The continuous-diagram indicator was known as 'BC-171'.

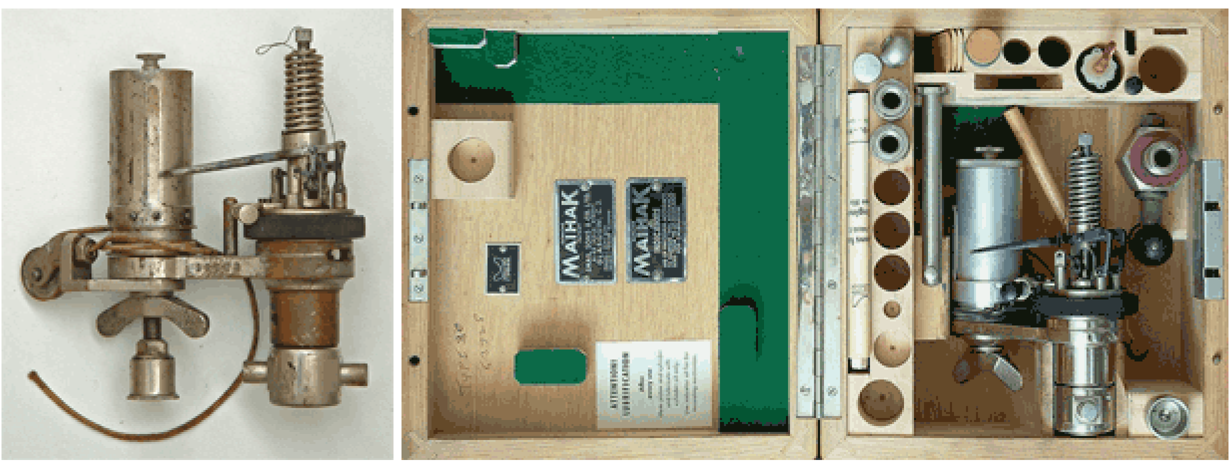
It is possible that the Great Depression that followed the Wall Street Crash of 1929 brought production of Crosby indicators to a standstill. They were still being sold in 1939, but it is suspected that no new production had been undertaken for several years. When the U.S.A. entered the Second World War at the end of 1941, it is perhaps no coincidence that the indicators supplied to the U.S. Navy and merchant marine were made by Trill (for use with steam engines) or by Bacharach (for the diesels).

The distribution of Crosby indicators throughout the work encouraged copies to be made. The most successful came from Germany. Only three manufacturers dominated the pre-1914 German market: Schaeffer & Budenburg of Buckau bei Magdeburg and Dreyer, Rosenkranz & Droop of Hannover made Thompson-type indicators with exposed springs, but Maihak made a variant of the external-spring Crosby with duplicated links and a ‘Y’-shape pointer that allowed the piston-rod extension to rise between its arms. This layout, which gave a symmetrical layout without the need to cut a slot in the piston-rod extension, had been patented by Wilhelm Lehmann in 1906.

MAIHAK TYPE

The 1902-type Maihak combined the Crosby linkage with two springs placed outside the body, where they were extended by a transverse bar attached to the piston rod — an ineffectual solution to the problem of providing an exposed-spring instrument; and undoubtedly a production expedient. It scarcely lasted in production for more than a year, being replaced in 1903 by a much more compact design. The Crosby linkage was retained, but the tail of the piston rod was extended upward through a bridge (held above the body-cap by two rod-like standards) and then through the spring. The compression spring was held in place by a threaded nut.

This was in turn replaced by the Staus design (1905–8) and then the Lehmann-patent type made from 1907 onward. These all embodied a modified Crosby linkage with a bifurcated tracer arm and the links duplicated to allow the piston rod to rise through the centre of the compression spring. The principal difference was that the Staus-pattern Maihak retained the small incurved standard at the front of the amplifying mechanism, had a single back link, and carried the spring on a cap supported by two rod-like standards; the pressure applied by the trace to the drum was controlled by a threaded rod (with a small turned wooden handle projecting to the rear), which contacted the back of one of the standards. The Lehmann pattern had a short peg-like standard anchoring each of the duplicated front links, a bridle-type back link, and a compression spring bearing on an abutment forged integrally with the body plug. The trace-stop rod lay towards the front of the unit, bearing on a post on the centreline of the platform.

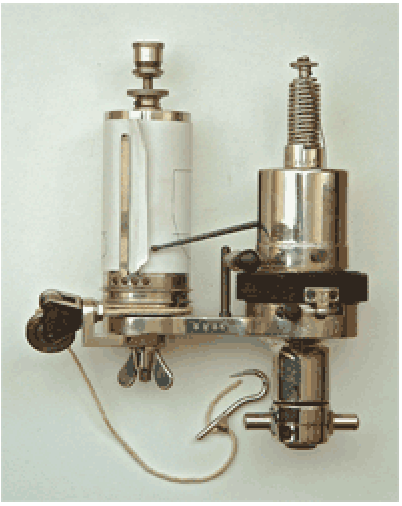
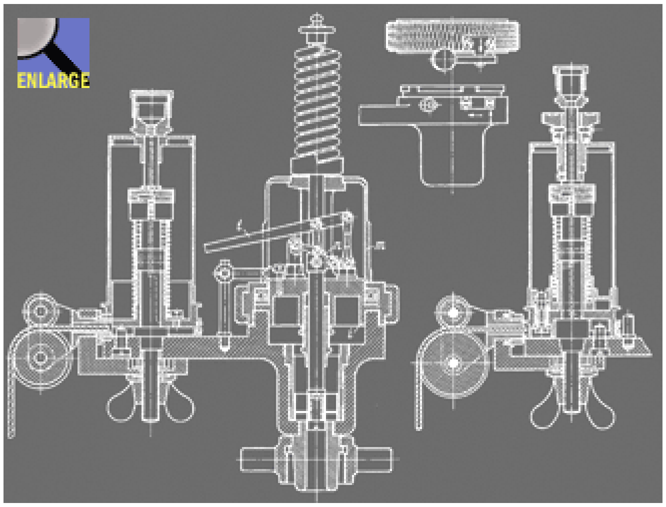


ABOVE
Left: Maihak Typ 50 indicator no. 20896 dates from the 1930s and shows evidence of hard use. The small cylindrical container protruding beneath the drum-nut is a Stauffer-type screw feed lubricator. *Right:* a Maihak-made Typ 50 indicator, dating from the 1950s, with its oak case and accessories. *Author's collection.*

The Staus indicator came in three sizes, large (*grosses Modell*), intermediate (*Mittelmodell*) and small (*kleines Modell*). Lehmann-type Maihaks were also offered in three sizes prior to 1914:'Grösse 1' with a 51mm diameter drum and a maximum speed rating of 300 rpm, 'Grösse 2' (38mm, 600 rpm) and 'Grösse 3' (30mm, 1500 rpm). Work on Lehmann-type indicators continued until 1985, when manufacture was then entrusted to Leutert GmbH. Though the current Leutert Typ 30 and Typ 50 indicators embody improved materials and simplifications in construction, they are essentially similar to the 'Original Maihak' instruments that were being made in the period between the world wars.

LEHMANN & MICHELS/LEMAG TYPE

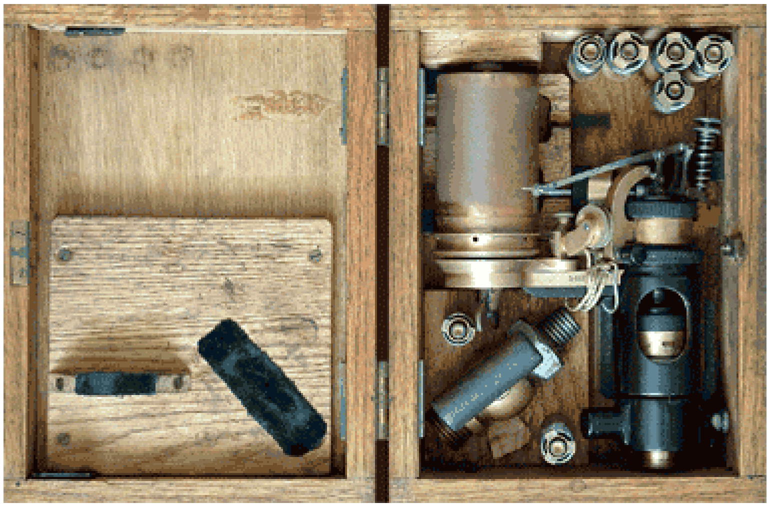
Though Dreyer, Rosenkranz & Droop made a few Crosby-like indicators in the 1930s, shortly before trading ceased, this was the only other German manufacturer to specialise in them. Founded in Altona in 1911, apparently to develop diesel engines, Lehmann & Michels soon began to make Maihak-like indicators in accordance with the 1906 patent granted to Wilhelm Lehmann. It is assumed that Lehmann had initially licensed his design to Maihak, but retained the right to exploit the design himself. Pre-1918 Lehmann & Michels indicators can usually be identified by a light bell-like housing protecting the amplifying linkage. Instruments of this type are still being made in Germany.

ABOVE
Left: 'Large Model' Lehmann & Michels indictaor, no. 5261. This particular example was sold in France soon after the end of the First World War and, to avoid anti-German resentment, shows no maker's marks. *Right:* a sectional drawing of a typical 1930s Lehmann & Michels indicator. Note the bell-housing protecting the amplifying mechanism, and the Stauffer-type lubricator on top of the drum spindle.

OTHERS

Copies of the standard Maihak Type 30 and Type 50 in-struments were certainly being made in the 1950s and 1960s in the German Democratic Republic (DDR) by Metallwerker AG of Meerane/Sachsen. In addition, Maihak/Lehmann & Michels-type indicators were made in Japan by Nagano KK until the late 1990s.



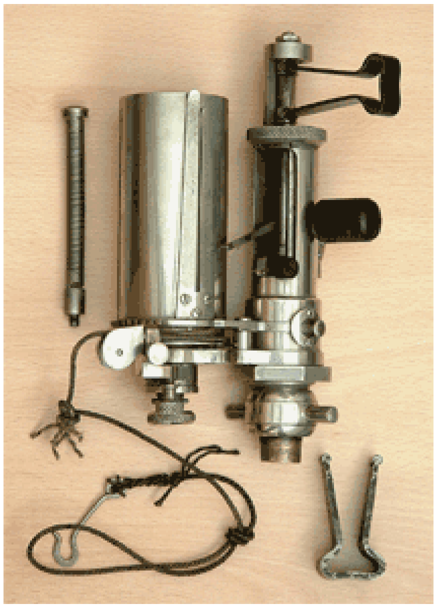
ABOVE
A typical British-made Casartelli indicator, probably dating from about 1910. This particular example has seven springs and two piston units (one for steam engines, one for 'internal-combustion engines'). Though the amplifying mechanism is similar to the McInnes and McInnes-Dobbie patterns, it is held to the cylinder cap by a large spiral spring at the rear.*Author's collection.*

James Atkinson (1846-1914) of 'Mellor, nr. Stockport [Lancashire], Engineer', was one of the best known of the British experimenters active prior to the First World War. His designs, which included the Differential Engine of 1885 and the Cycle Engine of 1886, were remarkable products of a fertile imagination. However, they failed to challenge the supremacy of the conventional horizontal-cylinder stationary engine. Atkinson was also responsible for modifying the design of the standard engine indicator to reduce the effects of the shock of combustion. Protected by a British Patent granted in 1906 (no. 5391/06),Atkinson's design shows Richards and Crosby-type indicators with a sturdy coil spring interposed in the links to 'register a more uniform and correct line as well as to relieve the gear from heavy strains or excessive vibration…' Indicators with Crosby-type amplifying gear were made by Casartelli of Manchester. They were similar to contemporaneous McInnes-Dobbie types, but could be easily identified by a large coil spring that rather clumsily held the rear of the amplifying mechanism to the platform. Indicators of this type were usually boxed with alternative steam/internal-combustion engine pistons to facilitate a dual-purpose role.

Simplex, 1894

A later embodiment of the pantograph will be found in the Simplex indicator, marketed commercially by Elliott Brotthers of London. Patented in Britain by Moses Wayne in September 1894, the Simplex is easily recognised by the 'sugar tong' or 'V' spring compressed between the top cap and the tip of the piston-rod extension. The spring could be removed simply by sliding it sideways. The piston unit could then be detached by unscrewing the locking ring and then lifting the piston and pointer assembly upward and out of the slotted tubular housing.

The patent showed a Darke-type elevator, but the pointer linkage of the production version was a classical four-lever pantograph which promised an accurate representation of pressures throughout its range without the need to ensure—as Ashcroft had done with the Tabor and Elliott with the Darke—that additional fixtures were required to direct the recording point in a straight line. The remainder of the Simplex was very similar to the standard Elliott made 'Improved Richards' indicator, which was still being made in quantity, and a modification of the Darke pattern detent slid in a small circular plate held to the piston housing with two screws.



ABOVE
The Elliott-Simplex indicator. The engraving (left) dating from 1897 shows what is assumed to be the prototype form, whereas the photograph of 'Pattern A' indicator no. 453.A (right) shows the perfected series-made type.

Vigorously promoted for the ease with which the spring could be changed and regulated, and the manufacturing advantages possessed by the distinctive spring ('lends itself to accuracy of calibration in any range', 'a simplicity of attachment [that] will recommend it to all engineers'), the Simplex was not particularly successful; production, apparently confined to1897–1901, was comparatively small. Two sizes were made: 'Pattern A' for normal speed ranges, and 'Pattern B', with a small drum, for high-speed use. Serial numbers will be found suffixed with the appropriate letter, and the springs were similarly distinguished to ensure they were used with the correct indicator-a typical example reads 'A' over '1/150' and '+375', showing a spring requiring a pressure of 150lb/sq.in to compress it by an inch and that 375lb/sq.in above atmospheric pressure was the maximum permissible in an 'A' class SImplex.

It is suspected that Simplex instruments were numbered in the same basic series and that no distinction was drawn between the two sizes other than the 'A' or 'B' identifier. If this proves to be true, then less than a thousand units were ever made. Sales were comparatively slow, as most British purchasers – still very conservative – preferred the Elliott-made Richards indicator. The highest-number Simplex yet found (no. 913.B) bears the marks of 'Elliott Bros. (London) Ltd', a change in corporate structure than does not seem to have occurred until shortly after the end of the First World War.

The problems with the Simplex are said to have concerned the excessive inertia of the heavyweight pantograph assembly, though the unique tong-springs may not have been popular. They may not have been as durable as the standard coil type, and regulating them may have been much more difficult than Elliott Brothers claimed. in addition, though the lighter springs were easily detached, changing the stiffer patterns required considerable manual strength or the assistance of a compressor.

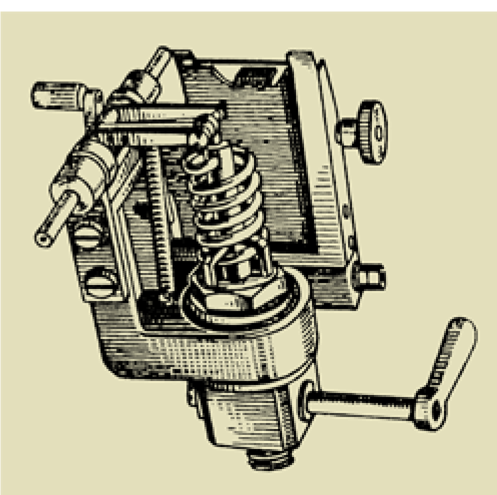
A comparison between the original 1897-vintage engravings and the surviving instrument shown in the photograph shows that the perfected version had a simplified lightweight folded-metal pantograph that was pinned together instead of heavy links retained with screws, and the design of the piston-support bracket was altered to improve rigidity. There are many other changes in detail, which suggests that tests undertaken either with a single prototype or a 'pre-production' batch revealed shortcomings that Elliott took pains to correct.

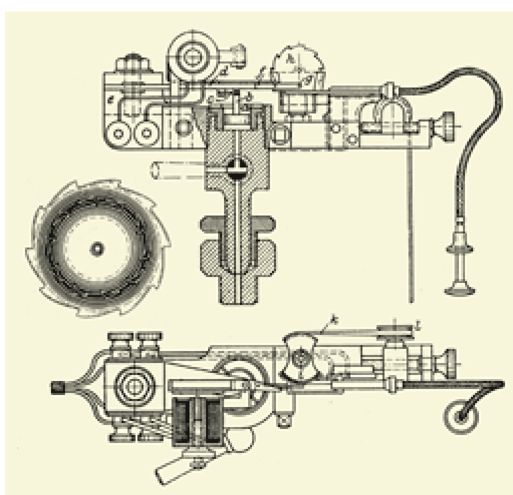
Others

External-spring indicators were more suited to internal-combustion engines than the enclosed-spring types, owing to the extreme temperatures encountered in the cylinders. An attempt to provide a comparatively conventional indicator suited to high-speed car and aeroplane engines was made in the 1920s by Englishman Charles Gale, who received British Patents 192551 and 192578, each sought in 1921, and US Patent 1483171 granted in 1924. Externally, Gale's indicator looked to be a conventional design with the spring mounted externally on a large bracket and an oscillating drum. The principal novelty lay in a valve controlled with a small hand-wheel, which allowed pressures in the engine to be monitored at differing positions in the operating cycle. A dash-pot or comparable damping system eliminated unwanted vibrations.

One method of overcoming the vibration problems encountered in high-speed running was provided by the micro-indicator, accepting that small-but-perfect diagrams were preferable to large traces compromised by undulations. The earliest attempt to provide an instrument of this type was made in Germany by Otto Mader, whose 1912 design was made in small quantities by Gebrüder Stärzle of München (Munich).

Mader's indicator consisted of a platform-like body containing a steam-cock and a small piston that could slide vertically against the resistance of a co-axial coil spring. A small 'writing lever' slid laterally on top of the piston rod as the short rocking-bracket to which it was attached was moved by a suitable part of the engine. A constraining spring anchored to the platform prevented the writing lever disengaging unexpectedly while a small stylus drew up to 24 minuscule diagrams (only about 2mm high) on a smoked-glass plate that slid in channelled supports in the rear of the indicator body. The 'cards' could be fixed by immersing the glass in Canada balsam, and viewed either with the aid of a low-power microscope or by enlarging them photographically.





ABOVE
Left: the Mader micro-indicator of 1912. *Right:* the Collins micro-indicator of 1922, showing the diagram disc (greatly enlarged). Drawings from K.J. DeJuhasz, *The Engine Indicator* (1934).

The 'Collins Micro-Indicator for High Speed Engines', patented in Britain in 1922 by W.G. Collins, director of the Cambridge & Paul Instrument Co. Ltd of London, took another approach. A very compact design, relying on a very small piston and a sturdy riband spring to move the stylus that engraved tiny diagrams on a small ratchet disc, the Collins design was praised by the British periodical *Engineering:* 'The moving parts are light and they move through small distances; there is little inertia, an entire absence of linkages and uncompensated joints, and there is, therefore, small liability to wear. With a piston area of 1/4 sq. in. the natural period of the recording system is about 1/1100 of a second.'

The diagrams produced by the Collins instrument were only about 3mm long, with a maximum height of about 2.5mm. Though they were difficult to interpret with the naked eye, a simple tubular microscope with a graticle allowed the operator to read the dimensions of the diagram to the nearest hundredth of an inch. The raised edges of the trace helped to make the diagrams surprisingly distinct.

Ten diagrams could be taken in rapid succession from high-speed engines, but the Collins design never prospered. This was partly due to the ready availability of conventional indicators, which could handle most of the day-to-day work of a travelling engineer; the need to have an electrical supply at hand, even if only a battery, and the impossibility of using a planimeter to interpret the micro-diagrams were considerable drawbacks. Though a few Collins micro-indicators were sold commercially in the 1920s, they soon faded into obscurity in the face of competition from multi-cylinder analysers such as the Farnboro pattern marketed aggressively by Dobbie McInnes.

Another type, the work of the German engineer Wolfgang Pabst, was used by the Deutsche Versuchsanstalt fur Luftfahrt from 1929 onward. Pressure on a diaphragm raised a lightweight rod attached to a diamond-point stylus, which engraved a diagram on a ground-glass slide that was oscillated during the engine cycles and moved sequentially by clockwork. The diamond allowed a very precise trace which could be as fine as 0.002mm: ideally matched to the diagrams, which were usually only about 0.5mm high!

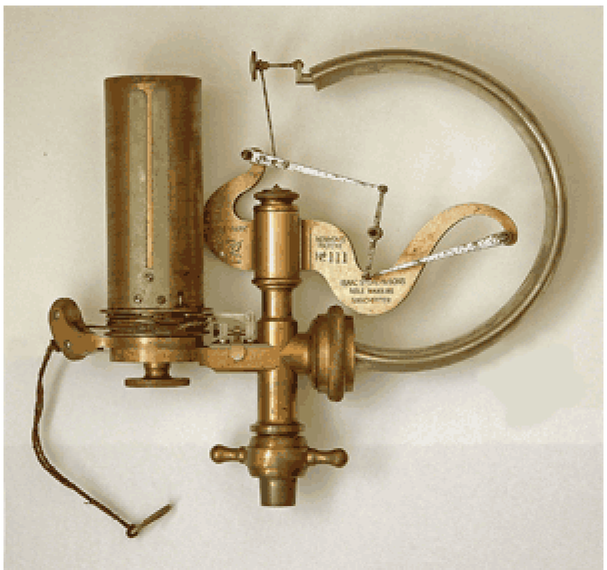
Tubes, diaphragms and discs

Many late-nineteenth-century inventors were determined to provide indicators relying on something other than a coil spring, not only because they sought something that was sufficiently different to patent but also in a genuine pursuit of simplicity.

The advent of the Bourdon tube and the Schaeffer & Budenberg diaphragm revolutionised the design of the pressure gauge, which had soon become a universal fitting on boilers and similar pressure vessels. It was only a matter of time before the principles were applied to indicators. Bourdon himself is said to have made a pressure-tube indicator in the 1850s, but no details have been found. More successful was the instrument protected by British Patent no. 2249/69, granted in August 1869 to Arnold Budenberg 'of the Firm of Schäffer and Budenberg, of Manchester, in the County of Lancaster, for the Invention of "Improvements in Apparatus for Indicating and Registering the Pressure of Steam in Steam Generators, and the Pressure in Hydraulic Presses and other Vessels or Chambers, which Improvements are also applicable to Indicating and Registering Pressure and Vacuum in Condensing Apparatus; also to

Indicating and Registering the Combined Pressure of the Steam or other Power employed to give Motion to an Engine, and the Speed of such Engine or other Machinery; also to Indicating and Registering Barometrical Variations"…'

The essence of the design was a conventional Bourdon-tube pressure gauge, connected to a toothed sector to rotate the pointer and a vertical rod to actuate a Richards-like amplifying mechanism. The pointer recorded pressures directly onto paper around the drum, which could be driven by clockwork to provide a permanent record, but could also be operated by 'the motion of the engine or other machinery to cause by band and wheelwork or otherwise a cylinder to revolve and complete…one revolution in a given time…' Indicators of this type were made in the late 1860s, and an improved design, introduced *c.* 1889, was described by Charles Budenberg during a lecture given to members of the Owens College Engineering Society in February 1890.

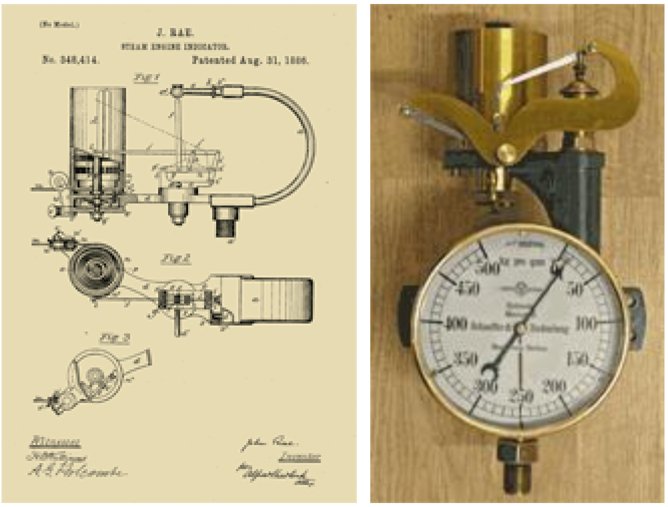


LEFT
The short-lived Kenyon indicator was basically a Richards-type instrument with a Bourdon tube instead of a conventional piston and spring. This is no. 111, made in Manchester, England, by Isaac Storey & Sons. *Museum of Making collection.*

The subject of British Patent no. 1278/78, granted on 1st April 1878 and sealed on 13th September 1878 to 'John William Kenyon, of Manchester in the County of Lancaster, England, Engineer', the Patent Pistonless Indicator was made in small numbers by Isaac Storey & Sons of Manchester. Though fitted with a Richards-type parallel motion, it also had a Bourdon Tube, bent into a semi-circle, instead of a conventional piston and cylinder. The tube expanded in relation to pressure, and, as the upper or 'free' tip of the tube was connected to the upper link bar, the pointer operated in the usual manner.

Indicators of the 'tube' class included that shown in U.S. Patent no. 185773, granted on 26th December 1876 to Thomas Minor and John Rae, which had a simple amplifier with a pointer sliding in a vertical channel cut in the mounting plate. Dreyer, Rosenkranz & Droop made not only diaphragm-type indicators embodying a Thompson-type amplifier, but also a few, patented in Germany by Hadicke, with a pantograph amplifier and an additional spiral spring above the diaphragm. The former was intended specifically to indicate Lindes Eismaschine (which used ammonia as a refrigerant) and the latter was suited to steam engines.

The Bourdon-tube and diaphragm indicators excited controversy when they first appeared. However, though they seem to have worked quite well when new and were at least the equal of a standard piston-type indicator, problems developed with age. Bourdon tubes in pressure gauges had to cope only with gradual changes in pressure; in an indicator, however, the change was sudden, violent and unusually rapid. Perpetual stressing of the brass caused the 'work-hardening' that altered the rate at which the tube responded to stimulus and degraded accuracy. In addition, though they advantageously isolated corrosive or poisonous gases from the atmosphere, Bourdon-type indicators proved to be unusually susceptible to vibration.



ABOVE
Left: the Rae indicator of 1886 was based on a Bourdon tube. It is assumed that a few prototypes were made, but there is currently no evidence that the design was ever exploited commercially. Conversely, the 'improved' Schaeffer & Budenberg design of *c.* 1889 (*right*) was made in small quantities. The example shown here, despite its Richards-type amplifying mechanism, dates from 1897. *Courtesy of the U.S. Government Patent Office, Washington DC, and Pieter Knobbe, the Netherlands.*

Public interest (lukewarm at best) had soon waned in Britain. John Rae and Walter Brown continued work in the USA, patenting several improved designs as late as 1887, but there is no evidence that large-scale distribution was ever undertaken; no surviving specimen of Rae's or Brown's later indicators has been traced. They resemble the Kenyon version superficially, though the amplifying mechanism usually proves to be a pantograph (Rae) or a Thompson (Brown). The Clarke and Clarke & Low optical indicators of the 1880s and 1890s also relied on a diaphragm to rock a mirror to deflect a beam of light.

Continuous recorders

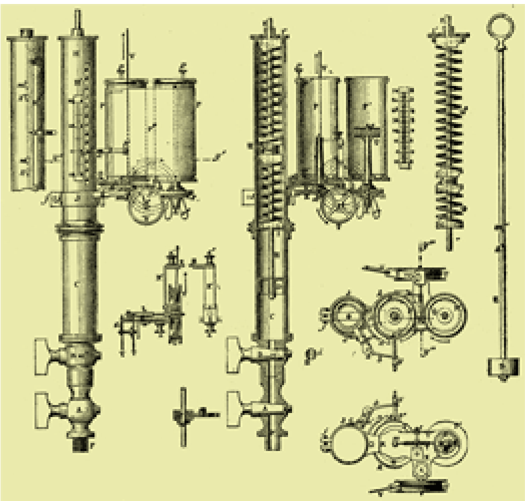
Watt and McNaught indicators gave a picture of the internal workings of an engine, but, obviously, only of one particular stroke. When academic research into the theory that lay behind steam-engine practice began in the second quarter of the nineteenth century, experimenters soon realised that analysis based on an isolated cycle was doomed to fail: there was nothing to show that the individual record was typical of the performance throughout a working day or if, for example, the working load on the engine had been changed.

The need for indicators that could record continuously was answered in the early 1840s, and some surprisingly sophisticated designs had been tried by 1860. These instruments came in several classes. Some recorded progress on conventional diagrams, either as a series of individual single-cycle traces that had to be analysed separately or as a single trace made from components of as many as a hundred cycles. The former type customarily relied on paper rolls, driven mechanically from one spool to another; the latter emboded stops and springs to take only a tiny horizontal 'slice' from the full-size trace that would otherwise have been produced during each cycle. A third class of 'totalisers' or 'totalisators' embodied the gears and wheels necessary to analyse (by mathematical integration) the performance of an engine over a period of time.

Multiple-trace indicators

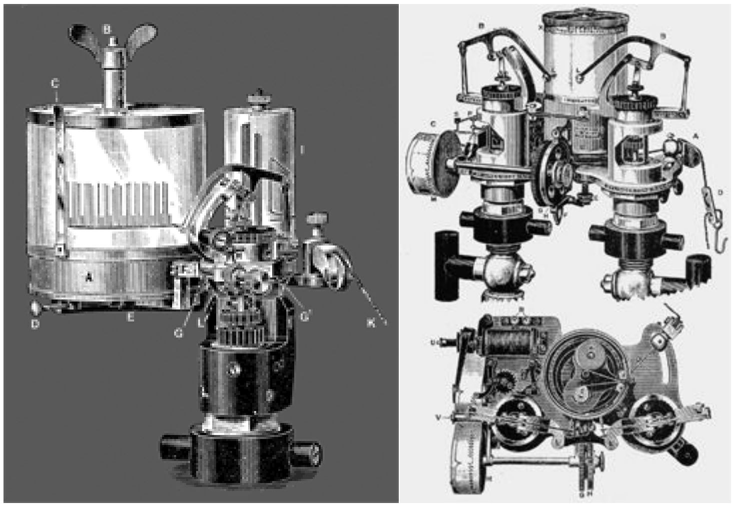
The continuously-recording machine proposed by Daniel Gooch (1816–89) was the first indicator to be used successfully on a railway locomotive at speed. It owed its origin to the 'Battle of the Gauges', a controversy that raged in Britain in the 1840s over the ideal dimensions for railway track. One powerful faction, led by the Stephensons, claimed that the 'standard' gauge (then 4ft 8in) was superior to the Broad Gauge (7ft 0.1/4in) championed by the maverick engineer Isambard Kingdom Brunel (1806–59). Among the sharpest differences of opinion concerned the resistance afforded by air pressure, friction and other factors to a moving train, and it was this that Gooch sought to investigate

The Gooch indicator comprised a horizontal-cylinder apparatus incorporating two half-elliptical springs and a slide valve instead of a turn cock. It was also the first instrument of its type to incorporate an amplifying recorder: a pencil bar, attached at one end to the piston rod was mounted so that the movement of the piston was magnified approximately fourfold. Unfortunately, the diagrams produced by the Gooch indicator took an unusual form, partly because of the continuous-recording feature but also because the recording pointer moved radially.



LEFT
A French MacNaught-type indicator fitted with a continuous-recording system. It was probably made by Duvergier of Lyon in the 1860s.

A few attempts were made to fit McNaught-pattern indicators with continuous-roll apparatus, most notably by the French clockmaker Paul Garnier in 1857-65. However, the success of the Richards design held immediate attention. Some continuous-record instruments relied on three drums — one holding the paper roll, one recording, and the other receiving the used roll — though others had only two, and a few attempts were made to contain the entire assembly in the recording drum. Elliott Brothers of London made Darke and 'Improved Richards' indicators of this type, but the universal acceptance of pillar-type torsion springs at the expense of flat spiral springs in the drum base subsequently favoured external paper feed systems.



ABOVE
Two Dobbie McInnes continuous explosion recorders, intended for use with gas and oil engines — the Mathot pattern (left) and the Cippolina type (right).

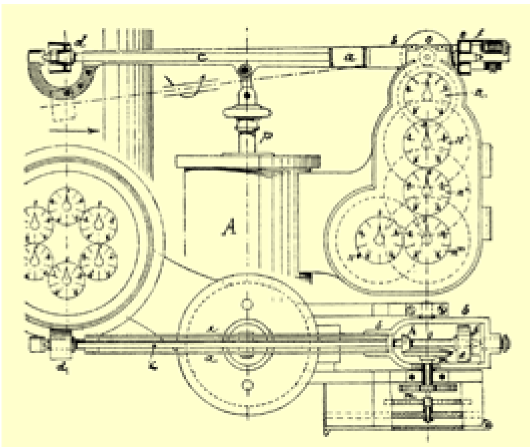
T.S. McInnes & Co. Ltd of Glasgow (and their successors, Dobbie McInnes Ltd) made a few Mathot-type indicators, combining a conventional vulcanite-clad external-spring body with a clockwork-driven paper drum. The design was patented in Britain in 1900 by Rodolphe Mathot, an engineer living in Brussels, Belgium, and was intended specifically for use with 'explosion engines' (gas, oil or petrol). The Mathot indicator was superseded by the Cippolina Continuous Double Diagram Recorder, production beginning in Glasgow in 1904 or 1905. Protected by a British Patent granted in 1902 to an Italian naval engineer, Giuseppe Cipollina of La Spezia, the instrument was basically two Dobbie McInnes No. 1 indicators sharing a common platform. Complexity and high price kept production to a minimum, even though production continued into Dobbie McInnes days.

Cumulative-trace and integrating/planimetringindicators

Perhaps the first of the limiting or 'slice' indicators was the work of an Alsatian engineer, Gustave Hirn (1815-90). Alterations had been made in the 1850s to a co-axial McNaught-type indicator. Hirn preferred the direct-reading instrument where absolute accuracy was concerned, but acknowledged that the oscillations that affected the pencil posed a real problem when the engine-speed rose above 20-25rpm. An answer was found by limiting the recording to a fraction of the cycle, then repeating it section-by-section until an overall picture was created. Hirn had first applied the method crudely, simply by pressing down on the pointer with his finger, but then progressed to mechanical stops. The slice diagrams or *tranches minces* were subsequently employed in France by Deprez, in the USA by Burkitt Webb, and in Britain both by Farnum & Bodley and by Moses Wayne.

Among the first attempts to develop a 'work meter' was made by a Briton, Professor Moseley, who published 'Result of a Trial of a Constant Indicator upon the Cornish Engine at the East London Water-works', undertaken in 1842, in the *Minutes of the Proceedings* of the Institution of Civil Engineers in 1844. The advent of the Amsler polar planimeter (see Accessories) inspired work to begin again. Though calculating indicators were developed — the Ashton & Storey design of 1869 was made in small numbers — the integrating indicator had greater potential.

The first of this type may have been the work of Henry Lea, patented in Britain in 1877. Built on the basis of a Richards indicator, Lea's design had a trace arm with a tiny wheel where the pencil-point would normally lie, and an abnormally long rearward overhang to accommodate the drive to the gear train of the recorder; a separate gear-train in the top of the drum recorded the number of strokes. The Lea planimetring indicator was theoretically capable of recording a single stroke, though it gave no clue to the steam distribution that would have been obvious from a pencil trace. Its true role was to record and calculate the mean performance of an engine over a period of time.



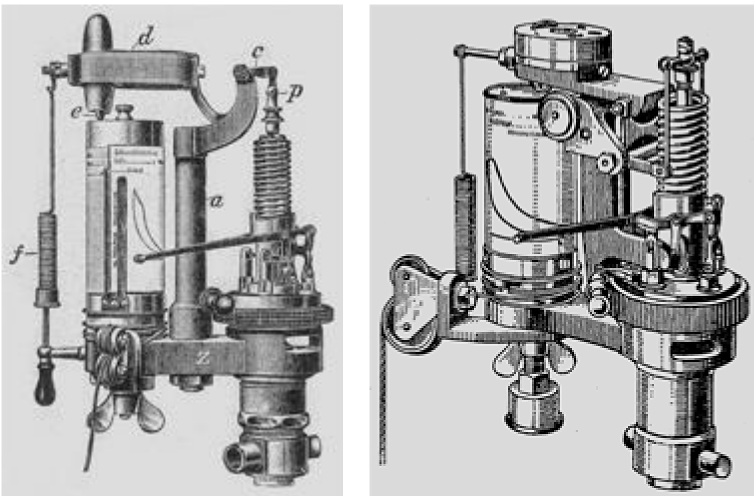
ABOVE
The Lea planimetring indicator, patented in 1877. From Jacques Buchetti, *Guide pour l'essai des Machines à Vapeur...*(Paris, c. 1887).

The planimetring indicator designed by the Briton Charles Boys, patented in June 1880, achieved much the same goals as the Lea pattern. However, it was also capable of simultaneously providing the trace of a single stroke or an accumulation of strokes produced at the same engine-setting. It had a cylindrical brass piston housing, flaring vertically into three standards to support the platform that carried not only the integrating arm but also a drum mounted on a spring-loaded reciprocating carriage. The carriage was driven from the engine cross-head or reducing gear, a drive rod from the drum to a gear train allowing readings to be taken from a large dial at the front of the instrument.

Patented in 1894-7, the integrating indicator developed by W.G. and C.W.G. Little of Bexley, Kent, was intended to provide a continuous record of the output of an engine working under varying load, keeping an accurate tally as work proceeded. Though the Little indicator could not analyse individual strokes in the manner of other instruments, it proved to be surprisingly accurate. Tests suggested that, over the course of 150 revolutions, the error amounted to only about a half of one per cent. However, Little indicators were not robust enough for run-of-the-mill engineering work and were generally confined to laboratories, schools, colleges and educational establishments. Production, never large, came to an end with the rise of the optical indicator in the early twentieth century. It is believed that the instruments were made by Elliott Brothers, though no survivor could be traced for inspection.

The Lea, Boys and Little indicators were made only in small numbers, and then, perhaps, only used for experimentation. Interest in instruments of this type seems to have lapsed for several years, only to reappear in earnest in Germany. Among the earliest of this group was designed by Heinrich Eicke, but more popular was the indicator patented by Anton Böttcher in 1908-9. This had an integrating wheel set in a housing hinged to the top of the recording drum, a spiral spring connecting the housing with the platform, and a prominent pillar (rising from the platform between the drum and the amplifying gear) that anchored a rocking link between the piston-rod extension and the planimeter head.

A few of these instruments were made by Maihak of Hamburg prior to 1914. During the 1920s, however, an improved version appeared with a sheet-steel carriage and bell-cranks between the piston-rod extension and the integrator. Finally, in the mid 1930s, Maihak produced a much-modified integrating indicator driven by a combination of gearing at the base of the drum and a rocking rod engaging a collar on the piston rod.



ABOVE
The pre-1914 (left) and 1920s (right) versions of the Böttcher planimetring indicator, made by Maihak of Hamburg. From Stephan, *Verbrandingsmotoren* (1917), and de Juhasz, *The Engine Indicator. Its Design, Theory and Special Applications* (1934).

All three of the Maihak/Böttcher planimetring indicators could also produce conventional diagrams. However, they were too complicated for most applications and were usually confined to research or teaching facilities. It is difficult to judge the true extent of production on the basis of a few survivors.

Optical type

The ever-increasing speed of steam engines, especially those that were to drive electricity-generating sets, internal-combustion engines, emphasised the limitations of the traditional indicator. Though continual improvements had been made in the design of the reciprocating drum, the amplifying linkage and the design of the piston assembly, few indicators of this type would provide satisfactory diagrams at more than 600rpm. The increasing popularity of the internal-combustion engine in the years immediately after the end of the First World War intensified the search for more accurate recording methods.

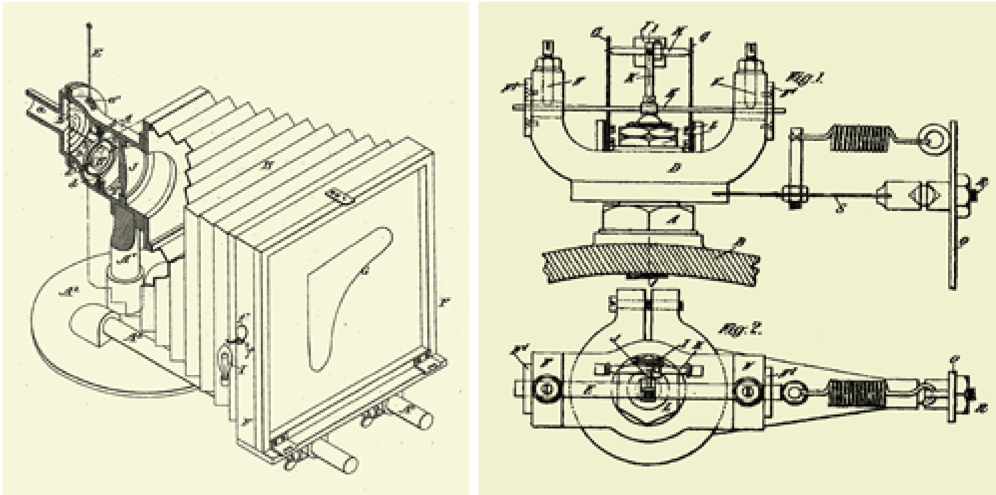
Many attempts were made to solve particular problems, particularly when pressures rose as high as they did in the chamber of a gun, with out the attendant problems of induced vibration and natural harmonics spoiling a trace. Among the most promising of the earliest designs were the optical indicators, but light had to be excluded to provide permanent records of performance. This suited them to laboratories or colleges, but not to consulting engineers who spent most of their time on-site; consequently, many other avenues were explored.

The essence of the first optical indicator seems to have originated shortly before 1880, when a letter appeared in *Engineering* suggesting the use of a flexible diaphragm. The Clarke & Low indicator of 1885, therefore, consisted of a hemispherical body containing an elastic diaphragm communicating with the engine cylinder through a conventional stop cock. A small concave mirror was mounted above the diaphragm on a frame that could be oscillated about its vertical axis by a connection formed with the crosshead or reducing gear. A small link or 'finger' on the diaphragm rocked the mirror on its horizontal axis as the chamber pressure changed. Combining the movements of the mirror and the supporting frame allowed a conventional diagram to be produced. A pin-point beam of light was directed onto the mirror and reflected onto a screen, where the changes of pressure during the operating cycle could be pricked-off or traced to provide a permanent record.

The system had inherent limitations — difficulties of calibrating or regulating the diaphragm, for example, or errors produced by projecting the diagram onto a flat instead of appropriately curved surface. However, the Clarke & Low system found a short-lived favour as a teaching aid, as it projected diagrams that could be several feet long.

The optical indicator designed by Dr John Perry, who subsequently became professor of mechanics and physics at the Royal College of Science, was described to the Physical Society in 1891. Clearly inspired by the work of Clarke & Low, it relied on a thin steel diaphragm contained in a circular disc that could be expanded by the admission of steam or combustion products from a union with the engine cylinder. The influx passed through a gas-tight joint into a cast-iron box or 'shoe', and thence into the chamber beneath the diaphragm. A small mirror was fixed to the diaphragm face, offset to one side so that it was tipped in relation to the rise and fall in pressure. The shoe, mounted in gimbals, was tipped laterally by a linkage attached to the reducing gear or a suitable component of the engine. The resulting bi-directional movement of the mirror could be mimicked on a screen or photographic plate by a beam of reflected light. Leaks from the admission port, which ran through one of the gimbals, could be prevented by tightening an adjuster screw at the opposing end of the shoe. However, the Perry indicator shared the weaknesses of the Clarke & Low type, even though the development of photographic recording apparatus allowed the traces to be recorded and the instrument could react rapidly to changes of load, speed or pressure.

The simplicity of the diaphragm-type optical indicator attracted many inventors. Among them was Charles Bedell of Swarthmore, Pennsylvania, who received a US Patent in January 1897 to protect one of the first to be fitted with photographic recording apparatus, the lens, the bellows and the plate becoming an integral part of the instrument. The diaphragm was flexed by steam pressure, the central push-rod being connected with the top edge of the mirror to move the trace vertically; lateral movement was effected by a rocking lever, pivoted on top of the mirror housing, which was driven by a suitable linkage attached (ultimately) to the piston rod cross-head. Though there is no evidence that the Bedell indicator was made in quantity, and it would probably have overheated during prolonged use, it did highight one particular trend in late nineteenth-century thought.

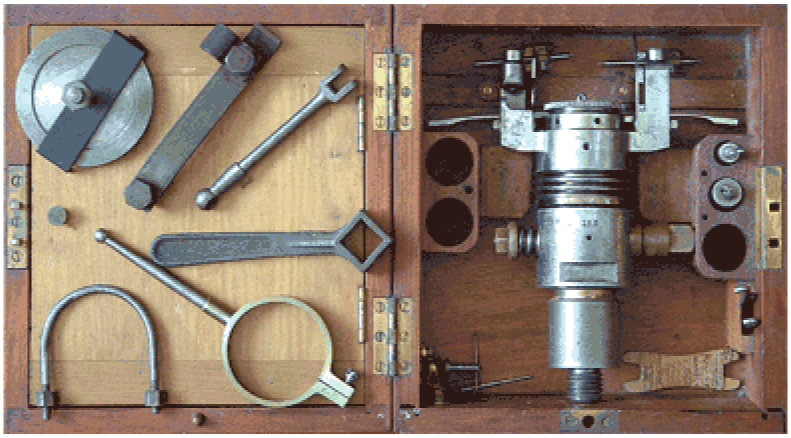


ABOVE
Left: the diaphragm-type indicator designed by Charles Bedell, showing the integral bellows-camera attachment. From the drawings accompanying the US Patent. *Right:* the original Hopkinson indicator of 1906, shown here in a patdent drawing, was much more compact than the 'production version' made by Dobbie McInnes.

The first optical indicator to achieve real success was developed by Bertram Hopkinson (1874-1918) of Cambridge University, Professor of Mechanism and Applied Mechanics from 1903 until his untimely death in an air crash. Its development history is obscure, though the engineer Harry Ricardo testified that he had been given the prototype were when he left Cambridge in 1906. An indicator pictured in *Engineering* on 25th October 1907 is identical with the perfected "Hopkinson's Flashlight Engine Indicator" marketed in quantity by Dobbie McInnes Ltd of Glasgow from 1908 onward.

Hopkinson indicators were supplied with two differing beam-type springs and three pistons (their surface areas were customarily one unit, a half-unit and a quarter-unit), which, with cylinder liners if necessary, allowed the operator sufficient choice to suit most circumstances. They proved to be successful teaching and experimental aids, as the spring calibration was found to remain remarkably constant over long periods of time — an error less than 2 per cent being customary.

However, the requirement either to plot the trace manually or employ comparatively cumbersome photographic recorders did little to commend Hopkinson indicators to consulting engineers. Even the manufacturer had lost interest by the early 1920s, concentrating instead on the Farnboro electrical engine indicator. Dobbie McInnes may have made as many as 250 Hopkinson optical indicators, but survivors are rarely seen...even though an illustration was still appearing in the company's promotional booklet, *The Engine Indicator. Its Commercial Value and Instructions for Use*, in the days of Dobbie McInnes & Clyde Ltd.



ABOVE
Hopkinson optical indicator no. 155, made about 1911/12 by Dobbie McInnes & Co. Ltd of Glasgow. Virtually all of the survivors reported to date (four of them) seem to have been used by colleges and reaching establishments. *Museum of Making collection.*

A modification of the Hopkinson 'beam spring' system was developed in Japan by Fujio Nakanishi, eventually working in collusion with Masaharu Ito and Kikuo Kitamura. A short-stroke pistol (eventually superseded by a pressure diaphragm) conveyed movement to a light beam-like spring with an angled mirror at the mid-point of each arm. Intended to minimise the effects of vibration, this construction allowed a beam of light from a source placed vertically above one of the mirrors to pass from mirror to mirror and then back to the recording medium (e.g., a photographic plate). Like the Hopkinson design, the Nakanishi oscillated around its vertical axis to provide the 'time' part of the diagram. The Japanese indicator progressed through several improvements in 1928–35, and was certainly made in small numbers—though never as widely distributed as the original Hopkinson design had been.

In 1910, Frederick Purdy, a 'Mechanical Expert' of Kenosha, Wisconsin, patented an indicator specifically for use with multi-cylinder internal combustion engines. The essence was a series of tubes leading to a block containing the valves that allowed the pressure in any single cylinder to reach a diaphragm. A rod touching the front of the diaphragm transmitted movement to a spring-loaded mirror pivoted on the front of a bevel gear which received its motion from the engine crankshaft. As the mirror rotated, fluctuations in pressure moved the point of light generated by an arc lamp away from the perfect circle that sufficed as the atmospheric line to trace an irregular closed loop on a glass screen or a photographic plate. Though the form of this diagram was unconventional, it was nonetheless possible to interpret the change of pressure with time.

The indicator patented in Britain in June 1913 by William Dalby and William Watson was another of the many diaphragm-and-mirror designs, the thickness of the diaphragm varying from 0.015 to 0.06 inches depending on the test-pressure range. The inventors were respectively Professor of Engineering at the City and Guilds Enginering College and Assistant Professor of Physics at the Imperial College of Science and Technology in London, showing clearly that the instrument was intended more for laboratory use than a commercial proposition. And, like virtually all of its type, it was heavy and cumbersome.

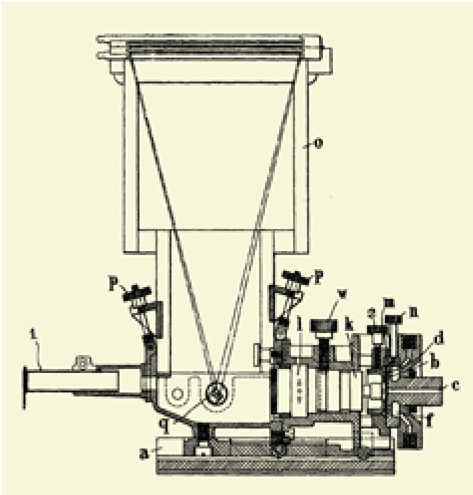
The apparatus consisted of a sturdy base, which was to be directly attached to the engine, beneath a detachable camera-box. When the connection between the cylinder and the indicator cock was opened, steam pressed on the diaphragm. The diaphragm in turn acted through a light spring-loaded rod to turn a small mirror on a vertical axis, the amount of deflection being directly proportional to the pressure applied. This gave a continuous record of the changes within the cylinder in the same way as the pencil arm of a mechanical indicator. Simultaneously, a mirror set with its axis horizontally was oscillated by a cam and rod driven by a chain from the engine being tested. The ratio of the throw of the eccentric to the length of the eccentric rod had to be the same as that of the crank radius of the engine to the length of its connecting rod, to ensure that the angular displacement of the horizontal (or 'stroke') mirror was proportional to the linear displacement of the engine piston. It also provided accurate timings for the rise and fall of pressure in the engine cylinder, effectively replicating the drum motion of a conventional mechanical indicator.

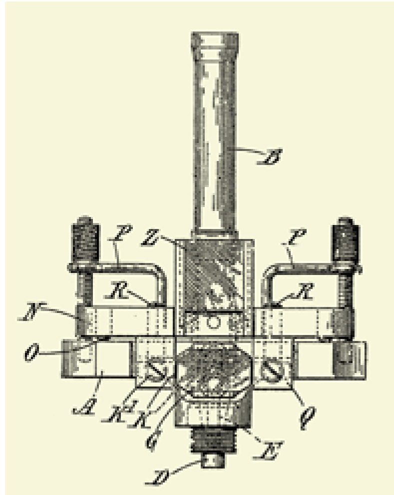
The trace was created by allowing light from an external bulb to enter a pinhole in the casing of the indicator. The light-ray ran the length of the body to strike the vertical (pressure) mirror and was then turned back to strike the horizontal (time) mirror before leaving at approximately ninety degrees to its line of entry. The reflected light-ray struck a ground-glass screen or a photographic plate in a wooden box attached to the indicator body to create a visual record of the events that had occurred within the engine cylinder.

Dalby and Watson claimed novelty not only in the way in which the pressure mirror could be adjusted to change the position of the reflected light beam, but also in the adjustable stop for the diaphragm. Provision was also made for a fixed concave mirror (in the wall of the tubular housing alongside the moving mirror) to provide an additional datum line. The ease with which the pressure-mirror unit could be removed was also noteworthy, as it was only necessary to detach the camera, release a lock screw, and withdraw the tubular housing containing the mirror.

The Briton Archibald Low, one of the best-known scientific writers of his day but then an army officer serving with the 'Royal Flying Corps Experimental Works', was still promoting a diaphragm-type indicator during the First World War. Low's British Patent of January 1918 shows two methods of obtaining a movement corresponding to pressure: by variations in the resistance of carbon granules or by a coil moving within a coil, each method varying the current in an electrical circuit in which a moving-coil galvanometer provided deflection to a small mirror. This mirror supplied the vertical (pressure) component of the pressure/time trace on light-sensitive paper, the horizontal (time) component being provided by moving a second mirror driven by any suitable method—an electromagnet, for example—as the crankshaft revolved.

Low's design was in some ways ahead of its time, and may not have been employed outside the military establishment to which he had been seconded. More successful, though with a similar genesis, was an indicator created in 1919 by Leonard Thring, an engineer once associated at Cambridge University with Bertram Hopkinson. This was developed specifically to obtain pressure/time information in situations where very high pressures rose exceptionally quickly. Though this applied to high compression engines in some respects, a much more obvious example was a gun—effectively a 'one stroke' internal-combustion engine.



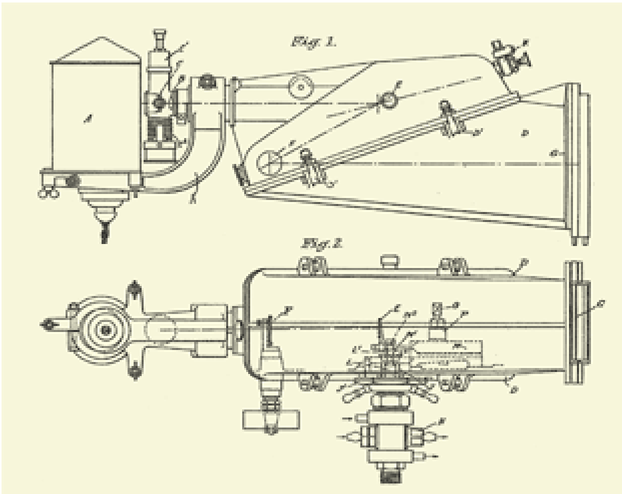


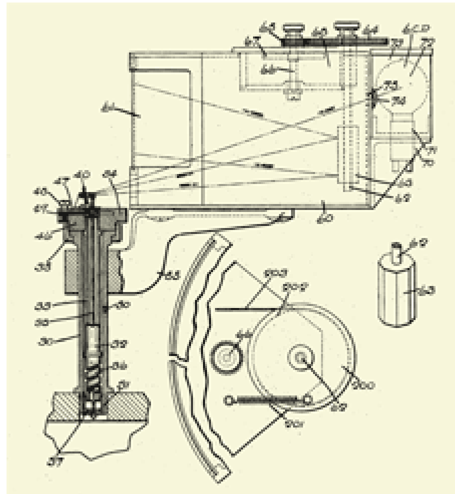
ABOVE
Left: the Dalby-Watson optical indicator patented in Britain in 1913. *Right:* the original type of Thring indicator, with traverse table, from the drawings accompanying the 1919 British Patent.

Thring proposed to harness high pressures to give a very small movement by attaching an inner tube securely to the top of an outer tube that had been screwed into a base plate. The lower end of the inner tube ended in a plunger communicating with the source of pressure, and a strut or plate extending vertically upward inside the hollow head of the plunger rocked a rigidly-mounted mirror by twisting either a flat spring or spring-loaded trunnions. When the gun was fired, pressure generated by the combustion of propellant forced the plunger upward. This had the dual effects of compressing the inner tube against its joint with the outer tube and extending the outer tube from its joint with the base plate. The resulting two-stage movement rotated the mirror, and allowed changes in pressure to be seen in a pinpoint beam of reflected light. Thring also proposed a 'traverse table' which, responding either to recoil or similar movement, rotated the mirror laterally to allow a conventional pressure/time diagram to be obtained. A later patent, sought in Britain in 1928, protected a simplified instrument in which the mirror strut was constrained at both ends to reduce the degrading effects of vibrations in the trace.

In May 1920, *Engineering* reported that an optical instrument designed by Professor Frederic W. Burstall of the University of Liverpool, representing 'we understand, the latest form which [the] indicator has taken', had been exhibited at the Royal Society soirée. The subject of a patent application made in Britain in October 1920, this was another of the mirror types. The two-piece body, with a diagonal joint, contained the mirrors in the upper half and the image plate in the lower part. Changes in pressure were registered by the lateral movement of a hollow-bodied piston against a bar spring terminating in a mirror, relying on a combination of a ball joint, a spring-locating screw and a 'V'-shape spring channel to ensure accuracy. A water-cooled cock and piston housing (and an optional forced lubrication system) kept the piston moving freely. The passage of time during an individual cycle was shown by a mirror, oscillated by the crankshaft or other part of an engine to divert the light path vertically, to complete the bi-directional movement required to trace a diagram on a photographic plate.

The Burstall indicator exhibited in 1920 had a water-cooled cylinder containing a tiny piston with a diameter of 0.4in and a stroke of just one-tenth of an inch. A stiff steel cantilever arm acted as a spring, reducing the effects of vibration until engines running at 2500rpm and pressures as great as 600lb/in^2 could be tested satisfactorily. A modified version appeared in the late 1920s, with the layout of the components refined to produce a more compact design, but the Burstall indicator was never made in quantity. Like the earlier Dalby-Watson design, it could never break free of the constraints of the laboratory.





ABOVE
Left: the original or 'straight line' type of Burstall optical indicator. The later pattern had the lamp housing offset to one side and the mirrors angled to make the design more compact. *Right:* the Midgely indicator, from the US Patent granted in 1923. Note the faceted mirror, part no. 63.

Thomas Midgely, Jr, of Dayton in Ohio, was a prolific designer. Among his many patents, usually assigned to the Fisk Rubber Company or the General Motors Research Corporation, was an optical indicator designed specifically to investigate the performance of high speed multi-cylinder internal combustion engines. Like some of the preceding designs. Midgely relied on two mirrors—one to show the changes in pressure by moving the trace vertically and the other to denote the length of cycle by deflecting the trace laterally. The vertical movement was undertaken by a tipping mirror controlled by a rod attached to the spring-loaded piston; and the horizontal movement was controlled by a faceted vertical mirror within the wood body, in plan virtually a quadrant, that supported the curved viewing screen. The vertical mirror was driven by a motor so controlled by the drive mechanism carried on a separate base plate that it rotated in phase with the engine crankshaft. Typically, the motor rotated at one-eighth of the engine speed; each of the eight facets of the mirror, therefore, recorded one complete revolution of the engine. Other features included the ability to alter the rotation of the mirror in relation to the engine crankshaft; to obtain a photographic record of even a single engine cycle when necessary; and to alter the instrument to become a pressure/volume recorder simply by allowing the faceted mirror to oscillate instead of rotate.

The Midgely indicator was a very sophisticated tool, and several patents of addition were filed by other employees of the General Motors Research Corporation (e.g., to J.H. Sheats and Harvey Geyer in 1923-4). These were usually concerned with adapting the indicator to other purposes: one of Geyer's designs allows an opposing pressure to be applied to the piston, and the other incorporates a spark plug to allow the piston unit to be inserted directly into the combustion chamber.

It is not known if Midgely indicators were made in quantity. One survivor dating from the early 1920s is marked 'Dayton-Wright Division' (which General Motors sold in February 1923) and numbered 'A-160', but it has been suggested that the number refers more to the laboratory inventory of the General Motors

Research Corporation than a large-scale manufacturing operation. Hopefully, more of these fascinating instruments may now be found.

Among the many other designs of optical indicator were the 'Manograph' of the Frenchmen Hospitalier & Charpentier. Diaphragm-type instruments included the designs of van Dijck & Broeze of Proefstation 'Delft' (a research establishment owned by a subsidiary of the Royal Dutch Shell petroleum company), made by Kipp en Zonen of Delft, and that of la Société Genevoise d'Instruments Physiques of Geneva, Switzerland. The indicators promoted in Germany by OTA-Apparate GmbH of Frankfurt am Main and Maihak AG of Hamburg-Altona—to the designs of Otto Schulze and Alfred von Gehlen respectively—were both based on cantilever springs. The Maihak indicator, which incorporated three mirrors, was a particularly compact unit which could be substituted for a spark plug.

Yet optical indicators began to lose favour in the 1930s. The incorporation of moving mirrors and mechanical drive introduced unwanted friction and inertia, and attention turned instead to measurement that could be obtained electrically. Though these often created a conventional trace on the screen of a cathode-ray tube, they are not regarded as 'autographic'-defined fore the purposes of this site as having overtly physical characteristics.

Spark tracers

The meteoric rise in the popularity of the internal-combustion engine was due partly to enthusiasm for motoring, and partly to the intervention of the First World War. Conflict often accelerates technological progress, and the years between 1914 and 1918 were no exception: the aeroplane, in particular, made a spectacular advance from the rickety craft of the first days of fighting to the gigantic bombers that were being built when the hostilities ended.

Though methods of testing engines on the ground had been provided, maximum-pressure indicators were too unsophisticated, pencil-arm autographic indicators were much too delicate, and optical indicators were too cumbersome to enable experiments to be undertaken in flight.

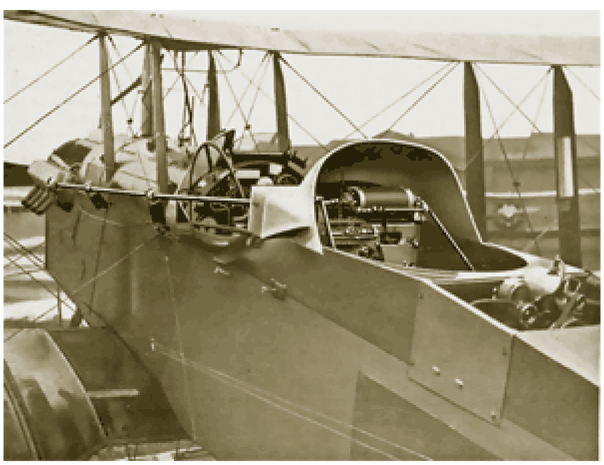
Development of the 'RAE Indicator' — named after the British Royal Aircraft Establishment, South Farnborough, Hampshire — began in 1919. The instigator was Squadron-Leader Geoffrey Norman, who sought, in the words of W. Sydney Smith, Superintendent of the research establishment, to provide 'an indicator which would record diagrams from the engine with entire satisfaction at high speeds, either on the bench or in the air'.

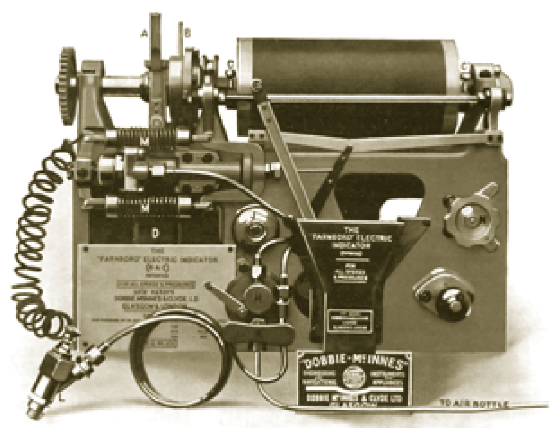
The basis of the indicator was a small disc valve with which air pressure on the top side, supplied from a separate bottle, could balance the pressure generated by combustion in the engine cylinder. When the latter just overcame the former, the valve lifted — a rapid and almost imperceptible movement that broke the primary electrical circuit and allowed a high-tension induction coil to induce a high-tension voltage in the secondary coil. This was forced to jump an air-gap on its way to earth in the form of a spark, scorching a mark on the diagram paper. The pressure continued to rise to a peak, then fell to make another mark on the opposite side of the pressure curve. The air pressure was then increased, giving another pair of marks, and the process was continued until the entire diagram had been constructed. The unusually large diagrams (7½ inches tall; 14½ inches wide) were easy to read, assuming that the spark points could be clearly seen.

In the earliest design, each diagram was a composite of 125 revolutions obtained as the spark-point moved from one end of the drum to the other. The drum was driven from the engine by either a shaft or a short chain, by way of a special clutch. The spring cradle on the casing accepted two 'main tension springs', attached to special anchors or 'spring horns', and a pair of compression springs on the central strut. The outer springs could be replaced, depending on the pressure-range required, or detached to enable light spring diagrams to be obtained with the assistance of the central springs alone.

A preparatory *Preliminary Report on Electrical Indicator for High Speed Internal Combustion Engines* was submitted on 16th January 1920 and the first prototype was completed in the summer of 1921, to be put immediately to the test. Tried for six months with an experimental aeroplane engine, taking more than 1500 diagrams, it proved to be very successful; six examples of an improved design, with the batteries, high-tension coil and distribution box built into the indicator body (or 'casing') followed in 1922. An application for a British Patent was made in April 1922 on behalf of Harry Wood of the RAE and Jessie Norman, widow and 'legal representative' of Geoffrey Norman; it was accepted in July 1923 as British Patent no. 200595. Later, in January 1924, Wood submitted an improved contact-breaker design. This was patented in April 1925.

The experimental indicators were initially confined to bench testing. On 3rd February 1923, however, one was successfully installed in the rear cockpit of a two-seater a DH 9 biplane and used to test the 400hp twelve-cylinder Napier Lion engine at altitudes of 500, 5000 and 10000 feet. This enabled the major goal of the project to be achieved: the investigation of engine performance, particularly at high altitude.





ABOVE
Left: the first successful in-flight test of the 'RAE' or Farnboro indicator was made on 3rd February 1923. This picture shows the instrument (one of the six improved examples made in the Royal Aircraft Establishment) installed in the rear cockpit of a DH 9 biplane. *Right:* the original Dobbie McInnes-type Farnboro, from the handbook published *c*. 1925.

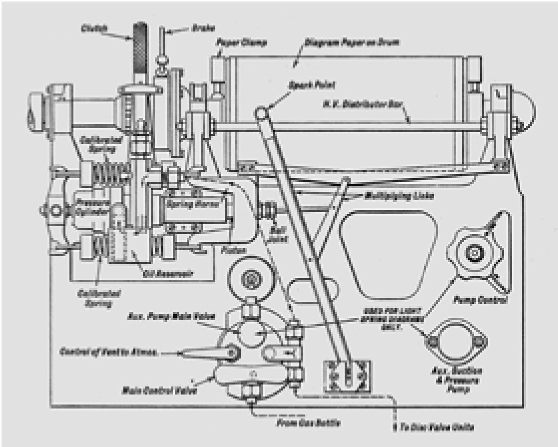
Series production of the RAE Indicator was licensed to Dobbie McInnes & Clyde Ltd of Glasgow, and work on what was known commercially as the 'Farnboro' (after the site of the Royal Aircraft Establishment) began almost as soon as the first patent had been granted. A review by A.W. Judge appeared in *The Automobile Engineer* in January 1925 and the first handbook seems to date from the same period: one of the illustrations inside the back cover shows the improved paper-winding system patented by Walter Clyde and Dobbie McInnes & Clyde Ltd in August 1923.

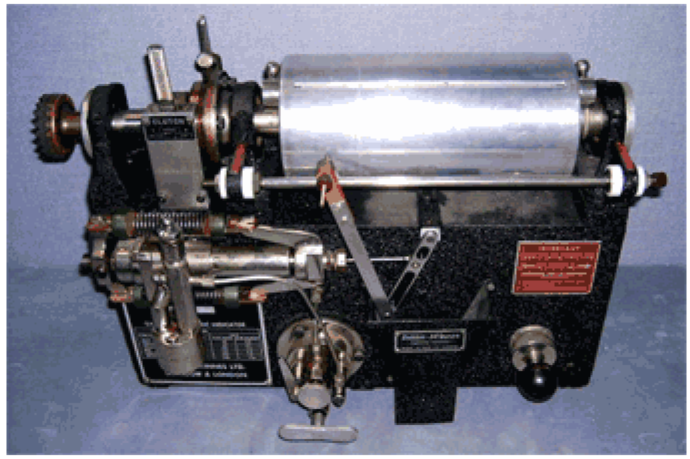
The earliest manual reveals that the indicator was supplied in a partitioned wooden case, accompanied by four pairs of tension springs, a pair of light compression springs fitted in position, three two-volt accumulators to be connected in series provide six-volt electrical power, a disc-valve unit with an 18mm thread, and a hundred black diagram sheets. The box was 24 inches long, 16½ inches high and about 11 inches wide. Tension springs were identified either by colour or, in written material, by individual letters: blue ('B') for 1in of diagram height per 40lb/sq.in., a maximum pressure of 300lb/sq.in; white ('W') for 1:80 or 600lb/sq.in.; yellow ('Y') for 1:100 or 750lb/sq.in; and red ('R') for 1:150 or 1125lb/sq.in. The compression springs were suitable for pressures ranging from 12lb/sq.in. below to 30lb/sq.in. above atmospheric pressure.

The Farnboro indicator was an instant success, but there were those who questioned its accuracy. The most damning report was made in the USA by John H. Collins of the Langley Memorial Aeronautical Laboratory: *Alterations and Tests of the "Farnboro" Engine Indicator* (Technical Notes, National Advisory Committee for Aeronautics, no. 348) subjected the standards of manufacture and the disc valve to trenchant criticism, as '…modifications were made to the instrument to improve its operation. The original design of disk valve was altered so as to reduce the mass, travel and seat area. Changes were made in the recording mechanism, which included a new method of locating the top center position on the record. The effect of friction on the motion of the pointer…was eliminated by providing a means of putting pressure lines on the record…'

There is little doubt that the modified NACA Farnboro performed better than the Dobbie McInnes & Clyde instrument in static testing; the new valve weighed only about a fifth, had a seat-width about one-seventh and a vertical travel of about one third of the original dimensions. This made it much more responsive, though it must be questioned whether the theoretical superiority claimed by Kalman DeJuhasz in the 1930s (1:156 in favour of the NACA pattern) has much validity.

Many experimenters subsequently used Farnboro indicators, though changes were sometimes made to suit specific requirements: Harry Ricardo used one in 1929–30 to investigate fuel-line pressures, and W.J.R. Roach & J.G.G. Hempson (Ricardo employees) used another in 1951–2 to investigate the performance of large marine diesel engines. Though Dobbie McInnes capitalised on Roach & Hempson's research, published in the British Shipbuilding Research Association Report no. 92 and also in *The Engineer*, the authors had been critical: "With the original valve, trouble was experienced due to gas leakage, over-heating, contact-face corrosion and internal fouling…' A new balancing unit had been developed to overcome the perceived problems, with a large flexible diaphragm. This was subsequently made commercially by Dobbie McInnes as the 'Pick-Up Type P' (for normal pressure ranges) and the 'Pick-Up Type L' (low pressure), replacing the original disc-valve system.





ABOVE
Left: a drawing of the Farnboro indicator from the Roach & Hempson report, 1952. *Right:* a standard Farnboro indicator of the type being made by Dobbie McInnes in the late 1950s. This example, no. GM 764, lacks the detachable Pick-Up unit.

Another type of drum-type balanced diaphragm spark-trace indicator was promoted in the early 1930s by Massachusetts Institute of Technology, relying on two circuits (one for the rise and one for the subsequent drop in pressure) and sparks generated in the secondary winding of the spark coil to mark the card. This was designed to minimise the tendency of the Farnboro indicator to miss points when the valve opened too slowly to cope with high pressures of increasingly shorter duration.

Spark-trace indicators were something of an evolutionary dead-end, as they suffered from several practical drawbacks — e.g., the leakage of air into the engine side of the valve or conversely, of combustion products into the air-pressure side. Consequently, the balanced-valve indicator developed in the early 1930s by Brandt, Viehmann and Urbach for the Deutsche Versuchsanstalt fur Luftfahrt (DVL) relied on a trace that was recorded photographically.

The rise of non-autographic systems based on cathode-ray tubes made the spark systems obsolescent, though the British Railways Board was still using the Farnboro in the 1960s and new instruments were being offered by EMPI Ltd, successors to Dobbie McInnes Ltd, as late as April 1972. By this time, a wide variety of accessories and two additional types of tension spring had been introduced: the springs were coloured green for 1:200 or a maximum pressure of 1500lb/sq.in., and orange for 1:250 and 1875lb/sq.in.

Peak-pressure type

These are included largely because they are easily confused with the true autographic indicators. Most of them do, however, provide a record in the form of a pressure-reading taken from engraved scales.

The conventional autographic indicator was, by the standards of its day, a highly sophisticated tool. It was also expensive. Among its greatest advantages was an ability to record the changes of pressure within a pressure-vessel (e.g., an engine cylinder) throughout an entire stroke. However, indicators were not particularly easy to install and operate; and the problems increased when the numbers of cylinders began to multiply.

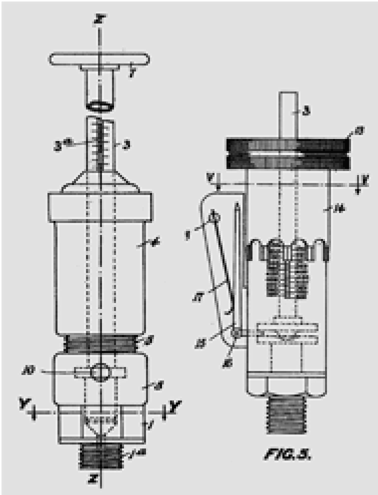
Most steam engines with three or more cylinders were large and costly, and comparatively little additional expense was incurred in the provision not merely of three springs, but three separate indicators. The situation changed with the rise in enthusiasm for internal-combustion engines in the decade prior to the First World War, when comparatively small engines with four, six or eight cylinders appeared. Among the most important goals of the design of internal-combustion engines was consistent performance, particularly when several cylinders were operating continuously and near-simultaneously.

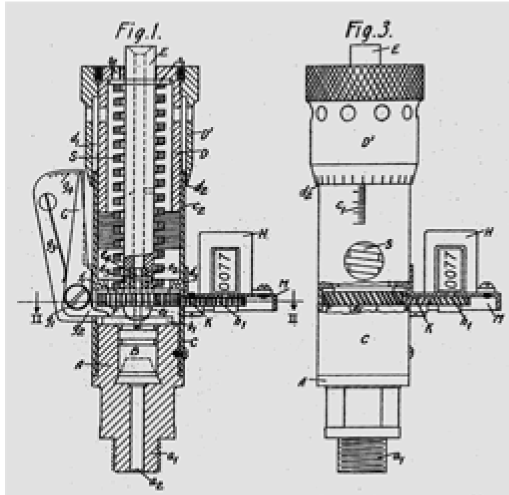
Analysing the performance of these with a conventional autographic indicator, preferable though it may have been under laboratory conditions, was often extremely difficult under normal circumstances. An easier way of checking performance was to ensure that each cylinder was achieving the same level of compression and the same amount of power when the compressed charge was ignited. The maximum-pressure indicator was developed specifically to ease the task of ensuring consistent ignition in multiple-cylinder engines.

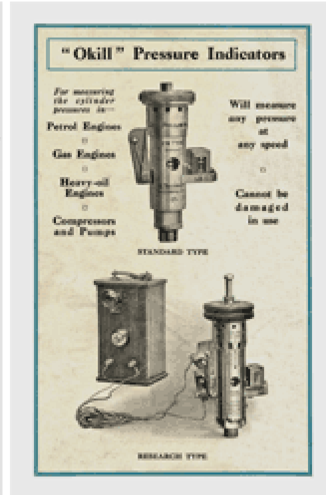
A few of the earliest continuous-recording steam engine indicators recorded maximum pressures only, but were out of step with the comprehensive pressure/time traces provided by the Watt, McNaught and Richards instruments. An alternative approach was shown by the simple and sturdy instruments that could show the maximum pressures generated in the cylinder during the firing process. It is assumed that they were inspired by the work of the Belgian engineer Rodolphe Mathot, but the earliest patents that could be traced were filed in Switzerland in September 1905 and in France in October 1905 by Albert Peloux '('résidant in Suisse'). French Patent 358422 shows a variety of methods of showing the pressure, including rapid-pitch screws raising pointers against scales and graduated rods protruding through collars. There is no evidence that the Peloux peak-pressure indicator was made in quantity, and the Okill type, described below, probably takes this particular laurel. However, it was cited by many subsequent patentees and it is likely that the influential Swiss Züblin design of the late 1940s was a direct descendant.

The first to offer a true peak-pressure indicator was an Englishman, John Okill (1875–1947), who received an appropriate British patent in 1907. The drawings accompanying the written specification showed several ways of achieving a balance between pressure in the cylinder, acting upward through a valve against a constrained piston, and that of a sturdy spiral spring. A finger-wheel allowed the pressure of the spring to be altered until a balance point was found, when the piston stopped vibrating. This could be seen either through a sight hole cut in the instrument body or by a vibrating pointer attached to the body side. The pressure could be read off scales engraved on the outside of the body. Not surprisingly, the pointer was much more convenient to use; if any of the 'sight hole' indicators were made, none is known to survive.

Whether many Okill indicators pre-dated the First World War is open to question. In June 1920, John Okill obtained a British Patent to protect an improved form of the vibrating-pointer indicator with a counter, driven by a gear train, which showed the pressure setting numerically (a comparable grant in the U.S.A. was delayed until September 1923). This was a considerable step forward, and surviving examples of what was advertised as the 'New Type Standard' invariably embody the counter system.





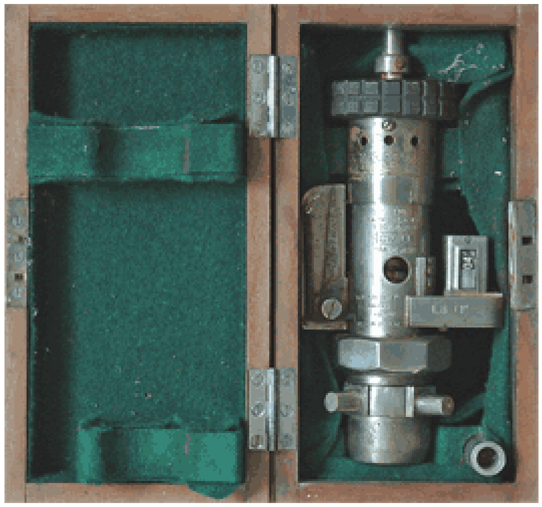


ABOVE
The Okill maximum-pressure indicators of 1907 (left) and 1920 (centre), and a page of a 1920s leaflet extolling the virtues of the 'Standard' and 'Research' patterns. Note the separate bulb-box that accompanied the latter.

Okill indicators were all made by George Taylor (Brass Founders) Ltd of All Saints' Street Works, Bolton, Lancashire, England. The range originally consisted of the ND1, ND2 and ND4 patterns — identified by their serial-number prefixes and respectively calibrated for maximum pressures of 1000, 2000 and 4000 lb/sq.in. — but had soon been extended to include the NP, NKD1 and NKD2 types. The NP was a low-pressure indicator, rated to only 400lb/sq.in; the others were metric-system instruments were calibrated for 70- and 140kg/sq.cm.

Another patent was granted in 1929, to John Okill and John Tate, protecting a variation of the basic Okill indicator developed for laboratory use. This relied on a variation of the 1920 system to activate a small bulb, contained in a separate box with its associated switchgear, each time the pointer moved. When the bulb ceased to illuminate, the pointer was static and the pressure could be read from a combination of circumferential rings engraved on the body and inclined rings on the spring cap. The production version of the 'New Type Research' instrument differed from the patent drawings, as the ball-tipped lubricating plunger was co-axial with the spring instead of protruding angularly from the lower body, and the recording graduations reverted to one of the forms that had been patented in 1907: circumferential rings engraved on the body and eight arrowhead flanges projecting downward from the spring cap.

Okill and Tate then developed adapted the 1920-type indicator to handle extremely high pressures without the use of an excessively stiff spring. This instrument was horizontal instead of vertical. A right-angle connection between the engine cylinder and a chamber in what the designers called the 'cylinder block' allowed pressure to be registered. Two rods entering the chamber in diametrical opposition were anchored to two crossbars which, linked with bars along each side of the cylinder block, were allowed to slide longitudinally. If their diameters were equal, the opposed rods would be 'in balance': no matter now high the pressure rose in the chamber, no movement would be detected. But by making the rod connected with the spring assembly larger than its counterpart, the pressure balance was disturbed and the larger rod would move back — but only proportionately to the true pressure, the precise relationship being controlled by the rod-diameter differential. A vibrating pointer lay on top of the instrument, anchored in a fork-like collar connecting the spring chamber and the cylinder block. High-pressure indicators of this type were offered commercially as the 'SP' ('Super-Pressure'), readily distinguishable by their unique construction. They were intended to be used with 'airless' injection engines, where the pressures could not only rise as high as 10,000lb/sq.in but also give what was effectively a hammer blow to the indicator piston.



ABOVE
Left: a page from a leaflet promoting the Okill SP or 'Super Pressure' indicator, made in accordance with a patent granted in Britain in 1931. *Right:* a typical 1936-type 'ND2' indicator, capable of handling pressures as high as 2000lb/sq.in. This particular example was probably made after the end of the Second World War. *Museum of Making collection.*

The 1936-type Okill & Tate peak-pressure indicator was an improvement of the 1920 patent, with a free-floating piston and a pressure block which could move axially without twisting the spring. Alternative methods of registering pressure were proposed, but the production version, which usually acknowledged the U.S. Patent granted in September 1938 instead of the earlier British equivalent, retained the gear-driven counter. This instrument replaced the 1920 type in production; it was certainly made in ND1, ND2, NKD1 and NKD2 versions, though ND4 seems to have been superseded by the SP.

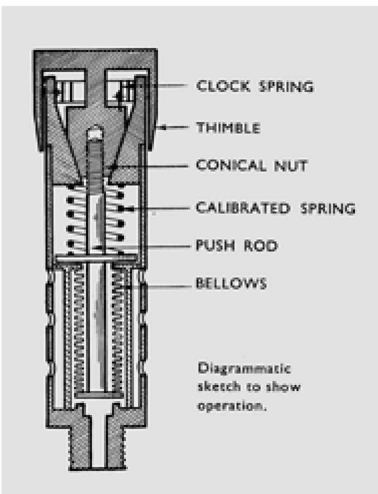
Others soon followed where Okill had led, though rarely with commercial success. One of the first was John Pearson, whose British Patent of August 1922 protected a simple indicator consisting of a spring-loaded plunger skidding vertically within its casing. The pressure was measured by the maximum height of the plunger-tip above the casing (where a sliding finger was held by a spring) or by a line engraved helically on the spring-cap.

The 'Acrometre', patented in France by Mazellier & Carpentier, relied on a thin disc-like valve to allow combustion gases to pass until the pressures on each side of the disk were equal. The level at which this occurred could then be read on a conventional Bourdon-type gauge. This particular system was unsuccessful; the disc valve was prone to damage and, owing to the dimensions of its seat, was also improperly balanced. An alternative approach was taken by the German inventor Robert Bosch, who set an indicator into the fuel line of the injection system. This could be adjusted against a pre-calibrated spring (by way of a micrometer thimble) until the valve began to leak.

None of these, however, were as simple, sturdy or reliable as the Okills, which remained supreme in Britain until a peak-pressure indicator was developed shortly after the end of the Second World War by

Gebr. Sulzer AG of Winterthur, Switzerland. Application for the relevant Swiss patent was made in October 1948, though the grant was delayed until the summer of 1950. U.S. Patent 2673464 (sought in August 1949 but not granted until March 1954) names the inventor as Marcel Wilhelm Züblin of 'Dumbarton, Scotland, Assignor to Sulzer Frères S.A., WInterthur'.

The specifications described and illustrated several ways that screws and springs could be used to rotate a cap against a graduated scale in response to rises in pressure. The commercially-successful version embodied expansible bellows attached to a push rod, which was in turn anchored in a conical nut. Operation was simple: when pressure was applied to the bellows, through the valve communicating with the pressure-generating vessel (usually an engine cylinder), the bellows expanded to force the push rod up against the counter-pressure of a calibrated co-axial coil spring. A conical nut was raised from its seat, but a clock-spring anchored in the cap instantly rotated the nut back again. The amount of rotation was directly proportional to the pressure being generated in the bellows, and an appropriate reading could be taken directly from a graduated thimble or cap.



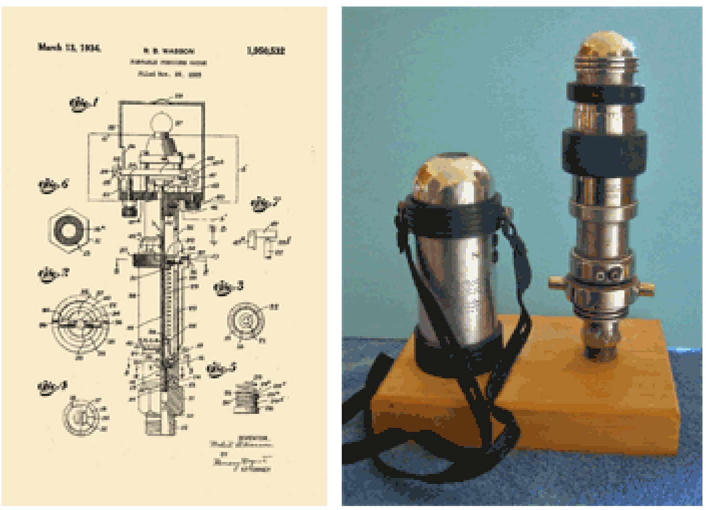
ABOVE
Left: a vertical-section drawing of the Dobbie McInnes version of the Sulzer peak-pressure indicator, showing the bellows and the conical nut. *Right:* the front of the Dobbie McInnes leaflet, probably dating from the early 1960s, clearly shows the construction of the standard indicator. Note the vulcanite casing and the graduated thimble.

Production of the Sulzer indicator was licensed to Haenni Präzisions-Maschinenfabrik AG (now Baumer Bourdon-Haenni AG) of Jegensdorf, Switzerland, and Dobbie McInnes Ltd of Glasgow. It was the first of its type to successfully challenge the supremacy of the Okill design, largely by offering automatic operation. All that was required of the operator was to re-set the instrument prior to each measurement and note the final reading. The British-made instruments were offered as the 'Air Cooled Cylinder Pressure Type' used with a standard indicator cock (usually calibrated for 200–1400lb/sq.in or 15–100kg/sq.cm), with ventilation holes in its fluted vulcanite body; the steel-bodied 'Water Cooled Cylinder Pressure Type', attached directly to the engine cylinder; and an 'Oil Fuel Pressure Type', designed to be inserted in fuel lines, which could handle pressures as high as 10,000lb/sq.in.

Many attempts were made in the U.S.A. in 1910-25 to develop indicators suited to internal-combustion engines, including, for example, the 'Gas-Engine Recorder' patented in November 1915 by Horace

Morrow of Willston, Ohio. The subject of U.S. Patent 1161875, this relied on a trace drawn on a circular tablet controlled by a spring and ratchet. The mechanism advanced one click for every cycle.

The introduction of Okill instruments into North America persuaded Robert Wasson of Cranford, New Jersey, to develop a peak-pressure indicator that he claimed to be simpler, more accurate and more easily understood than its English antecedent. Protected by U.S. Patent 1950532 of 13th March 1934 (sought as early as November 1925), the Wasson design used a graduated sleeve and an electric lamp to show the point at which pressure of the spring balanced that in the cylinder. Whether the Wasson indicator was ever exploited commercially is currently unknown, but it undoubtedly influenced the patent granted in July 1936 to Rudolf Ulrich of Pittsburgh, Pennsylvania (U.S. no. 2046801). This protected another modification of the Okill principle, but incorporating a lifter attached to the piston to activate a tension spring controlled by an indexing sleeve.



ABOVE
Left: drawings taken from the U.S. Patent granted to Robert Wasson in 1934. Note the light-bulb inside the top casing.*Right:* Bacharach-made Premax indicator no. 2650, shown with its flash-lamp unit to the left. *Courtesy of the U.S. Government Patent Office, Washington DC, and Bruce Babcock, Amanda, Ohio.*

A combination of the Wasson and Ulrich patents was subsequently made by the Bacharach Industrial Instrument Company as the 'Premax'. Its operation was described in *Use of the Indicator for Diesel Engine Maintenance*, published by Bacharach, which stated that it was '…composed essentially of a piston exposed to the engine pressure, the helical tension spring against which the piston force acts, index sleeve, which is used to adjust the tension of the spring, and the contact of the neon circuit which gives a visual method of checking piston motion… By inspection [of a diagram] it is seen that a force upon the piston is transmitted to the spring through a pusher tube. The opposite end of the spring is connected to a micrometer sleeve so that in rotating this sleeve downward, the spring will be deflected, eventually giving a force which balances the upward thrust of the piston. A direct pressure reading can then be taken from the micrometer scales… A visual means is supplied for determining the equilibrium point and thus the compression or firing pressure. As the piston moves up due to the gas pressure, the switch closes and the neon light flashes. The circuit is broken when the cylinder pressure drops during expansion. A continuous flashing of the neon light occurs until the sleeve is rotated to stop the piston motion. When the exact point of balance between the two forces is reached, the switch will remain open [the flashing ceases] and the cylinder pressure is then read from the micrometer.'

Bacharach was also the assignee of a U.S. Patent, no. 2610508, sought in October 1946 and granted in September 1952 to Joseph Stein and John Wagner. This combined the tension-spring and indexing-collar system with a digital counter.

Accessories

Indicators were customarily accompanied by a variety of accessories. Advertising literature published in 1917, for example, shows that each Crosby instrument came in a lockable velvet-lined walnut case with a compartmented lid. In addition to the indicator, the case contained one spring and a small scale-ruler, one straight steam cock, fifty diagram cards, a hank of indicator cord, a spring bracket, a cord adjuster, one small oil bottle, a turn-screw, a hollow wrench, and an instruction booklet.

Dobbie McInnes indicators of the same vintage were usually supplied in mahogany boxes with a hinged platform and a compartment in the lid. In addition to an indicator cord, each box also contained a cylinder cock, a spare recording drum spring, a hexagon spanner, a turn-screw, an oil bottle, a set square, a detent-cord adjuster, a small sheet-metal tube containing spare pencil leads, a cord-adjusting plate, a radial dividing board, and a cylinder cleaning rod. Some cases will also be found with a short tubular wrench.

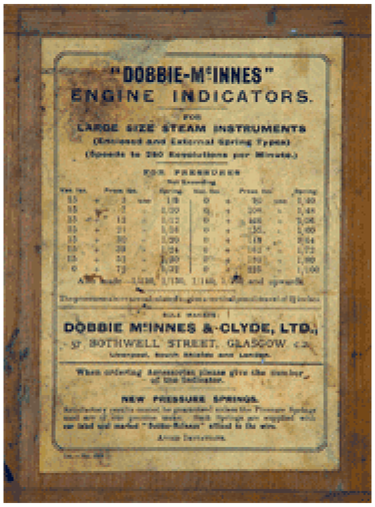
LEFT
A selection of accessories accompanying a German-made Dreyer, Rosenkranz & Droop external-spring indicator dating from *c.* 1907. They include two steam cocks, springs, rulers, pencil leads, an oiler and a selection of tools. *Museum of Making collection.*

Additional springs or scales could be purchased separately, as the supply of indicator springs varied according to individual requirements. Some cases had provision for as many as twelve springs, but the absence of springs from a case does not necessarily mean that they were always there: indicators that were purchased specifically for use with a solitary single-cylinder engine (or for one particular cylinder of a triple-expansion engine) may only have had one spring! Indicators accompanied by a wide range of springs were often used by consulting engineers or by representatives of insurance socie-ties.

The springs

A catalogue published by the Crosby Steam Gage & Valve Company in 1915 recorded the range of indicator springs as 4, 8, 12, 16, 20, 24, 30, 40, 50, 60, 80, 100, 120, 150, 180, 200, 250 and 300lb 'to the inch', which referred to the amount of pressure required to move the indicator pointer by the specified amount. The metric sizes were rated at 2, 2·5, 3, 4, 5, 6, 7, 8, 10, 12, 15, 16, 18, 20, 30, 45 and 60, but these figures referred to the height in millimetres the pointer moved for each additional 1kg/cm² of pressure. The classification of the metric springs was the opposite of the imperial patterns, as the '2mm' version was thirty times stronger than the '60mm' type.

Trial and error showed that hot springs performed differently to those that were tested cold, but most manufacturers were aware of the problem and calibrated accordingly. Though there were undoubtedly errors from spring to spring, and also from indicator to indicator, the system was efficient enough to provide acceptable results.



LEFT
Instructions pasted into the lid of the box of a 1893-vintage McInnes indicator, showing the range of springs that could be obtained. The trading style 'Dobbie McInnes & Clyde, Ltd.' dates from 1921-37, though other evidence suggests that the label was printed in June 1928.

Reducing gear

The comparatively small size of the recording drum on even the largest indicator faced the analytical engineer with a major problem. The stroke of even the smallest engine was considerably greater than the 4.5-5 inches that represented the limits of diagram length, and the stroke of a beam engine or a large horizontal mill engine could exceed ten feet. The engine-testing handbooks illustrate many ways of reducing the motion of the crosshead to suit the indicator, with the assistance of rods, bars, pulleys, pantographs or lazy tongs.

LEFT
A typical adjustable pantograph, a means of reducing the long stroke of an engine to the comparatively small rotative movement of the indicator drum. Most pantographs were wooden, though metal examples are known.*Courtesy of Bruce Babcock, Amanda, Ohio, USA.*

There were a few champions of systems that involved rods and gearing, avoiding the stretching of cord or even braided wire, but these methods failed to prosper. Excepting the pantographs and the lazy tongs, which could be purchased commercially, most of the rod and bar systems were the extemporisations of individual engineers. This was actively championed by many of the textbooks, as it permitted the quirks of individual engines to be accommodated. In addition, many of the solutions were simple and accurate.

Another solution, more popular in Europe and the USA than in Britain, was the reducing wheel. This usually consisted of a large-diameter wheel, connected by cord or wire to the crosshead, which shared a common axis with a much smaller wheel that accepted the indicator-drum cord. The wheels were made of aluminium, to keep their weight (and inertia) as low as possible, and could be adapted to a variety of different strokes simply by substituting pulleys. It was not unusual for reducing wheels to come with two crosshead wheels and eight carefully-graduated pulleys. The only other system that could compete was the adjustable pantograph.

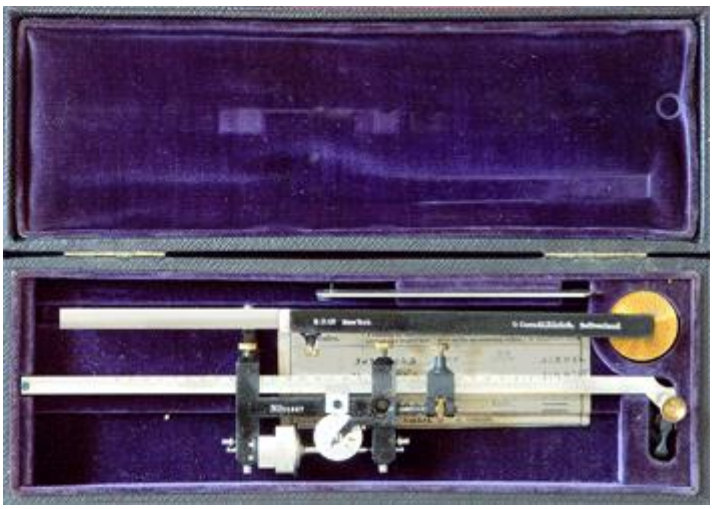
ABOVE
Left: made in surprisingly large numbers in the USA in the 1890s, the 'Straightline' indicator is occasionally found with reducing gear. This particular design relies on pulleys and gearing to scale-down the motion of the piston until it is appropriate for the size of the recording drum. *Right:* a Trill external-spring indicator with continuously-operable reducing gear. This example may date as late as 1936. *By courtesy of Bruce Babcock, Amanda, Ohio, USA.*

Diagram-analysing aids

The traces provided a surprising amount of information, among the most useful being the 'atmospheric line' drawn simply by allowing the drum to revolve without allowing steam to reach the indicator piston. Each spring was marked with a 'scale' that, in imperial-measure terms, signified the weight required to compress the spring by one inch. A '24' spring, therefore, required a weight of 24lb to compress it by an inch; each inch of diagram-height, therefore, equalled a steam pressure of 24lb. Once the horizontal lines of pressure had been deduced, the 'mean pressure' of the cylinder could also be obtained in any of several ways. The simplest was to divide the diagram into narrow vertical sec-tions, total the heights of the sections, and then divide the result by the number of sections. This gave a good approximation, and was helped by the manufacturers who provided grids to facilitate an accurate division into sections.

Another way, potentially more accurate and often quicker, was to use a polar planimeter. Invented in the 1850s by a Swiss mathematician, Jacob Amsler, these instruments automatically calculated the area of an enclosed figure with the aid of graduated wheels and verniers. Their popularity as mathematical instruments ensured that huge quantities were made. Many engine-indicator manufacturers, such as Crosby and Dobbie McInnes, offered 'own brand' planimeters; however, these were customarily purchased from specialist manufacturers in Europe or (subsequently) the USA.

The simplest forms of these instruments, set for a single pre-determined value (e.g., 10 square inches) have integrating wheels divided into units and tenths, relying on a vernier scale on the carriage or trace arm to give an accurate reading. A more sophisticated version, sharing the same basic construction, had an additional counter-wheel driven by a worm gear on the integrating wheel shaft. The best polar planimeters had additional features. The integrating wheel, worm, counting-wheel and vernier may be carried on a carriage that can be slid along the trace bar, allowing the instrument to be set to different base units.



ABOVE
A Swiss-made Coradi polar planimeter. Dated '14th October 1910', it was sold in the USA by the Eugene Dietzgen Company (the mark 'E.D. Co.' lies on top of the pole arm). *Museum of Making collection.*

The manufacture of planimeters has been restricted to specialist instrument-makers such as Amsler and Coradi in Switzerland; Keuffel & Esser, Ott and others in Germany; the Los Angeles Scientific Instrument Company ('Lasico') and Keuffel & Esser (originally a subsidiary of the German company) in the USA; W.F. Stanley in Britain ('Allbrit'); and a variety of businesses in Japan. However, individual planimeters may occasionally be found with the markings of distributors. These can include a few of the indicator makers, such as Elliott Brothers of London, but usually prove to be drawing- or mathematical-equipment suppliers.

In addition to conventional Amsler-type polar planimeters, there have been several idiosyncratic designs. In the USA, for example, J.L. Robertson & Sons of New York offered Lippincott and Willis planimeters, and the Trill Indicator Company, successor to Robertson, was still offering improved Willis-type planimeters in 1916. These differ greatly from the Amsler type in construction, though the underlying theory of operation was identical.

ABOVE
A typical Willis 1901-type or 'Improved' planimeter, showing the integrating wheel and the rotatable boxwood scale.*Author's collection.*

An alternative method of assessing the indicator diagram was provided by the 'Averageometer', patented in the USA in 1882 by John Coffin, made by the Thompson & Bushnell Company of New York City and favoured by (amongst others) Ashcroft, maker of Tabor-type indicators. This was a form of linear planimeter combined with a board-like base with a metal channel set into the left edge and a clamp sliding in another channel placed horizontally across the centre. To use an Averageometer, the diagram was attached to the board with its vertical edges against the fixed clamp on the left and the adjustable clamp to the right. The point of the trace arm was then taken around the diagram in the usual way, allowing the integrating wheel to record movement. Most Averagers had wheels with a circumference of 2.5in and a six-inch trace arm, giving a total of 15 sq.in for one turn of the integrating wheel.

More information

We had intended to amplify the website material in a conventional book, but the size and complexity of the project—not to mention the hundreds of high quality illustrations—have raised costs to a point where, for the moment at least, they are uneconomic. Fortunately, thanks to the generosity of the Canadian Museum of Making sponsorship in 2006–9, we can give free access to each of the chapters (as completed!) as 'work in progress', with the intention of publishing the story in three parts. The current draft of the first part can be viewed by clicking the 'Publications' button (left) and following the link.

Marks found on indicators

American Steam Gauge Company, Chardon Street, Boston, Massachusetts, USA (with a 'New York Branch' in Dey Street, New York City, and a 'Western Branch' in North Canal Street, Chicago). Made Richards indicators, then Thompson and 'American Thompson' designs, internal- and external-spring, from the early/mid 1870s apparently until taken over by Schaeffer & Budenberg during the First World War.

Ashcroft Manufacturing Company, New York City, and Bridgeport, Connecticut, USA. Made internal- and external-spring Tabor indicators from about 1880 to the First World War.

LEFT
A typical advertisement published in *Cassier's Magazine* by the American Steam Gauge Company. This, which dates from 1903, helpfully records than more than five thousand indicators of this type had by then been made — a great help when it comes to dating individual examples.

Bacharach Industrial Instrument Company, Pittsburgh, Pennsylvania, USA. Originally imported Maihak indicators prior to 1939 (?), but then began production in the USA. Work continued until the 1950s.

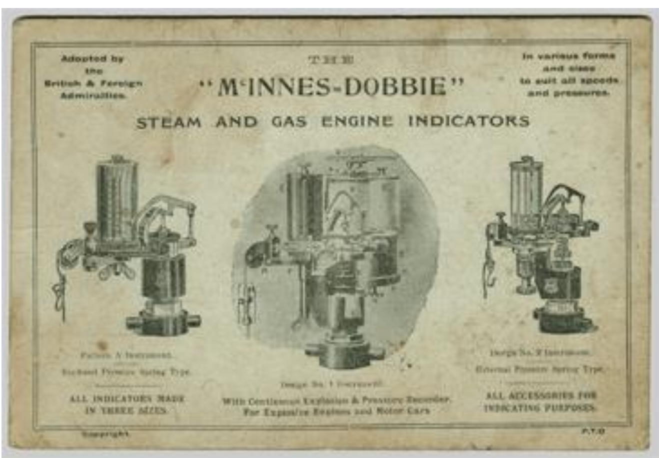
Sir W.H. Bailey & Co. Ltd, Salford and Patricroft, Manchester, England. Reportedly found on a Richards-type indicator made by Casartelli.

Buckeye Engine Company, Salem, Ohio, USA. Made the original Thompson-type indicators, but only for a few years.

J. Casartelli & Sons Ltd, Manchester, England. Made Richards, 'Improved Richards' and own-brand indicators from the 1870s until 1914 or later.

A. Clair, Saint-Étienne (?), France. Made Guinotte and other indicators.
Corry Instrument Company, Corry, Pennsylvania, USA. Made (or perhaps simply assembled) a few Trill indicators, 1945-7.
Crosby Steam Gage & Valve Company, Boston, New York, Chicago and London. Made internal-spring and external-spring Crosby indicators until the 1930s.

Marcel Deprez, Paris (?), France. Probably made by Garnier or Lefebvre.
Dreyer, Rosenkranz & Droop, Hannover, Germany. Made a few Richards and then many Thompson-type indicators, including an exposed-spring design patented in 1902. Continued production independently until c. 1937.
Dobbie McInnes Ltd, Glasgow, Scotland. Made McInnes, McInnes-Dobbie and Dobbie McInnes indicators from 1903 until 1921, and then again from 1937 until the late 1950s.
Dobbie McInnes & Clyde Ltd, Glasgow, Scotland. A trading style found on McInnes-Dobbie and Dobbie McInnes indicators only from 1921 until 1937, when a reversion was made to the orignal name.
A. Duvergier, Lyon, France. Made McNaught-type indicators in the 1860s, often fitted with continuous-recording drums.



LEFT
a typical example of the ephemera produced by Dobbie Mcinnes and Dobbie McInnes & Clyde Ltd. This particular example, which dates prior to the First World War, includes the rarely-seen Mathot continuous indicator used with internal-combustion engines.

Elliott Brothers (Ltd), London, England. Made Richards, Richards-Darke, Darke, Wayne and SImplex indicators from 1863 until the First World War.
Engineering Appliance Company, Jamestown, New York, USA. Made Excelsior and Howard-Thompson indicators from the early 1890s until 1902.
Engineering & Power Company, Jamestown, New York, USA. Superseded the Engineering Applicance Company in 1902, but was then purchased by Trill in 1910.

Paul Garnier, Paris, France. Two generations of clockmakers made McNaught-type, Martin and Deprez indicators from the 1860s until c.1900
Globe Engineering Co. Ltd [The], Manchester, England. Promoted Ashcroft-made Tabor indicators in the early 1890s.

Hall Brown, Buttery & Company, Glasgow, Scotland. Made distinctive Thompson-type indicators from c. 1895 until 1901.
John Hannan, Glasgow. The predecessor of Hannan & Buchanan, active from the 1850s. Made McNaught indicators, apparently for McNaught himself.
Hannan & Buchanan, Glasgow, Scotland. Made Richards, McKinnell & Buchanan and Thompson-

type indicators from 1869 until the First World War.
Hine & Robertson, New York. Made Thompson-type indicators from the 1880s until 31st December 1896, when the trading name changed to James L. Robertson & Sons.
Hodgson Hartley Ltd, Manchester, England. Found on Ashcroft-made Tabor indicators sold in the 1900-14 period.
Joseph Hopkinson, Huddersfield, Yorkshire, England. Made co-axial and parallel-axis non-amplifying indicators from c. 1854 until 1877.

Kraft & Sohn, Vienna, Austria(-Hungary). Made Richards and Thompson-type indicators from the 1870s until 1900 or later.

Victor Lefebvre, Paris (?), France. Made Thompson-type indicators from the early 1880s until 1895 or later.
Lehmann & Michels, Altona bei Hamburg and Hamburg, Germany. Made Crosby-type external-spring indicators from 1919 (possibly earlier) until the end of the Second World War. Very similar to some of the Maihak products, which were originally protected by the same 1906 patent. Lehmann & Michels indicators are still being made in modernised forms.
Leutert GmbH, Germany. Makers of Maihak-style external-spring and torsion-bar indicators since 1985.
W.G. Little & Company, Bexley, Kent, England. Made patented integrating indicators, apparently using Crosby components.
Lippincott Steam & Specialty Company, New York. Made surprisingly large quantities of Lippincott indicators and planimeters, etc, from the 1890s until, perhaps, as late as 1914.

R. McAughtry & Son, Glasgow, Scotland. Sole Britain and British Empire distributor for German-made Maihak instruments, 1921-52. Succeeded by 'Smail Sons & Co.', below.
T.S. McInnes, Glasgow, Scotland. Makers of McInnes-patent internal-spring indicators from c. 1887 until Dobbie McInnes was formed in 1903. Became '& Co.' in 1889 and '& Co. Ltd' in 1894.
McInnes & Cairns, Glasgow, Scotland, and Liverpool, England. A ships chandlery that sold, among other things, McInnes-made indicators.
Maihak GmbH & Companie, Hamburg, Germany. Maker of Crosby-type external indicators from c. 1909 onward.
Metallwerker AG, Meerane in Sachsen, German Democratic Republic. Maker of Maihak-type indicators in the 1950s and 1960s.
John Musgrave & Sons Ltd, Bolton, Lancashire, England. Sold Ashcroft-made Tabor indicators in the 1890s.

LEFT
A label found in the lid of a box containing a Richards-type indicator, apparently incorporating improvements made by Thomas Struthers McInnes. The style '& Co. Ltd' suggests that the label (if not necessarily the indicator itself) dates from 1894 or later.

Negretti & Zambra, London, England.
Novelty Iron Works, New York City, USA. Made McNaught-type indicators in the 1850s, and also the prototype Richards indicator of 1862.

James L. Robertson & Sons, New York City, with 'Branch Offices in Boston, Philadelphia, St. Louis', USA. Succeeded Hine & Robertson on 1st January 1897, making New Century and Robertson-Thompson indicators, internal- and external-spring types, until 1910 or later.

Schaeffer & Budenberg, Brooklyn, New York City and Chicago. Imported German-made Thompson indicators (internal- and external-spring types) until the First World War began, then began to make 'American Thompson' instruments in the USA.
Schaeffer & Budenberg GmbH, Buckau bei Magdeburg (later Magdeburg-Buckau), Germany. Made Thompson-type indicators from the 1880s until the end of the First World War.
Schaeffer & Budenberg Ltd, Manchester, England. Marketed indicators made by the German parent company prior to 1914. Subsequently became the Budenburg Gauge Co. Ltd.
Ernest Scott & Co. Ltd, Newcastle upon Tyne, England. Said to have marked Richards-type indicators made by Casartelli.
Smail Sons & Company, Glasgow, Scotland. Distributed German-made Maihak instruments from 1952 onward. See 'McAughtry', above.
Star Brass Manufacturing Company, Boston, Massachusetts, USA, and London, England. Made internal- and external-spring indicators from the 1880s until the 1920s?
Isaac Storey & Sons, Cornbrook, Manchester, England. Made Kenyon's Pistonless Indicator in the 1880s.

Thompson & Bushnell Company, New York City, USA. Made the Bachelder indicators from c. 1888 until 1905 or later.
Trill Indicator Company, Corry, Pennsylvania, USA. Made Triumph and Trill indicators, internal- and external-spring types, from 1901 until the end of the Second World War.

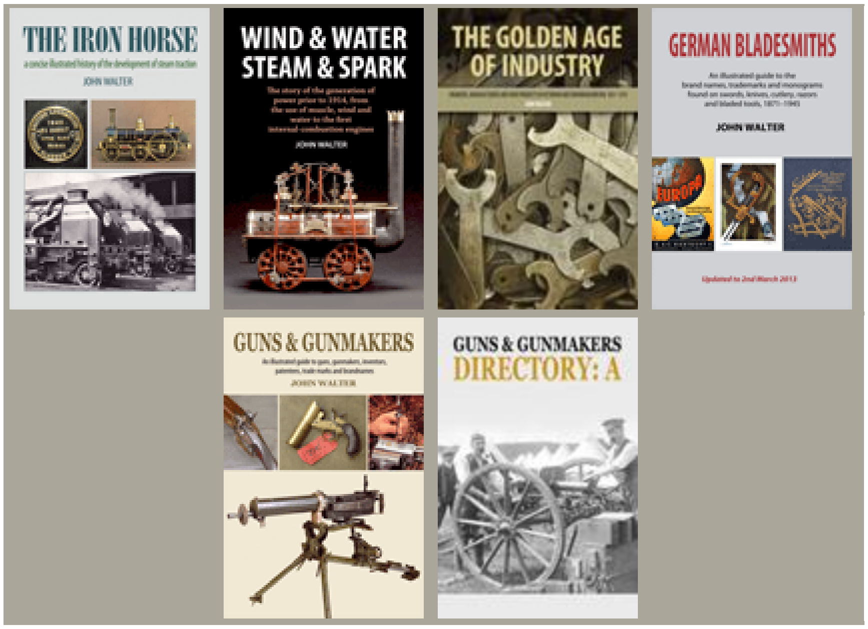
Whyte, Thomson & Company, Glasgow, Scotland. Formed in 1889, and made a few Thompson-type and 'own brand' indicators in the early twentieth century.

LEFT
The only Whyte, Thomson & Company indicator found to date, 'Model I' no. 305. Superficially similar to the 1887-patent McInnes design, it differs internally. Owing to the use of McInnes-type Vulcanite sheathing on the body, it is suspected that the instrument dates no earlier than 1901.*Museum of Making collection.*

PUBLICATIONS

This page collects together all the individual documents that were previously scattered among the different parts of the site. It is anticipated that the first four will be available as books from Nevill Publishing in the summer of 2013. Those that remain ‘work in progress’ will remain available in downloadable 'low res' pdf form.

When this page is completely interactive—it is still under construction!—clicking individual icons will show the status of each project


THE IRON HORSE
a concise illustrated history of the development of steam traction
JOHN WALTER
WIND & WATER STEAM & SPARK
The story of the generation of power prior to 1914, from the use of muscle, wind and water to the first internal-combustion engines
JOHN WALTER
THE GOLDEN AGE OF INDUSTRY
GERMAN BLADESMITHS
An illustrated guide to the brand names, trademarks and monograms found on swords, knives, cutlery, razors and bladed tools, 1871–1945
JOHN WALTER
EUROPA
Updated to 2nd March 2013
GUNS & GUNMAKERS
An illustrated guide to guns, gunmakers, inventors, patentees, trade marks and brandnames
JOHN WALTER
GUNS & GUNMAKERS
DIRECTORY: A