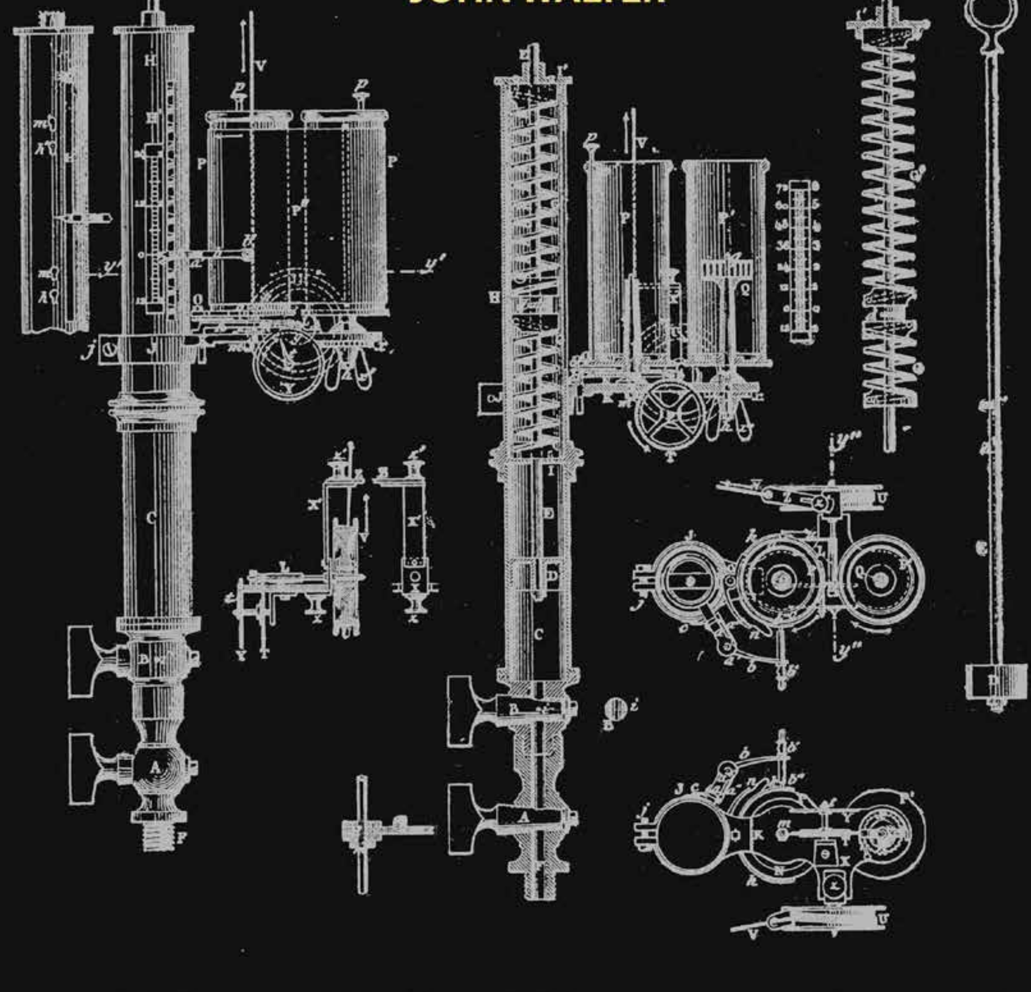
THE ENGINE INDICATOR

Autographic and associated designs from James Watt until the present day

IN THE BEGINNING: WATT & McNAUGHT

JOHN WALTER

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1. IN THE BEGINNING: WATT AND McNAUGHT

JOHN WALTER

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The series...

This multi-volume project began life as a simple guide to the indicator. I had become involved in 1993 with the British Engineerium in Hove, Sussex, England, where a small group of steam-engine indicators had been placed in a show-case with minimal explanation. My father had worked for Dobbie McInnes, the principal British manufacturer of indicators in the twentieth century, and so I had a vague idea of what they had been designed to do.

A search of the museum storerooms revealed more instruments, often in good condition, and so we decided to make a better display. I set out to provide a short overview and captions for the individual items, but this only succeeded in proving how little I knew. I then ransacked the museum library for additional information. There were many fascinating nineteenth-century 'steam engineering' textbooks, but these concentrated more on the utility of the indicator than on its history. Some gaps were filled with material drawn from the pages of *Engineering* (the museum library had a more-or-less complete set from 1868 to the 1960s), which included some superb engravings, but progress was slow. It was apparent that very few colleagues in the museum industry knew much about the history of the indicator, though one or two informative articles had been published in Germany and the U.S.A.

Gradually, I began to piece a story together. This was greatly helped by the enthusiasm of individual collectors, by other museums with indicators of their own, by obtaining patent specifications, and by drawing together manufacturers' and distributors' literature. What had once been a fog of information slowly cleared into a cogent narrative. There were many gaps where information had proved difficult (if not impossible) to obtain; and many hunches were shown to be mistaken. Yet progress was made. This was helped greatly by the interest shown by the Engineerium, in particular by its founder Jonathan Minns (1938–2013), and then by Ian McGregor and the Canadian Museum of Making when the Engineerium closed in 2005.

I would also like to pay tribute to the many people who have helped to bring the project to this point. In particular, I am grateful to Dr Bruce Babcock of Amanda, Ohio, U.S.A., for chasing information, taking superb photographs, and keeping me on the right track; I owe Larry Parker thanks for details of his wonderful collection of indicators; I thank Ben Russell of the Science Museum, Internal Fire, and the Powerhouse Museum in Sydney, Australia. I'm also grateful for the support of individuals far too numerous to mention individually (I hope this corporate 'thank you' will suffice!).

The project soon grew too large to be published in conventional form, and it was decided to break it into sections. These are being released in electromic form, at least for the moment, because we are well aware that information is still needed. There are far fewer gaps than there were five years ago, but this is not to say that none remain…

The individual booklets in the series are currently intended to be:

1. In the beginning: Watt and McNaught.
2. Amplification: internal-spring patterns.
3. A cooling breeze: external-springs.
4. Mirrors, wheels and sparks: new tricks.
5. Aids, accessories and overview.

JOHN WALTER, PORTSLADE, 2015

Introduction

"…The Indicator is a means of recording the pressure and rate of pressure change in an engine cylinder at all points of the cycle, and provides…an important indication of the efficiency and working of details of the engine. With proper study of the diagrams, maximum economy with a low fuel bill, small cost of repairs, greater output, an even speed, absence of breakdowns, minimum loss from depreciation and consequently longer life can be attained…' *A quotation from* The Engine Indicator, *a small handbook published by Dobbie McInnes Ltd of Glasgow, the leading British indicator manufacturer of the twentieth century.*

The advent in the first decade of the eighteenth century of the Newcomen atmospheric engine—the predecessor of the true steam engine—was a huge step forward technologically. However, the ready availability of fuel in the collieries where the engines were set to work was initially a great inhibitor to improving their efficiency; that they worked well mattered much less than that they worked at all. There was no experience to guide the first engine erectors, and no yardstick by which output could be gauged.

The first man known to have investigated the atmospheric engine with real purpose was the English engineer John Smeaton (1724–92), born in the small village of Austhorpe, near Leeds, and inspired by stories of the local engine that had been only the sixth of its type to be erected.[1] The failure of his own New River Engine of 1767 to fulfil expectations persuaded Smeaton to undertake exhaustive studies of engines working in the Northumberland coalfields and the Cornish tin mines. He was also the populariser of an arithmetical expression of the 'Duty' of individual machines.

It seems unlikely that Smeaton himself originated the concept of 'Duty', but he was the first to link it with the amount of work that could be done in

1. The identification of the earliest Newcomen engines is still contentious. There were probably two prototypes, and then the first of the working installations—Coneygree coal works, Tipton ('Dudley Castle'), 1712; Griff Colliery, 1714; Woods Mine, Hawarden, 1714/15; and Moor Hall, Austhorpe, 1714/15.

a particular time. Virtually all of the atmospheric engines working in Britain in the 1760s were being used to drain huge quantities of water from mines, and it is no great surprise, therefore, that Smeaton should base his calculation on the weight of water that was being lifted. His 'time frame' was effectively the length of time taken to burn a bushel of coal.[2]

Among the useful features of Smeaton's work are lists of the atmospheric engines that had been erected prior to 1769: he had commissioned the erector William Brown to survey the installations in northern England and Scotland, and had probably asked John Nancarrow to undertake similar work in Cornwall. The oldest (and probably also the smallest) of the 98 machines assessed by Brown had either been reduced to stand-by or were no longer in use by the time of survey, but the cylinder dimensions of most of them were known—diameters ranging from merely thirteen inches, in the cases of the Black Close, Norwood and one of the four Throckley engines, to '75 inchers' in Tynemouth Moor and Benwell collieries.[3]

Smeaton selected fifteen Tyneside engines for detailed study, from which he calculated for each one not only 'Duty' but also 'Great Product' (the weight of water lifted through one foot each minute). Perhaps to Smeaton's surprise, additional size did not necessarily generate additional power: one of the 75-inch engines, for example, returned a Duty of 4·59 million compared with 5·88 million for a 60-inch example. Horsepower was subsequently deduced to be 37·6 and 40·8 respectively.[4]

A trial undertaken in Cornwall in the late 1770s produced similar results. Fifteen engines in Wheal Virgin, Poldice, Wheal Maid, Dolcoath and Wheal Chance, all with cylinder diameters of 60–70 inches, returned Duties of 5·02–7·63 million. Horsepower ranged from only 14·78 for the Poldice 60-inch (which with a Duty of 7·17 million was regarded as the best engine in Cornwall) to 29·65 for the 70-inch Wheal Virgin New Engine. The running speeds were slow, averaging only a little over six strokes each minute.

2. There was then no 'national standard' for the weight of a bushel of coal, which, consequently, varied according to district. The London bushel weighed 88lb; the Newcastle bushel weighed 84lb; and it was not uncommon to encounter a bushel of 90lb or 96lb in Cornwall.

3. Many of the mines of the day had more than one engine, the result of a perpetual search for additional pumping capacity which was almost always satisfied on the basis that biggest was best. Byker Pit had six engines in 1769, Benton had five; and Heaton, Jesmond, Newbiggin, Throckley, Tynemouth Moor and Whitehaven had four apiece.

4. The concept of 'horsepower' as a method of comparing output of engines dated back at least as far as the work of Thomas Savery (1702). Smeaton calculated in the 1770s that a horse (a pit pony, perhaps?) was capable of an output of 22916 ft.lb/min, but experiments undertaken by James Watt in the 1780s with a 'brewery horse' suggested that Smeaton's value underestimated the power of the average animal. In 1783, therefore, Boulton & Watt standardised their horsepower as equivalent to 33000 ft.lb/min.

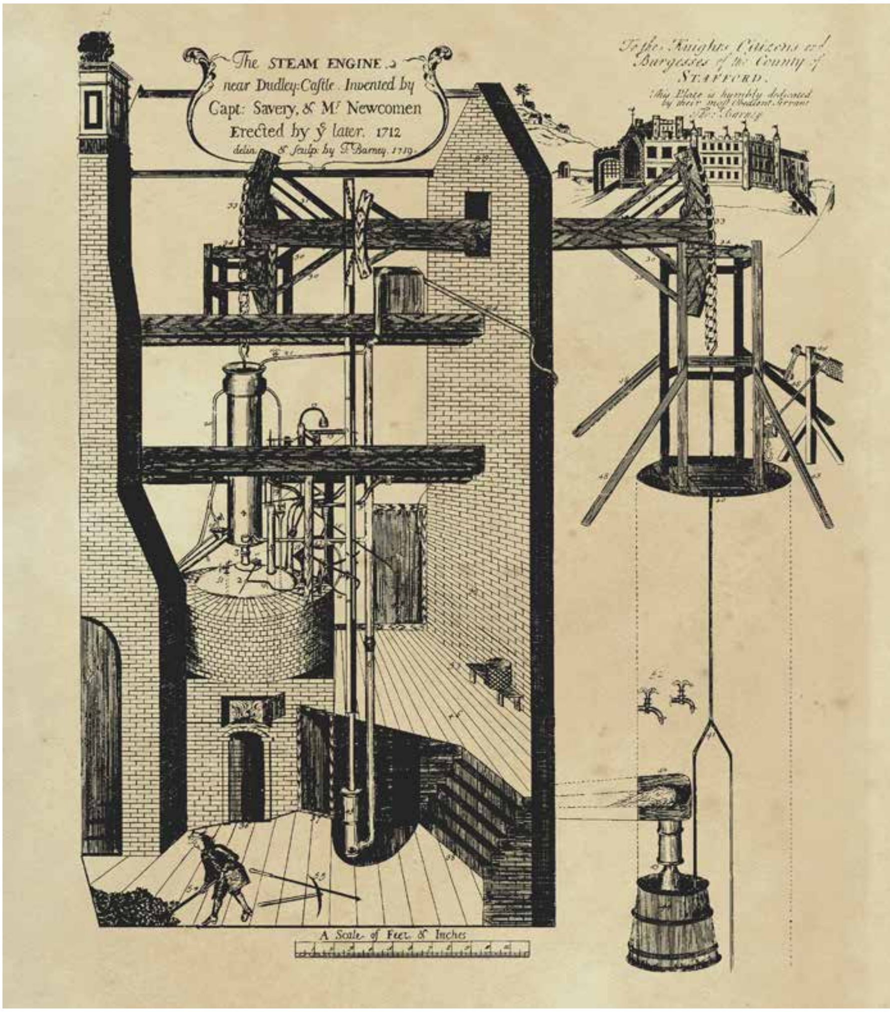


Plate 1. This reproduction of an engraving by Thomas Barney, originally dating from 1719, is the earliest known illustration of a Newcomen atmospheric engine—in this case, the so-called 'Dudley Castle' engine erected in 1712. *John Walter collection.*

Consequently, John Smeaton was among the first people to recognise that many of the engines of his day were as badly designed as they were poorly made, identifying, among other factors, cylinders which were badly proportioned; fire-grates which were poorly positioned; boilers which were weak and badly made; steam pipes which were customarily far too small; and that the water used to condense the steam was introduced to the cylinder much too abruptly to create an effective vacuum.

The commercial success of Watt engines occurred at the end of John Smeaton's life, before he was able to make any use of the engine indicator developed initially by Watt and then by Watt & Southern (see Chapter One). However, it is to Smeaton that much of the impetus to develop testing systems should rightly be credited.

The introduction of the indicator, and in particular the post-1796 moving-tablet design, not only allowed the performance within the cylinder to be investigated but also acted as a catalyst to improve efficiency. There was a sound commercial reason for this: Watt engines were often licensed on the basis of fees paid against performance; the greater the Duty, therefore, the greater would be the returns. A survey of more than twenty Watt engines working in Cornwall in 1798 showed an average Duty of 17·67 million—three times that of the Newcomen atmospheric engines reported only twenty years previously. The best of the Watt machines had given a Duty of 27·5 million.

The publication of performance tables in the *Philosophical Magazine* encouraged competition among mine captains; 'Greatest Duty' was a source of particular pride amongst these Cornish enginemen, and each vied to be at the head of the list. Consequently, Cornwall saw many of the earliest advances at first hand, with the erection of Trevithick high-pressure engines and Hornblower or Woolf compounds.

Duty grew rapidly. This was undoubtedly due in part to ever-increasing size, but also reflected improved efficiency. In 1814, for example, the Stray

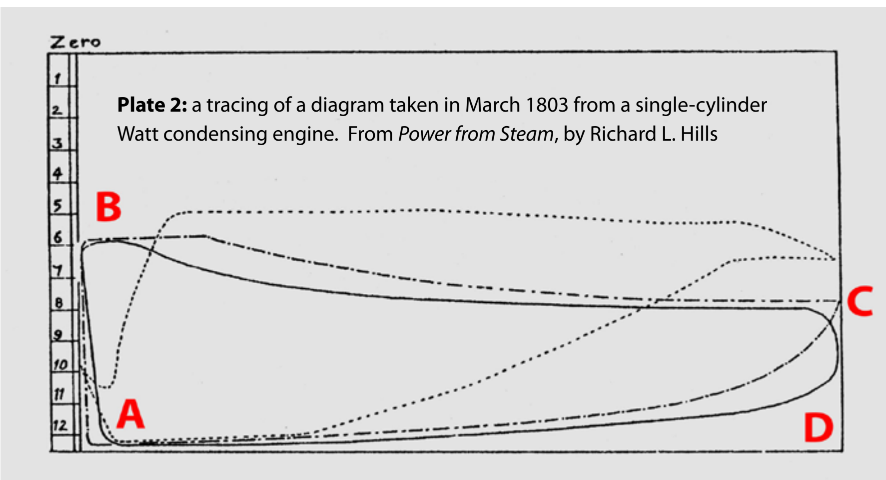


Plate 2: a tracing of a diagram taken in March 1803 from a single-cylinder Watt condensing engine. From *Power from Steam*, by Richard L. Hills

Park engine (34·1 horsepower), a Watt-type machine with a 63-inch diameter cylinder and a stroke of 7ft 9in, had given an average monthly Duty of 32·03 million. In August 1816, the old 45-inch Wheal Chance engine was altered from its original single-cylinder Watt configuration to a two-cylinder Woolf compound, Duty leaping from 25·37 million in July to 44·35 in September. By 1839, the single-cylinder Cornish Engines, working expansively with high-pressure steam, were returning impressive performances: the 80-inch West Julia machine (120·9hp), with a piston stroke of eleven feet, gave a Duty of 73·94 million, and the Consolidated Mines 80-inch Davey engine (159hp) gave 70·35 million. During this period, steam pressures associated with these huge engines had risen from barely above atmospheric level to 30–40 lb/sq.in; and coal consumption had been reduced from 25–30 lb/hp/hr to 7–8 lb/hp/hr.

The introduction of the McNaught indicator (described in Chapter One), even though distribution was initially very slow, simplified assessments to a point where they became routine. This was particularly important, as the advent of high-pressure engines, pioneered near-simultaneously by Oliver Evans in the USA and Richard Trevithick in Britain, placed ever-increasing premiums on performance.[5]

One long-lasting consequence of the use of indicators, which allowed a precise calculation of 'indicated horsepower', was the demise of the older system of analysis. Though 'Duty' had been a valuable method of assessment at a time when none other existed, the basis on which it was calculated was open to criticism. The quantity of coal was usually assessed on a monthly basis, making no allowance for the times the engine stood idle or the fuel that was used to fire-up; nor were the effects of inertia and friction in the pump rodding taken into account. Consequently, horsepower calculated on the basis of Great Product was often substantially lower than each engine was actually delivering.[6]

The use of indicators eliminated many errors, though a dynamometer was still required to allow the mechanical efficiency (and hence the useful output) to be deduced. It is reckoned that the thermodynamic efficiency

5. The exploits of Trevithick (1771–1833) and Evans (1755–1819), which were very controversial at a time of ultra-conservatism, seem to have occurred independently. Both men saw cumbersome construction and feeble boiler pressures as inhibitors to progress. Trevithick, in particular, pioneered self-contained non-condensing engines, road carriages and the railway locomotive.

6. Very few indicator diagrams were ever taken from atmospheric engines, and, consequently, even fewer survive. Diagrams obtained in 1895 from a '66-inch' engine erercted in Ashton Gate, Bristol, gave 51.4ihp. Even though this particular machine had been greatly altered, undoubtedly improving performance, it seems very unlikely that it would have given much more than 30hp assessed on the basis of Duty.

THE

ENGINEER'S PRACTICAL GUIDE,

and the WORKING of the

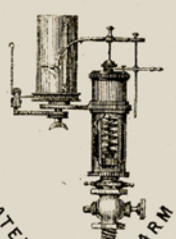
STEAM ENGINE

EXPLAINED

By the use of the

INDICATOR.

What the Stethescope is to the Physician the Indicator is to the skilful Engineer, revealing the Secret working of the inner System, and detecting minute derangements in parts obscurely situate.



PATENT SWIVEL ARM INDICATOR

BY

J. HOPKINSON & CO.

HUDDERSFIELD.

Illustrated with Engravings & Diagrams.

An Exposition of the Best Mode of Producing the Greatest Amount of Power from a given Quantity of Steam with the Least Expenditure of Fuel.

with a description of

The Mode of Expanding Steam, and the Compounding of Engines, with the Rationale of Steam Jacketting.

SEVENTH EDITION, ENLARGED AND IMPROVED.

Plate 3. The title page of the 1875-edition of the book promoting the improved form of the Hopkinson indicator, typical of the grandiose style of the day. Note the drawing of the indicator in the central oval. *Museum of Making collection.*

of the Newcomen engines was only about one per cent, improved by even the finest of the Watt engines to little more than two per cent. Mechanical efficiency of the best Newcomen engines was 65–75 per cent; Watt engines were better, returning 75–85 per cent.

As early as the 1840s, the British engineer Daniel Gooch (1816–89) was indicating railway locomotives—even then running with boiler pressures of 120 lb/sq.in—and Jacob Perkins (1766–1849) had produced boilers capable of withstanding pressures more than ten times higher. The rapid rises in piston speeds and operating pressures were initially handled merely by increasing the strength of indicator springs, but the problems of vibration also grew to a point where the validity of the traces was often compromised.

The McNaught indicator was still rarely seen in 1857, when Enoch Gledhill wrote to Joseph Hopkinson that 'In travelling the country, I find that a great number of owners of Engines have yet to derive the advantages which others are deriving by allowing the steam to expand before leaving the cylinder. The reason of this is, that the means of carrying out expansion and early exhaust are but little understood by those who ought to have a practical knowledge of the subject. No doubt one great cause is a want of a more general knowledge of the Indicator…'

Hopkinson also remarked that, when an engine in a Dewsbury Mill tested poorly in 1859, the 'Engineer…could not agree with the report, as established by the diagram, that his Engine valves were improperly set, "because", as he said, "he had had great practice with the Engines". He would not accept the facts pointed out by the Indicator, because of that most silly of all reasons—long habit in a certain rule and routine…'

Testimony such as this suggests that the engine indicator, far from being commonplace, was rarely seen in 1860 and it is tempting to conclude that total production at this point could be numbered more in hundreds than thousands. However, though some engineers remained hostile, often because it suggested their grandiose claims to be mistaken, the advent and large-scale manufacture of the Richards indicator from 1863 onward (see Part Two) was too great a step to be retraced.

The Richards indicator, though retaining popularity for use with slow-speed steam engines until the beginning of the First World War, was rapidly supplemented by improved designs with lighter amplifying systems. Often

G

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NATIONAL TELEPHONE No. 1409.

ESTABLISHED 1864.

Chief Engineer's Report on Inspecting Engineer's Examination of Engine.

Chief Engineer and General Manager:
EDWARD G. HILLER, B.Sc., M.I.C.E., M.I.Mech.E.

E778.

March 28th, 1906.

Messrs. Albert E. Reed & Co. Ltd.,
Tovil Paper Mills,
Tovil, Maidstone.

IN REPLY PLEASE QUOTE
C H

Gentlemen,

On the 15th inst. one of our Inspectors visited the above address and made indication of the engine described below:-

No. 2 Horizontal Tandem Compound Condensing Steam Engine:
Cylinders 11" & 20" diameter x 30" stroke.

The engine was indicated when driving a load consisting of three Callenders. We enclose herewith copies of our Inspector's diagrams, from which we have calculated the power developed in the cylinders to be:-

H.P. Cylinder... 28
L.P. Cylinder... 55
TOTAL 83.......INDICATED HORSE POWER.

The high-pressure front diagram shows complete absence of compression, but in other respects the form of the diagrams is on the whole satisfactory. We note, however, that the cut-off in the L.P. cylinder is somewhat late and if made earlier the load will be more equally distributed between the cylinders and the vacuum in the L.P. cylinder will probably be improved owing to the steam passing to the condenser at a lower terminal pressure.

Our calculations from the diagrams show that there is apparently considerable leakage of steam from the high ~~low~~-pressure to the low ~~high~~-pressure cylinder, probably at the blow through valve, which Inspector thinks is in need of overhaul, or at the high-pressure exhaust valves. At the time of this indication we estimate that the engine was using at least 30 lbs. of steam per I.H.P. per hour, exclusive of leakage.

Our Inspector reports that there was considerable condensation at the L.P. cylinder. In order to prevent this as far aspossible, we advise that the flanges of the steampipes where bare should be covered with composition and in additi on the junction valve on the pipes near the engine and about three-feet of pipe at the bend above the engine which are bare should also be covered.

The running of the engine was generally satisfactory and all generally as far as seen was in good working order.

Yours faithfully,

Edward G. Hiller

Chief Engineer.

2

M.D.

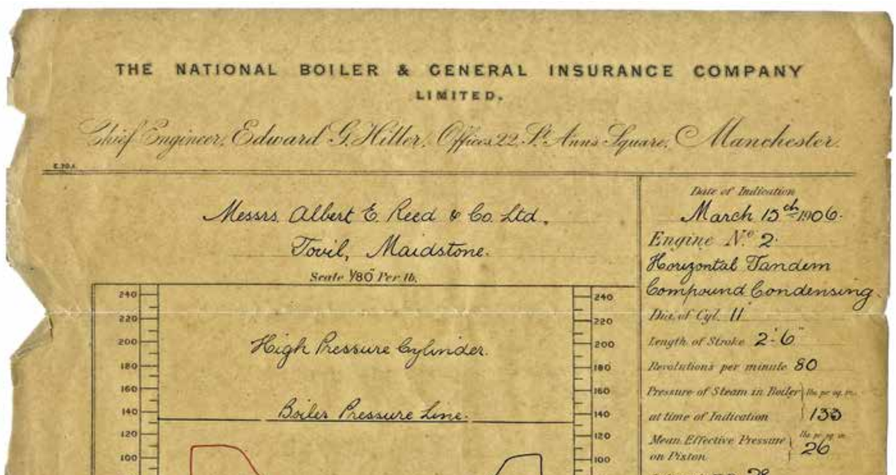
E 6. 2/05.

specifically designed for use with high-speed machinery, these included the principal US patterns: the Thompson of 1875, the Tabor of 1878 and the Crosby of 1882 (all included in Part Two).

The amplifying reciprocating-drum indicator was an extremely flexible tool, easily adaptable for use with fast-running high pressure steam engines, multi-cylinder internal-combustion engines, hydraulic equipment, guns, compressors, pumps and other pressure vessels.

The frequency with which boilers failed soon attracted public attention. The earliest attempt at regulation seems to have been legislation accepted in the U.S.A. on 7th July 1838 in an attempt to reduce the ever-increasing number of maritime boiler explosions, seeking to prevent needless loss of life on the steamboats plying rivers such as the Mississippi. This was succeeded by the Steamboat Act of 30th May 1852, then by an extensive revision of procedures in February 1871. Eventually, a Boiler Explosions Act passed into law in Britain in 1882 (Victoria 45 & 46, c. 22), providing inspiration not only

Plate 4 (previous page) and **Plate 5**, below. A survey of a two-cylinder tandem compound steam engine owned by paper manufacturers Albert E. Reed & Co. Ltd, undertaken in March 1906, produced several diagrams from an Elliott-Richards indicator and a letter from the insurers detailing a variety of problems. *John Walter collection.*



for later amendments but also for comparable legislation accepted in France and Germany prior to the First World War.

The British had not always been keen to hamstring industrial development with restrictive legislation. However, a spate of accidents—in 1859, 51 boiler explosions had cost 107 lives—inspired the creation of specialist insurance societies, beginning in Manchester in the middle of the nineteenth century. The effects were immediate and beneficial; only eight of the first eleven thousand boilers to be insured by societies failed within a year of inspection, compared with more than 260 among the uninspected/uninsured group.

Yet the most parsimonious boiler-users were reluctant to spend money on inspections and trusted instead to providence. Not surprisingly, as the use of steam plant increased so the accidents increased in proportion. By 1880, the problem had become sufficiently acute to persuade the British Government to intervene. The Act of 1882 and its 1890 amendment (Victoria 53 & 54, c. 35) not only made insurance obligatory, but introduced severe penalties if negligence on behalf of the owners or their representatives could be proved in court. Ironically, statistics show that accidents increased substantially in the decade after the 1882 Act had first been implemented, but this testifies more to the rapid rise in the number of boilers in use in Britain, their ever-increasing complexity, and possibly also the failure of old plant that had deteriorated before legislation could be enforced. Returns for 1894, the worst year, showed 115 explosions and collapses, causing 32 deaths; in 1930, though the usage of steam plant had greatly increased, comparable figures were 56 and five respectively.

Inspections were facilitated by the use of indicators, which could show if the performance of engines and boilers had deteriorated; if steam lines were too constricted; or if the valve gear had been adjusted to make best use of the steam supply. In 1930, the British Engine Boiler & Electrical Insurance Co. Ltd, based in Manchester, had 22 branch offices scattered throughout the United Kingdom from Plymouth in the south to Dundee in the north. The 'Classes of Business Transacted' included 'Boilers, and other Vessels under pressure, Steam and Feed Piping used for Power, Heating, Cooking and Manufacturing Processes insured against Explosion and Collapse…'

The annual *Technical Report* stated that 'In all the foregoing classes of insurance the interests of both the Insured and the Insurer are protected by the system of periodical inspections, which are made by the Company's own staff of Surveyors, specially trained for the different branches of work. After each visit of a Surveyor, a report is sent to the Insured pointing out any defects that may have been detected, with advice as to the best means of remedying them.'

Plate 6. This Dobbie McInnes Design No. 1A indicator, no. 16813L dating from *c*. 1917, is known to have been used by a Surveyor employed by the British Engine Boiler & Electrical Insurance Co. Ltd. Unlike standard Design No. 1A instruments, which have the distinctively arched tracer bar, the 'L' type has a straight arm and a large drum intended for use with Richards-type paper. *John Walter collection.*

This particular company is known to have used Dobbie McInnes indicators, as a substantial number of Design No. 1 instruments (often showing non-standard modifications) were sold by auction in the 1980s. See Plate 6.

The letter reproduced here, as Plate 4, notes an inspection undertaken in March 1906 by a surveyor of the National Boiler & Insurance Co. Ltd, when faults were found during a trial of 'No. 2 Horizontal Tandem Compound Condensing Steam Engine, Cylinders 11″ & 20″ diameter × 30″ stroke' owned by Albert E. Reed & Co. Ltd of Tovil Paper Mills, Tovil, Maidstone, Kent. The diagrams were taken with an Elliott-Richards indicator.

Indicators remained at the forefront of engine-testing for many years, adapting from the steam engine to the many forms of internal-combustion engine that were unknown in all but the most obscure rudimentary forms when the Richards indicator appeared in the early 1860s.

One of the most important modifications to be made prior to 1914 was the introduction of special recorders, sometimes driven by clockwork, to enable performance to be monitored continuously. This was particularly valuable owing to the rapid introduction of the fast running multi-cylinder petrol engines destined for motor vehicles and aeroplanes. In a contribution to a discussion arising out of a 'symposium of Papers on Indicators' given by the Institution of Mechanical Engineers in January-February 1923, Captain H. Riall Sankey of the Marine Oil-Engines Trial Committee observed that 'Going back to the old steam-engines running at very few revolutions, the diagrams were large, and the pencil could be seen moving over the paper; there was practically no shock from the steam and no inertia. These diagrams gave the indicated power of the engine to under one-half of 1 per cent. With a high-speed steam-engine there was still no shock, but there was inertia and the diagrams were small...

'[He recalled that]…in the classic trials by Willans the Crosby indicator was used, and Willans stated that they produced clear and measurable diagrams at 400 r.p.m., the inaccuracy probably did not exceed 1 per cent. In the case of the slow speed internal-combustion engine, there was no inertia but there was the shock of the explosion, which introduced a disturbing factor, and the error was 2 to 3 per cent or possibly more. With high-speed internal-combustion engines the indicator had to deal both with shock and inertia, and it was these difficulties that had stimulated the introduction of the optical and the micro-indicator.'

By the time of the 1923 lectures, running speeds of 2000 rpm and pressures in excess of 500 lb/sq.in were not uncommon. Pioneering airborne trials were undertaken in February 1923 with the first RAE spark-trace indicator (subsequently developed into the 'Farnboro'), in a De Havilland DH9A fitted with an eight-cylinder Napier Lion engine rated at 450hp at 2150 rpm. An indicated mean effective pressure of 148 lb/sq.in was deduced at an altitude of 500 feet. Static tests on a 160hp six-cylinder inline Benz aero engine running at 1650 rpm, undertaken a few months earlier, had given an average explosion pressure of 510 lb/sq.in with a maximum of 800 lb/sq.in. Output of this magnitude was a far cry from pressures barely above atmospheric level and the paltry six strokes per minute of the Newcomen engines that had been introduced only two centuries earlier.

Variations on the Thompson and Crosby themes continued to be made in quantity until the end of the Second World War, and then, in increasingly smaller numbers, into the post-war era. Mechanically-driven indicators were increasingly challenged by optical and electrically-operated systems (see

Plate 7. Dobbie McInnes Design No. 4 indicator no. 47381. The general simplification of construction is clearly evident.

Photograph by courtesy of Bruce Babcock, Amanda, Ohio, U.S.A.

Plate 8. Dobbie McInnes Ltd introduced the Design No. 4 indicator, a refinement of the old No. 1A, shortly after the end of the Second World War. This example, no. 45074, probably dates from 1948. British-made indicators customarily lacked the wide range of accessories offered with the German rivals. *Museum of Making collection.*

Chapter Seven), yet many survived in everyday use into the 1960s, when the closure of last great steam-driven textile mills and the demise of the steam railway locomotive ultimately relegated most of them to the scrap-bin.

For more than 150 years, however, the indicator had allowed engineers to see inside the cylinders of a steam- and internal-combustion engines. So attractive are their characteristics for specific tasks, particularly the regulation of large marine diesel engines, that two German manufacturers—Lemag (formerly Lehmann & Michels) and Leutert (successors to Maihak)—*still* offer modernised Crosby-style indicators commercially. The Moto-Meter or Mo-Test compression meter of 1940 (q.v.) can also be purchased.

MAKING AN INDICATOR

The production of indicators has always been a tortuous, labour-intensive process. For example, virtually all of a typical Dobbie-McInnes indicator—

including the gas cocks—was made in the company's workshops.[7] "…The indicator body/platform was a 'naval brass' casting, made on site, but was customarily sent out to be nickel plated. The ebonite cover, cap and operating handle were bought-in as required… The steel parts were all made by Dobbie McInnes, including the adaptor, which was machined from solid. The sealing washer was bought in from a specialist supplier. We also made the pistons and the springs. Springs were the most important of all the parts. The end pieces were made from special bar stock, machined to shape externally, bored and threaded centrally. The two ends were identical.

"The vanes on the end pieces were cut to differing lengths, holes being cut through the vanes at an angle that suited the individual spring helix [spring construction varied according to working load]. The springs were individually made on our work benches, close-tolerance spring steel wire being wound on a mandrel whilst soft and then hardened after assembly. The requisite number of coils for each spring, plus a small allowance for adjustment, was cut off the wire and the ends were secured by brazing. The free ends of the wire protruding through the vane were cut off and ground flush. Spring length was checked, and the end pieces were then faced and cleaned up.

"The springs were placed in the hardening furnace (at that time a small electric muffle) for 3–4 hours until they reached 950 degrees Centigrade. They were then plunged into the oil quenching bath. However, as it had become extremely brittle, each spring was then tempered by heating to a 'colour code' (middle blue?); it was then allowed to cool, and finally cleaned up.

"Springs were tested on a dummy 'skeleton' indicator rig, using a dead-weight unit to test the load required to compress the spring through a pre-determined distance. The weights were removed and the spring was polished with medium grade emery tape (all of it, top to bottom) if adjustments were needed. It was then re-tested; if still too strong, more was removed from the coils and the re-test process continued until the right performance was indicated. If too much of the spring was removed, and the spring became too weak, it was either moved down to the next range or simply rejected. Mistakes of this type, however, were rare.

"The pointer linkage was made 'on the bench' in the machine shop, either cut from flat plate or machined from bar stock, depending on strength required. The original silver tracer points left a trace on chemically impregnated paper; later, however, the specification was changed to a combination of steel tipped pointers and silver iodide paper.

7. Personal reminiscences of Thomas G. Walter (1917–2003), Assistant Works Manager, Dobbie McInnes Ltd, 1947–51. Dictated to John Walter, 4th January 2001.

"The cylindrical paper holder was made 'in house' from stock brass tube, with the ends machined flush; the paper fingers were made by Dobbie McInnes, but the butterfly nut that held the components together was acquired elsewhere. The pulley assembly and the cord hook were made on site, but the specialised non-stretch cord, though a Dobbie McInnes design, was subcontracted. It was purchased 'by the mile'.

"Virtually all the parts were hand finished; indeed, most were hand made. Indicators were manually assembled on the bench, each assembler drawing the appropriate parts from store, and tested individually. Each indicator/spring combination was tested on a special deadweight recording rig to ensure that spring recovery and the performance of the pointer linkage were satisfactory. [It is believed that an error as great as two per cent existed in new machines, rising to five per cent after heavy use.]

"The Admiralty indicators were checked annually; those used by the mercantile marine, though nominally checked every twelve months, were in practice much more rarely returned to Broomloan Road for scrutiny—even from our other offices. Springs were changed if necessary and new diagrams with spring ranges were supplied to double as a certificate of test. It wasn't unknown for indicator boxes to bear three or more labels.

"The boxes were made in the Broomloan Road works by a foreman and 4–5 men, who between them could make about a hundred a day. However, owing to other demands, capacity was sometimes at a premium and work was occasionally put out to tender, notably to furniture makers. One subcontractor submitted samples of cypress [unacceptable]; other orders were terminated because the polishing was not up to our own standards, often because it had been applied by spraying instead of the usual three hand-applied layers.

"Boxes, like the indicators, were made to Admiralty Standards and had to be mahogany, with comb or dovetail joints and fittings of brass or bronze. Boxes delivered to the Royal Navy had to be French polished by hand, six women being employed to do the work. The handles were made in the woodworking shop, but fittings such as hinges, screws and locks were bought-in as required. The spanner supplied in the box and the oil bottles, etc, were all bought-in as required.

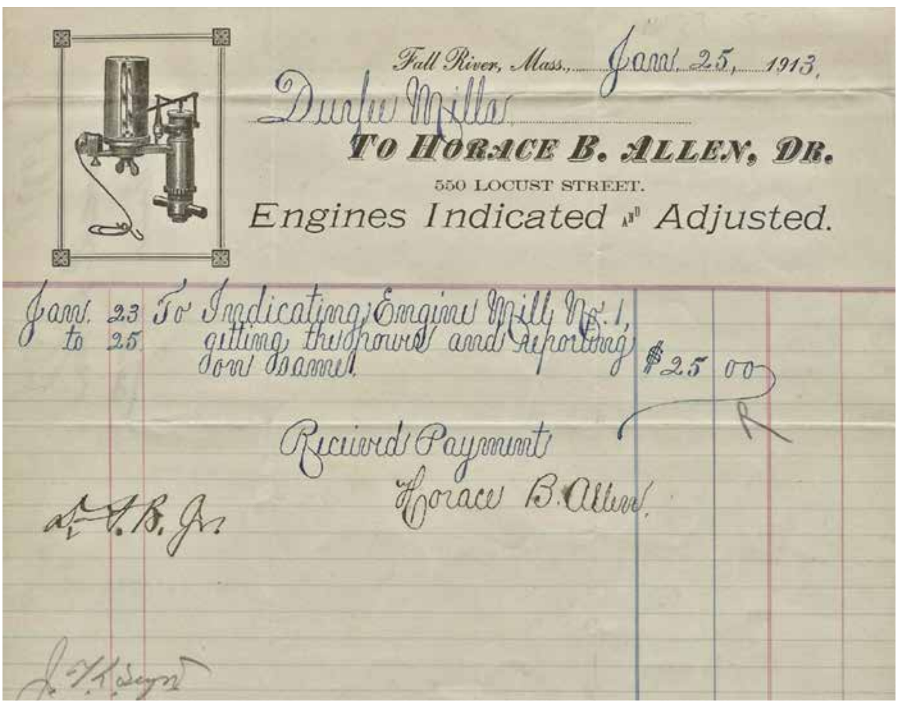
"I think that some of the boxes made during the Second World War, when supplies of mahogany were restricted, were made of marine plywood (perhaps birch). I've seen several boxes of this type, with alternating light close-grain sapwood and dark open-grain heartwood layers crossed for strength.

"The 52½-hour working week of five and a half days (including Saturday mornings) was cut in 1948 to 47½ hours on the five weekdays. The hours were 8–6 daily, with a half-hour lunch and 15 minutes morning and afternoon for tea breaks. Wages averaged £2–10–0 a week, with skilled spring makers making £3 or more. The assistant works manager received £800 annually.

"Production of indicators is difficult to assess, but we probably averaged five kits per day. Some parts were easy to make, even steam cocks taking just four minutes apiece, but the spring-making and testing processes were protracted. About ten men were employed in the indicator department, including apprentices. Four men usually made springs and the remainder assembled the machines, though the numbers were varied according to demand. The Broomloan Road workshop employed another twenty men, but, by the late 1940s, an automated machine shop equipped with a Wadkins seven-spindle automatic, capstan and turret lathes had been added.

"The retail prices were calculated on the basis of '(material + 10 per cent) + (labour at 1/6d to 6/- per hour [depending on complexity of manufacture] and an 'on cost' of 300%) + (25 per cent profit)'…"

Plate 9. The indicator provided many engineers with work. This billhead is typical of many.
By courtesy of Bruce E. Babcock, Amanda, Ohio, U.S.A.


Fall River, Mass., Jan. 25, 1913.
Durfee Mills
TO HORACE B. ALLEN, DR.
550 LOCUST STREET.
Engines Indicated and Adjusted.

Jan. 23 to 25 To Indicating Engine Mill No. 1, getting the power and reporting on same. $25 00

Received Payment
Horace B. Allen.

H. B. Jr.

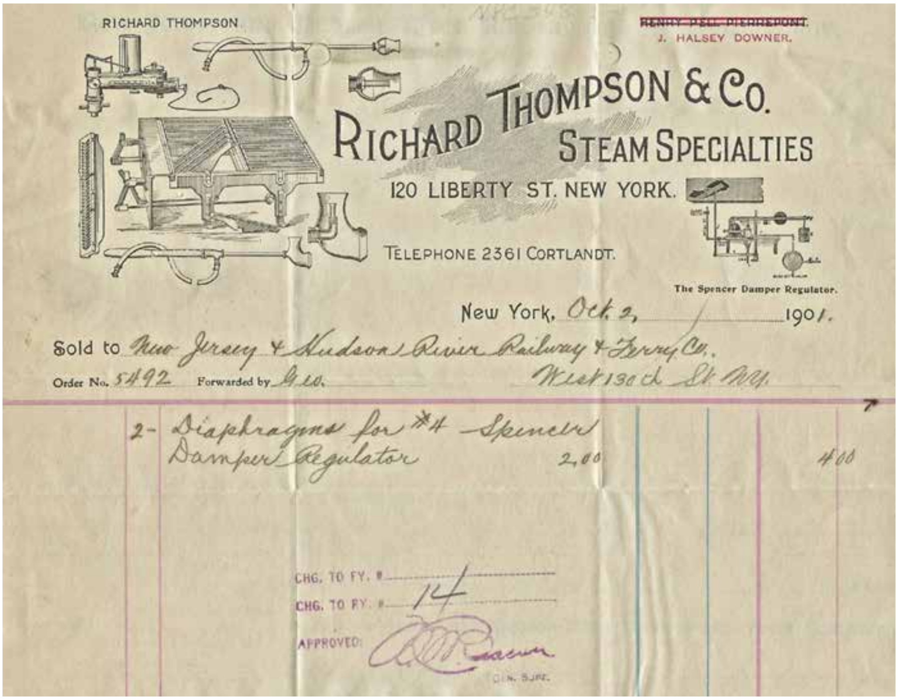
DISTRIBUTION

Indicators were often accompanied by surprisingly sophisticated handbooks which not only instructed the purchaser in the use and care of the instrument and its accessories, but also acted as a promotional tool. This was particularly true of the 1880–1900 era in the U.S.A., when the American Steam Gauge Company, Ashcroft, Crosby, Hine & Robertson and others were all jostling for supremacy. The use of testimonials and the assembly of impressive-looking lists of clients were among the favoured methods of self-promotion.

Written by George Barrus on behalf of the Ashcroft Mfg Co., *The Tabor Steam Engine Indicator* (*c.* 1889) contains impressive testimonials. A typical page reproduces letters from the Altoona Car Works of Altoona, Pennsylvania, 'Builders of Stationary Engines, Railroad and Mine Cars'; the Westinghouse Machine Company of Pittsburgh, Pennsylvania; the Taylor Mfg. Co. ('Steam Engines, Boilers & Saw Mills'), of Chambersburg, Pennsylvania; engine-builder John Ramming of St Louis, Missouri; and the McKinnon Mfg. Co. of Bay City, Michigan, 'Manufacturers of and Dealers in Boilers, Engines and all Kinds of Machinery'.

The Tabor handbook also contains a list of nearly 350 purchasers of Tabor indicators. By far the greatest number of entries refers to engineering businesses. In addition to the US Navy and the US Light House Service, these included many of the best-known steam-engine builders—e.g., Armington & Sims, the J.I. Case Threshing Machine Company, the Cooke Locomotive & Machine Company, A.L. Ide & Son, the Straight-Line Engine Company, the Wheelock Steam Engine Company, and Vulcan Iron Works—but also many lesser manufacturers, ranging from the Ansonia Brass & Copper Company, the Arctic Ice Machine Company, the Brush Electric Light Company, Elgin National Watch Company and the Hartford Engraving Company, to the Racine Hardware Company, the O.J. Stifel Brewing Association and the Willimantic Linen Company. Many of the purchasers clearly employed steam power as part of the manufacturing process, but there were others where steam was more probably used simply to provide power or heat to offices.

Public utilities, railroads and shipping companies were also represented on the list, among them the Atlantic Dredging Company, the Chicago Arc Light & Power Company, the Cleveland & Detroit Steam Navigation Company, the Illinois Central Rail Road, the Inter Ocean Transportation Company, the Mexican Central Rail Road, Milwaukee Water Works, the Mutual Life Insurance Company, the Norfolk & Western Rail Road, the Pennsylvania Rail Road, Saratoga Springs Water Board, and the Union Pacific Rail Road.


RICHARD THOMPSON

~~HENRY BELL PIERREPONT.~~
J. HALSEY DOWNER.

RICHARD THOMPSON & Co.
STEAM SPECIALTIES
120 LIBERTY ST. NEW YORK.
TELEPHONE 2361 CORTLANDT.

The Spencer Damper Regulator.

New York, Oct 2, 1901.

Sold to New Jersey & Hudson River Railway & Ferry Co.

Order No. 5492 Forwarded by Geo. West 130th St N.Y.

2- Diaphragms for #4 - Spencer Damper Regulator 2,00 4,00

CHG. TO FY. #
CHG. TO RY. # 14
APPROVED:
GEN. SUPT.

Plate 10. Richard Thompson was once a partner in the Thompson & Bushnell Company, which dissolved *c.* 1896 to allow the partners to trade independently, though Thompson initially continued as 'Thompson & Bushnell'. Note the Bachelder indicator in the top left corner of this billhead, though Thompson's name is more usually associated with the Robertson-Thompson type. *By courtesy of Bruce E. Babcock, Amanda, Ohio, U.S.A.*

The mining industry was also keen on indicators, purchasers of the Tabor including the Calumet & Hecla Mining Company and Susquehanna Coal Company. And among the many schools and colleges that could see the educational value of an indicator were the Chicago Manual Training School, Cornell University, Massachusetts Institute of Technology, Pennsylvania State College, the Universities of Maine, Michigan and Missouri, and Vanderbilt University. Some of the individual purchasers were consulting engineers, such as Isaac Holmes, Charles Emery and Edward Wood, though the profession of others in this particular category is now difficult to assess.

The catalogue published in 1896/7 by the American Steam Gauge Company, extolling the virtues of the Improved Thompson indicator, provides a fascinating list of 484 clients. This duplicates several of the names found

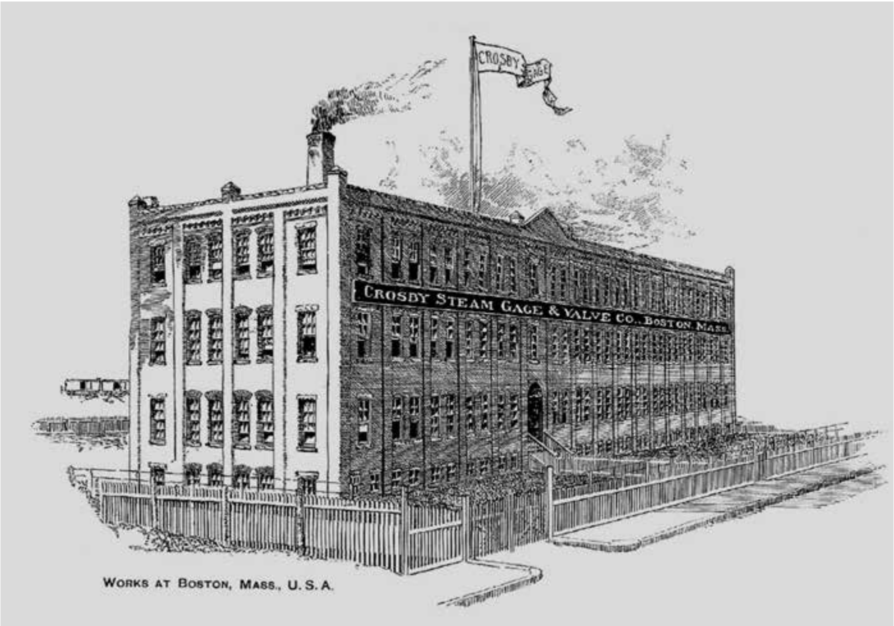


Plate 11. The main block of the Crosby Steam Gage & Valve Company factory in Boston, Massachusetts, from a catalogue published by the company in 1897. *By courtesy of Bruce E. Babcock, Amanda, Ohio, U.S.A.*

in the Ashcroft Manufacturing Company's Tabor book (see above)—e.g., the Calumet & Hecla Mining Company, the Strong Locomotive Engineering Company—and so at least a few of the users who had been satisfied with the Tabor in the late 1880s were favouring the Improved Thompson instrument a decade later.

The American Steam Gauge Company numbered a variety of railroads among the users of Thompson indicators, including the Baltimore & Ohio, Canadian Pacific, Mexican Central and St Paul & Sioux City companies. And among steamship companies and shipbuilders were well-known names such as William Cramp & Sons of Philadelphia, Pennsylvania, and Harlan & Hollingsworth of New York.

The names of individual manufacturers present a microcosm of North American industry—such as the Amoskeag Mfg Co. of Manchester, New Hampshire, the Brayton Petroleum Engine Company of East Bridgewater, Massachusetts; the Brown & Sharpe Mfg Co. of Providence, Rhode Island; Colt's Patent Fire Arms Mfg Co. of Hartford, Connecticut; the Eclipse Wind

Engine & Pump Company of Beloit, Wisconsin; the Little Falls Knitting Company of Little Falls, New York State; and the Utica Steam Gauge Company of Utica, New York. One particularly interesting entry is the Star Brass Mfg Co. of Boston, Massachusetts, which subsequently made indicators of its own but was clearly not doing so prior to 1897.

American Thompson indicators were also used by many leading engine builders, such as the Corliss Steam Engine Company of Providence, Rhode Island, and the Edward P. Allis & Company of Milwaukee, Wisconsin, who would be the first to reject ineffectual instruments. The Universities of Minnesota and Wisconsin, and Massachusetts Institute of Technology, were among the many educational-establishment purchasers. There were consulting engineers such as William Lee Church and Henry W. Bulkley of New York, or John W. Hill of Cincinnati, Ohio, and public utilities ranging from the St Louis Gas Light Company to waterworks in Cincinnati, Ohio, and Wilmington, Delaware.

Evidence provided by these catalogues has been taken to show that the indicator was an inexpensive tool, but an understanding of the wages of the day puts prices into context. The hourly rates of men entering the employment of the Tabor Manufacturing Company in 1900–10 ranged from 12 cents for a tool boy (1905) and 15¢ for a labourer (1900) to 28¢ for a pattern maker (1910) and 36¢ for a toolmaker (1907); the wages of a Gang Boss rose from 34¢ in 1902 to 46¢ in 1906. Assuming that the men worked an average of 56 hours weekly, the take-home pay of a 1906 Gang Boss would only have amounted to $25.76. Indicators were selling for $60–$80 at that time, representing more than two weeks' wages.

A qualified engineer working for Tabor in 1906 would undoubtedly have been able to buy an indicator with the equivalent of a week's wages, which suggests that the instruments were cheaper than in Britain prior to 1914. In Britain in 1901, for example, the approximate average weekly earnings were £1.15.0d (£1.75) for a miner; £2.5.0d (£2.25) for a skilled engineering worker; £2.18.6d (£2.85) for a teacher; and £6.8.0d (£6.40) for a surveyor or engineer. Even for a qualified engineer, therefore, a £15 indicator would cost more than two weeks' wages. The reason was probably the competitiveness of the US market, where many manufacturers were wrestling against each other; in Britain, conversely, the market was dominated only by a single company—Elliott Brothers prior to 1900, Dobbie McInnes thereafter.

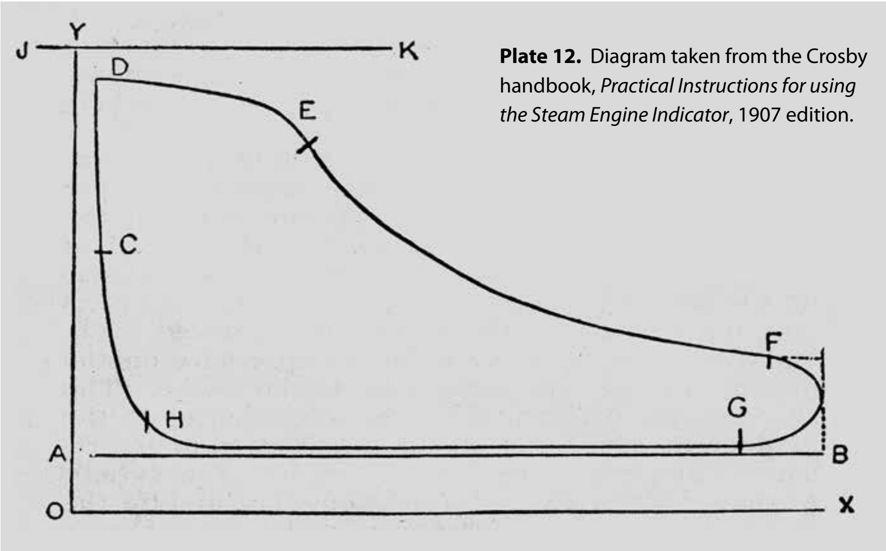


Plate 12. Diagram taken from the Crosby handbook, *Practical Instructions for using the Steam Engine Indicator*, 1907 edition.

WHAT DOES AN INDICATOR DO?

An engine indicator was originally a small mechanically-operated instrument which gave an insight into the operation 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 allowed variations in pressure to be recorded on both the outward and return strokes of the operating cycle.

Excepting some of the continuously-recording instruments and virtually all maximum-pressure recorders, indicators give a trace in the form of a closed loop. The handbook accompanying Crosby indicators, *Practical instructions for using the Steam Engine Indicator*, provides a brief but informative guide to the diagram:

“[Plate 12 shows] the names by which the various points and lines of an indicator diagram are known and designated… The closed figure or diagram C D E F G H is drawn by the indicator, and is the result of one indication from one side of the piston of an engine. The straight line A B is also drawn by the indicator, but at a time when steam connection with the engine is closed, and both sides of the indicator piston are subjected to atmospheric pressure only… The straight lines O X, O Y and J K, when required, are drawn by hand…, and may be called reference lines...

"*The admission line* C D shows the rise of pressure due to the admission of steam to the cylinder by the opening of the steam valve. If the steam is admitted quickly when the engine is about on dead-center this line will be nearly vertical.

"*The steam line* D E is drawn when the steam valve is open and steam is being admitted to the cylinder.

"*The point of cut-off* E is the point where the admission of steam is stopped by the closing of the valve. It is sometimes difficult to determine the exact point at which the cut-off tales place. It is usually located where the outline of the diagram changes its curvature from convex to concave.

"*The expansion curve* E F shows the fall in pressure as the steam in the cylinder expands behind the moving piston of the engine.

"*The point of release* F shows when the exhaust valve opens.

"*The exhaust line* F G represents the loss of pressure which takes place when the exhaust valve opens at or near the end of the stroke.

"*The back pressure line* G H shows the pressure against which the piston acts during its return stroke. On diagrams taken from non-condensing engines it is either coincident with or above the atmospheric line... On cards taken from a condensing engine, however, it is found below the atmospheric line, and at a greater distance or less, according to the vacuum obtained in the cylinder.

"*The point of exhaust closure* H is the point where the exhaust valve closes. It cannot be located very definitely, as the change in pressure is at first due to the gradual closing of the valve.

"*The compression curve* H C shows the rise in pressure due to compression of the steam remaining in the cylinder after the exhaust valve has closed.

"*The atmospheric line* A B is a line drawn by the pencil of the indicator when its connections with the engine are closed, and both sides of the piston are open to the atmosphere. This line represents on the diagram the pressure of the atmosphere, or zero of the steam gage.

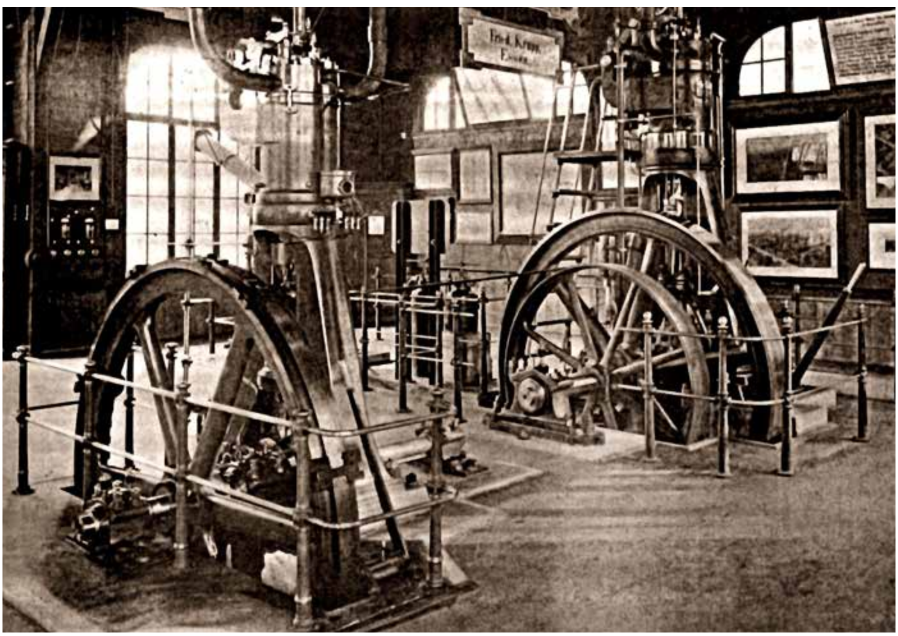
"*The zero line of pressure*, or line of absolute vacuum O X, is a reference line, and is drawn by hand, 14 7/10 pounds by the scale, below and parallel with the atmospheric line. It represents a perfect vacuum, or absence of all pressures.

"*The line of boiler pressure* J K is drawn by hand parallel to the atmospheric line and at a distance from it, by the scale equal to the boiler pressure shown by the steam gage. The difference in pounds between it and the line of the diagram D E shows the pressure which is lost after the steam has flown through the contracted passages of the steam pipes and the ports of the engine.

"*The clearance line* O Y is another reference line drawn at right angles to the atmospheric line and at a distance from the end of the diagram equal to the same per cent. of its length as the clearance bears to the piston travel or displacement. The distance between the clearance line and the end of the diagram represents the volume of the clearance and waste room of the ports and passages at that end of the cylinder."

Diagrams often revealed running faults which were not immediately apparent 'by eye' or 'by ear', but a few simple alterations could greatly improve smooth running and general efficiency. 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.

Plate 13. Two of the earliest diesel engines to be made by Maschinenfabrik Augsburg–Nürnberg ('MAN'), seen on display in the machinery hall of the international exhibition held in Leipzig in 1900. The design of autographic indicators was rapidly improved to accommodate internal-combustion engines. *John Walter collection.*



THE INDICATOR AND ACCURACY

The advent of the mechanical-operated indicator allowed a realistic look to be taken at the inner working of the steam engine. Though progress was slow, largely owing to the secrecy surrounding the first Watt indicators, the series production of the Richards pattern by Elliott Brothers of London, beginning in the early 1860s, was an enormous technological stride which can only be dimly appreciated today.

It heralded the first textbooks designed to educate the apprentice engineer, and showed that performance could often be improved by the substitution of instruments for even the most intelligent guesswork. However, the science of thermodynamics was still to take its first steps towards consensus, not only allowing bad practise to flourish but also letting individual experimenters make claims that the next generation would rapidly demolish.

Instrument makers were very keen to advertise the 'exceptional qualities' of their products—even if, in cases such as the non-amplifying Hopkinson, they fell far short of the performance of the Elliott-Richards—but were much less willing to acknowledge drawbacks. Yet by the 1870s, once high-speed engines were becoming commonplace, the analytical process was increasingly questioned. Tests had been undertaken on selected engines with several indicators, often of the same general type, and the results often revealed discrepancies; these were sometimes blamed on differences in individual piston strokes, or, at other times, on the age or condition of the indicators. Attempts were made to quantify the errors, but there was no reliable point of reference: the indicator was the *only* analytical tool of its type.

Exchanging makes or types of instrument suggested that the underlying principles of the indicator were sound, and that results obtained from a clean, well-lubricated example truly reflected what happened within a cylinder. In addition, the earliest continuous recorders showed that individual diagrams could be replicated. Trials sometimes showed that the over-trace of twenty consecutive strokes was nothing other than a 'thick-line' version of each individual component. But this did not identify or quantify errors inherent in the indicator, showing merely that they were repeated from stroke to stroke.

In 1885, the British Institution of Civil Engineers published two significant lectures: 'On the Theory of the Indicator and the Errors in Indicator Diagrams' by Osborne Reynolds, and 'Experiments on the Steam-Engine Indicator' by Arthur Brightmore, 'late Berkeley Fellow in Owens College, Manchester'. Attended by some of the leading British engineers of the day, these stimulated lively discussion. Reynolds had opened the proceedings by questioning the 'extreme extent [to which] the indicator is now trusted to give a true measure of the work on the piston'. He continued: '…In ninety-nine cases out of every hundred, there is absolutely no check within 20 or 30 per cent. In some engines (winding and pumping) the work they are performing is of a measureable kind, but rarely or never is the work measurable to within 5 or 10 per cent. The only work which is definitely measurable is that done on the friction-brake…; and even then, although the brake may give a measure of the actual work to within 1 per cent or less, it does not furnish a check on the indicator to within from 5 to 20 per cent, for between the work measured by the indicator and that measured by the brake is the unknown work done in overcoming the resistance of the engine. This…is an absolutely unknown quantity, except in so far as it is found by subtracting the brake power from the indicated-power, and hence furnishes no check within its own magnitude on these qualities… There is thus absolutely no check on the indicator, which is now made the sole standard, not only of performance, but of the value of engines.'

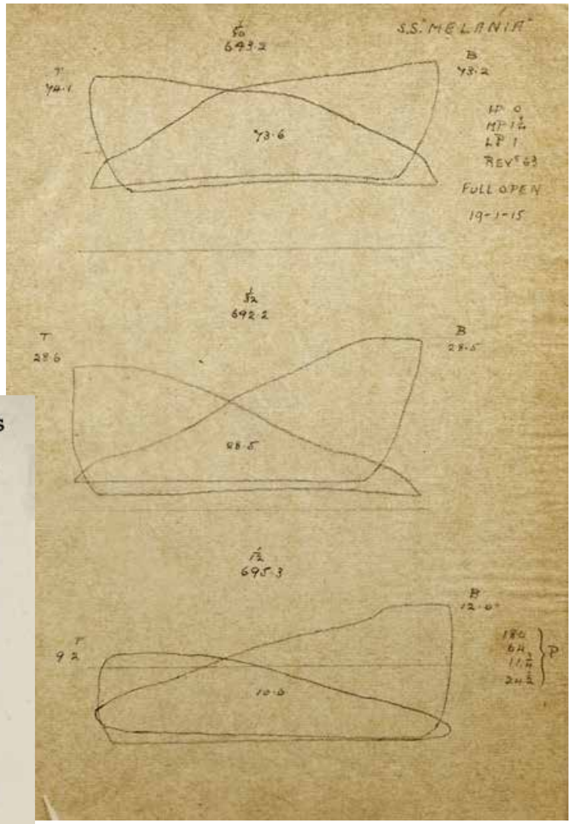
Reynolds went on to enumerate inherent causes of inaccuracy: inertia in the amplifying mechanism, friction arising between the trace-point and the card, variations in the performance of the springs, the inertia of the drum, and the friction in the drum. He attempted to deduce equations to explain performance, though these were often little more than attempts to express empirical results mathematically; at their best, however, they did predict what could happen and showed how to avoid the worst operating problems.

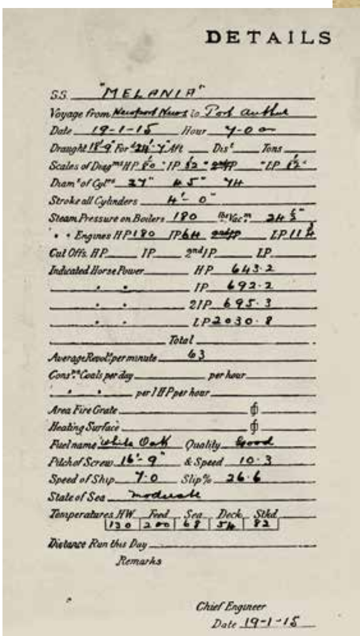
A major headache was provided by the individual parts of an indicator, as the forces of inertia and the direction of travel could not be easily be reduced to a simple calculation. However, Reynolds did provide specific data for the Elliott-Richards indicator. Experienced engineers knew that the instrument was reliable at 'normal' speeds, but that the diagrams deteriorated as running speeds increased. They also knew that substituting stiffer springs, though reducing the height of a diagram commensurately, provided smoother traces.

Reynolds suggested that for a '20lb spring', 'the limiting [maximum] speed at which diagrams can be taken as accurate to 5 per cent', was 138 rpm, and that the limiting speed 'for the diagrams to be sensibly accurate' was merely 69 rpm; for a '100lb spring', however, the figures were 310 and 155 rpm respectively. This accorded well with practise, which regarded 250 rpm as the maximum speed at which a Richards indicator would be satisfactory.

The lectures promoted a lengthy, lively, if partisan and often contradictory exchange of views. Some respondents took offence at Reynolds' suggestion that indicating errors could be as high as 30 per cent, arguing that trained

Plates 14 and 15. Tracings of cards taken in January 1915 from the engine of Shell tanker *Melania* by her Chief Engineer, George Clark, and details entered into his personal copy of McGibbon's *Indicator Diagrams for Marine Engineers* (third edition, 1906). *John Walter collection.*




DETAILS

SS "MELANIA"
Voyage from Newport News to Port Arthur
Date 19-1-15 Hour 7-0 am
Draught 18'-9" For'd 24'-7" Aft Dis.t Tons
Scales of Diag.ms HP 1/60 IP 1/32 2nd IP LP 1/12
Diam.r of Cyl.rs 27" 45" 74
Stroke all Cylinders 4'-0"
Steam Pressure on Boilers 180 lbs Vac.m 24½"
" " Engines HP 180 IP 64 2nd IP LP 11¼
Cut Offs HP IP 2nd IP LP
Indicated Horse Power HP 643.2
" " IP 692.2
" " 2IP 695.3
" " LP 2030.8
Total
Average Revol.s per minute 63
Cons.n Coals per day per hour
" " per I H P per hour
Area Fire Grate
Heating Surface
Fuel name White Oak Quality Good
Pitch of Screw 16'-9" & Speed 10.3
Speed of Ship 7.0 Slip % 26.6
State of Sea moderate

Temperatures HW	Feed	Sea	Deck	Stkd
130	200	68	54	82

Distance Run this Day
Remarks

Chief Engineer
Date 19-1-15

Taken from a triple-expansion engine, the diagrams show the high-pressure cylinder (top) to be working effectively, but also that remedial work to the intermediate (middle) and low-pressure (bottom) cylinders must be done to balance the output of the out/in strokes. The low-pressure unit shows this clearly.

engineers could not be hoodwinked so easily; others drew attention to the fact that no other type of indicator had been subjected to scrutiny, and that results pertaining to the Elliott-Richards may not necessarily apply to newer designs in which the weight of the moving parts had been greatly reduced.

The promoters of the Crosby, which was generally agreed to be the best of the designs available in 1885 for use on engines running at 400 rpm or more, argued for the superiority of their design. Engineer Arthur Rigg 'observed that the Richards indicator was undoubtedly a great improvement on its predecessors; but as speeds had increased, it had long ago been distanced by others, and nobody would think of using it [even in 1885!] for very accurate researches'. Charles Richards himself 'thought it probable…that the best of the most modern forms of indicators, when applied in the careful manner now generally practised by educated engineers, did give indications which were generally correct. In addition, he had 'examined critically a large number of indicator cards, taken from various engines, with modern indicators, used interchangeably at the opposite ends of engine cylinders, and he could not discover a difference of more than 1⁄50-inch in the lengths of the diagrams from opposite ends… This of course did not prove the absence of defects in the drum's movements; but…it seemed to him that evidence was afforded of the practical correctness of the movement of the drums in the best indicators'.

In addition to the faults that could be attributed to the indicator, many other factors were named as contributing to errors: stretching of the cord connecting the engine to the indicator and an inefficient means of reducing stroke-length to the dimensions of the diagram-card could each contribute an error far greater than anything attributable to the indicator itself. So, too, did steam pipes that were too long or unduly narrow; using a single instrument to indicate both ends of a cylinder without ensuring that the steam pipes were of identical length; or even using separate indicators to record each cylinder-end, as the performance of the two springs, even if rated similarly, could not be guaranteed to perform identically.

Reynolds' work concentrated almost exclusively on drawbacks of the indicator, but a potentially greater threat to accuracy was posed by the springs. Exceptionally detailed trials had been undertaken in 1874–6 by Professor Berndt of the königlich höheren Gewerbeschule zu Chemnitz, a summary of the results being published in the school's own yearbooks and in the proceedings of the Sächsische Ingenieur und Architecten Verein. The springs were accompanied by seven Richards indicators—three made by Elliott Bros. (nos. 466, 499 and 1834), four by Schaeffer & Budenberg (nos. 221, 306, 474 and 895)—and at least one Ashton & Storey cumulative recorder. Individual springs were tested in a 'free' state, unencumbered by the indicators, both at room temperature and after being heated in steam at 90° C; they were then tested in the indicators. Among the goals was to discover if the springs compressed consistently, if there was a difference between 'cold' and 'hot' performance, and if the scales supplied with the indicators could be trusted.

The results made unhappy reading for those who believed the indicator to be infallible. Rates of compression varied as loads increased, springs acquired a 'set' at the limits of compression which often only partly dissipated when

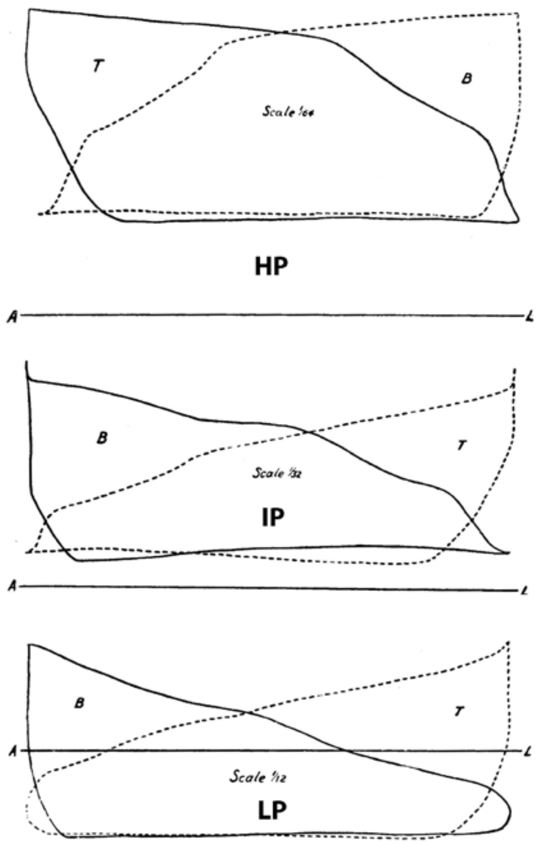


Plate 16. Cards taken from the cylinders of the triple-expansion engine of SS *Clan Macalister* prior to 1914. Note that each diagram was taken using a different spring; to gain an idea of the relative power of each of the cylinders, the height of the high-pressure diagram (top) needs to be doubled, and the height of the low-pressure diagram (bottom) needs to be reduced to three-eighths. Changing springs ensured that the vertical spread of the diagrams made best use of the indicator-drum.

Taken from the fifth edition of McGibbon's *Indicator Diagrams for Marine Engineers*.

they were re-extended; heated springs performed measurably differently to those tried at room temperature; and the results predicted by scaling the diagrams from the rulers almost always deviated from those predicted by gauging the spring. Rates of compression varied as load was applied (most obviously when loads were less than a quarter of the maximum) and the differences between individual springs could be considerable.

One particular spring ('E'), tested at pressures rising from 34 to 68 lb/sq.in, then falling from 68 to 19 lb/sq.in, read 11·6 per cent greater than the scale-ruler predicted on the upward movement and a staggering 24·1 per cent high on the descent; another ('C_1'), tested at 36–68 and 68–19 lb/sq.in, recorded 3·6 per cent low on the ascent and 7·8 per cent high on the descent!

Discrepancies between the phases of the trials were also evident, as 'C_1', accompanied by a scale that suggested a rate of 45·1 lb/sq.in per inch, when tested with a supply at 64 lb/sq.in returned figures ranging from 42·5 to 46·4. Interestingly, the 'free spring' tests on 'C_1', hot and cold, both originally gave 37·7 lb/sq.in per inch. But the implication was clear: assessing results on the basis of the scale-rule risked considerable error.

The results of Berndt's painstaking experiments were summarised in the leading British journals in 1877, including *Engineering*.[8] Acknowledging the value of the work that had been done, the editor could not resist a jibe reflecting British notions of technological superiority: 'It should be mentioned that… German springs have not, or at least had not until lately, the scale indicated on them…, nor was there any statement on the boxwood scales supplied with the instruments as to what the scales were intended to stand for… The intended scales for the English indicators are, of course, always known.'

Three of the indicators used by Berndt had been made by Elliott Brothers, and there was little to suggest that they had performed much better than the Schaeffer & Budenberg instruments (with the exception of S&B indicator 'E', no. 306, which was admitted to have been 'a good deal used').

Of course, great strides had been made in the manufacture and regulation of springs by 1914—but just how good were they? There were many factors to consider: whether the spring was new, if it had been subjected to prolonged exposure to excessive heat or moisture, and if it had ever been recalibrated. It seems likely that virtually every maker of indicators offered maintenance facilities, though, judged by surviving literature, not all of them drew attention to these services. And it is true to say that few indicators are now found with any indication that they have been regularly serviced.

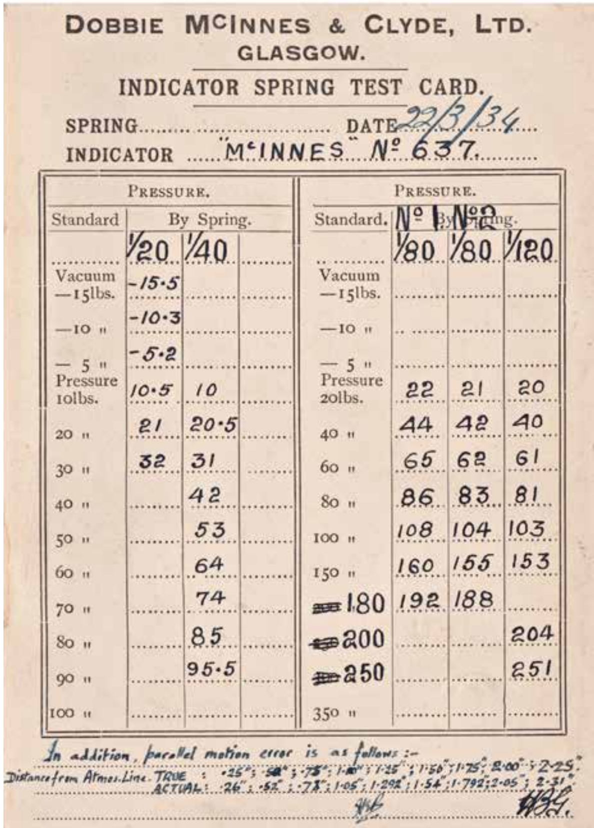
There are exceptions: Dobbie McInnes advised periodic recalibration (the Royal Navy indicators are said to have been returned annually), and 'check cards' will occasionally be found in their boxes. In addition, a few modern German instruments—Maihak, Leutert, Lemag—are occasionally found with information pasted inside the lid or in the accompanying manual.

Typical is a card found with McInnes indicator no. 637—an old instrument made in the early 1890s, but still in good repair when the assessment was made on 22nd March 1934. The box contained five springs: 1/20 and 1/40 for low-pressure use; 1/80 'No. 1', 1/80 'No. 2' and 1/120 for higher pressures. There is no way of knowing if new springs had been substituted, though careful examination of patina, wear-patterns and discolouration of the box-

8. See issues of 16th November 1877, pp. 382–3; 30th November 1877, pp. 420–2; 1st February 1878, pp. 77–8; and 19th April 1878, pp. 294–5.

Plate 17. A test card made by Dobbie McInnes & Clyde in 1934, to test the performance of springs accompanying an indicator that had been made than forty years previously. The results confirm that not only were errors to be expected, but also that they varied considerably from spring to spring.

John Walter collection.



DOBBIE McINNES & CLYDE, LTD.
GLASGOW.
INDICATOR SPRING TEST CARD.
SPRING .... DATE 22/3/34
INDICATOR ...... "McINNES" No 637.

Pressure. Standard	By Spring. 1/20	1/40		Pressure. Standard.	No 1 1/80	No 2 1/80	1/120
Vacuum —15lbs.	-15·5			Vacuum —15lbs.			
—10 "	-10·3			—10 "			
— 5 "	-5·2			— 5 "			
Pressure 10lbs.	10·5	10		Pressure 20lbs.	22	21	20
20 "	21	20·5		40 "	44	42	40
30 "	32	31		60 "	65	62	61
40 "		42		80 "	86	83	81
50 "		53		100 "	108	104	103
60 "		64		150 "	160	155	153
70 "		74		180	192	188	
80 "		85		200			204
90 "		95·5		250			251
100 "				350 "			

In addition, parallel motion error is as follows :-
Distance from Atmos. Line. TRUE : ·25"; ·50"; ·75"; 1·00"; 1·25"; 1·50"; 1·75"; 2·00"; 2·25".
ACTUAL: ·26"; ·52"; ·78"; 1·05"; 1·292"; 1·54"; 1·792; 2·05; 2·31".
W.B.G.

wood suggested that they were probably original. Testing showed that the 1/20 spring gave results ranging from –15·5 at 15lb/sq.in to 10·5 at 10lb/sq.in and 32 at 30lb/sq.in. The 1/40 spring was accurate at 10lb/sq.in, but the error grew as pressures increased: 53 at 50lb/sq.in and 95·5 at 90lb/sq.in. Both of the 1/80 springs read high—21 (No. 2) and 22 (No. 1) at 20lb/sq.in; 83 (No. 2) and 86 (No. 1) at 80lb/sq.in; and 188 (No. 2) and 192 (No. 1) at 180lb/sq.in. The 1/120 spring was accurate below 50lb/sq.in, but read 3lb/sq.in too high at 100lb/sq.in and 4lb/sq.in high at 200lb/sq.in. That the 250lb/sq.in figure read merely 1lb/sq.in high was due largely to the fact that the springs were hand-made, hand-finished and manually calibrated (apparently when cold).

Testing also revealed that the amplifying mechanism of McInnes no. 637 contained significant errors. Deviation from the atmospheric line was 0·01 at a true 0·25 inches, 0·042 at a true 1·25 inches, and 0.06 at a true 2·25 inches. All the errors were high.

Dobbie McInnes DS1/2576, dating from *c.* 1903, was accompanied by two 'Indicator Spring Test Cards'. The older, dated 13th May 1908, suggested that no errors could be found with the suite of springs: 1/10, 1/40, 1/80, 1/120, 1/160 and 1/200 (a questionable assessment which smacks of approximation, even though the springs were merely five years old).

The later card, made on 9th September 1952, revealed that all the springs under-read, though the error varied. The 1/40 'No. 1' spring was accurate to 40lb/sq.in, but gave 49·7 at 50lb/sq.in and 59·3 at 60lb/sq.in; 1/40 'No. 5' was accurate to 20lb/sq.in, but gave 29·5 at 30lb/sq.in, 39 at 40lb/sq.in, 49 at 50lb/sq.in, and 58·5 at 60lb/sq.in. The 1/80 spring gave 59 at 60lb/sq.in, 78 at 80lb/sq.in and 98 at 100lb/sq.in. The 1/120 spring gave 79 at 80lb/sq.in, 99 at 100lb/sq.in, 149 at 150lb/sq.in and 176 at 180lb/sq.in.

The 1/150 spring was accurate to 60lb/sq.in, then gave 79 at 80lb/sq.in, 98 at 100lb/sq.in, 145 at 150lb/sq.in, 195 at 200lb/sq.in and 218 at 225lb/sq.in. Finally, the 1/160 spring read accurately to 80lb/sq.in, then gave 98 at 100lb/sq.in, 147 at 150lb/sq.in, 197 at 200lb/sq.in and 245 at 250lb/sq.in. These all seem reasonable assessments: an error of two per cent was usually accepted as normal when mechanical indicators are employed.

Cards accompanying Maihak no. 20896, prepared on 26th May 1953, showed that the one of the 1/36 springs was reading two per cent high at loads between 10 and 50lb/sq.in—30·6 at 30lb/sq.in, for example—and that the other was reading one per cent high (30·3 at 30lb/sq.in). The cards show that slight alterations had ensured that the calibration was 'Now Correct'.

Dobbie McInnes & Clyde Design No. 1G no. D1B/24769.R., dating *c.* 1932, was accompanied by a test card prepared on 7th December 1945. This shows that the indicator was accompanied by four springs: 1/16 for low-pressure diagrams, and 1/400 and two 1/500 examples for use on internal-combustion engines. The 1/16 spring registered –14.8 instead of –15lb/sq.in on test, but was otherwise accurate; the 1/400 spring registered 98 and 198 instead of 100 and 200lb/sq.in, but was accurate at pressures up to 600lb/sq.in. The 'No. 1' 1/500 spring was accurate from 100 to 400/sq.in, but then gave 498 for 500/sq.in, 598 for 600/sq.in, 695 for 700/sq.in, and 790 for 800/sq.in; 'No. 2' was accurate at 100lb/sq.in, gave 196 for 200/sq.in, 295 for 300/sq.in, 395 for 400/sq.in and 497 for 500/sq.in, but the results for 600–800lb/sq.in coincided.

Almost all of these test results show that most indicators suffered from inherent inaccuracy, though few manufacturers were prepared to admit it. Claims and counter-claims were made in engineering literature, and periodic attempts were made by individual manufacturers to promote their products to the detriment of others. In 1913, *Engineering* reported a lecture by James

Stewart 'of Dundee', undertaken with the assistance of the University of Birmingham, which attempted to identify and then quantify the principal factors that degraded accuracy. Yet the mechanical indicator had much to commend it, even though inherent errors of one per cent were probably unavoidable and the tendency to deduce results to several places of decimals was too often encouraged.

In 1923, a series of lectures championed by the Institution of Mechanical Engineers drew attention to new types of indicator—micro, optical and spark-trace. The opening lecture was given by Loughnan Pendred, who began by acknowledging the validity of the work of Osborne Reynolds nearly fifty years previously: 'Although…Reynolds probably exaggerated the inaccuracy of indicator cards, and although improvements in the instruments themselves

Plate 18. Hopkinson Flash-Light Indicator no. 183, made by Dobbie McInnes, looks to be as simple as its mechanically operated rivals, but needed a large light-fast hood to obtain a satisfactory photographic trace. It also had unique inherent accuracy problems which were never truly resolved.

John Walter collection.

have been effected since he wrote, yet a careful survey of the whole subject leads to the conclusion that no indicators can be relied upon to give results accurate enough to justify the use that is sometimes made of the cards… The Author [Pendred] ventures to suggest that just as in making standard mechanical parts a tolerance is recognized, so in expressing relationships between factors which have to be obtained by fallible instruments it would be more honest to state clearly that an error of unknown amount exists. In the case of indicated horse-power he would make that tolerance something like five per cent for all engines running at or over 300 r.p.m. and *for all indicators* [my italics]…' [9]

Pendred then remarked that 'All indicators designed for the highest speeds differ in one important respect from the familiar mechanical indicators. Their portability is far less, they are, without exception, rather the instruments of the laboratory than of the engine-house or its equivalent. There remains therefore still plenty of scope for the invention of an instrument which could be carried about as readily as a Tabor or a Crosby…'

The mechanical indicator had proved itself not only with steam engines, but also with the first internal combustion engines.[10] It could be applied to

Plate 19. Compact mechanical indicators such as this Maihak 30z operated sufficiently well at high-speed to fend off the advances of competing systems for many years.

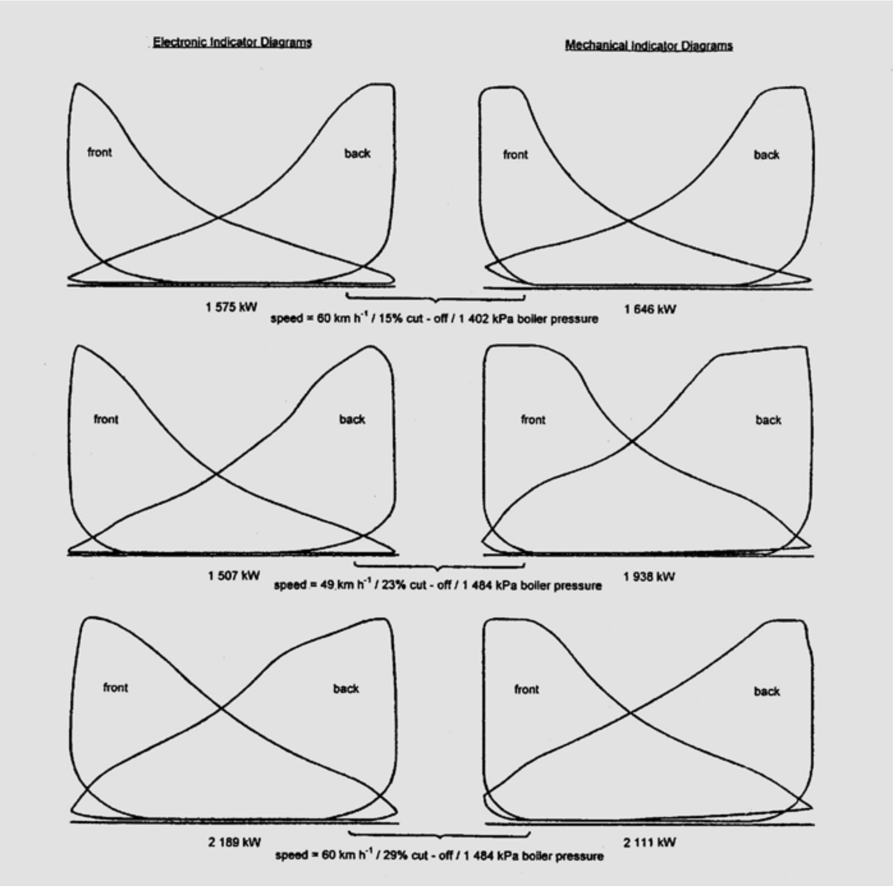
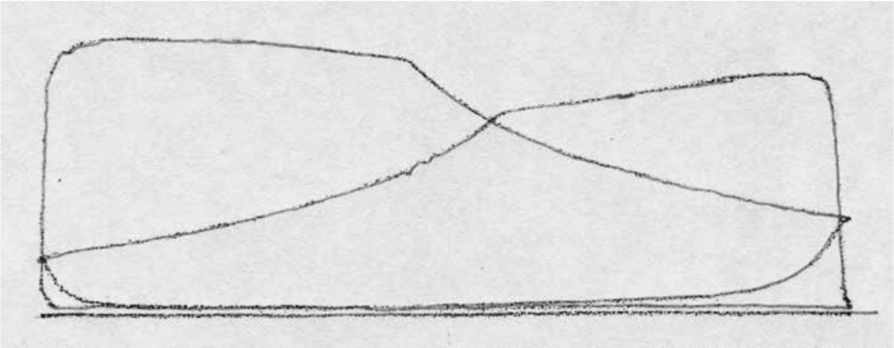


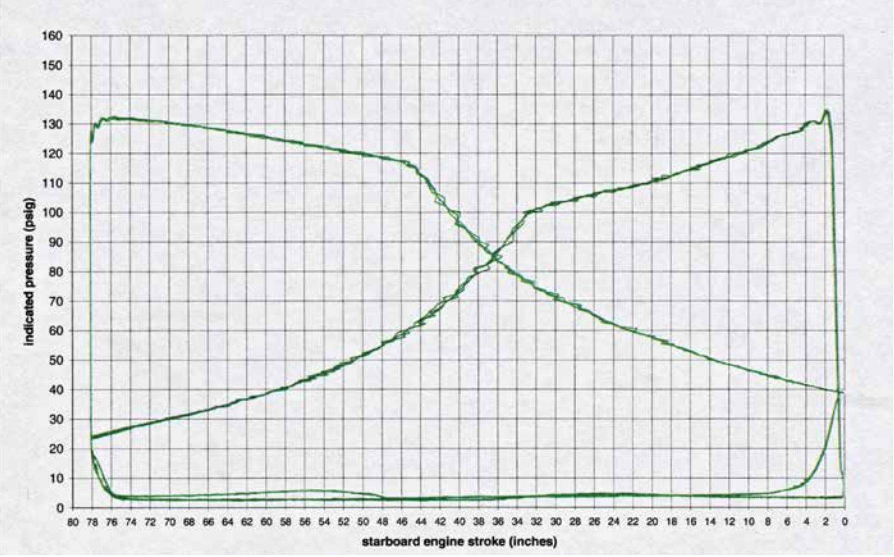
Plate 20. Typical indicator diagrams obtained from the South African Railways Class 26 locomotive—generated electronically (left) and mechanically (right). Though the two groups take essentially similar forms, they differ greatly in detail. This was at least partly due to a problem with the reversing shaft, which, as a result, gave a longer cut-off in the left cylinder than the right. This was sufficient to prevent exact comparisons being made. From *The Red Devil and Other Tales of the Age of Steam*.

9. The engineering periodicals of the period were littered with details of experiments recording results with unacceptable precision. Even the Royal Navy was not immune to the practice, as published trials confirm. For example, the trials of HMS *Powerful* run in 1896 gave '18433' ihp, which would have been more acceptably written as '18430±450', assuming an indicator error (not unreasonably) of 2·5 per cent.
10. However, though mechanical indicators can give acceptable cards from two- and four-stroke 'explosion engines' (gas, oil, paraffin, petrol), they are at their best with compression-ignition (Diesel) designs, in which the operating cycle is not generally as violent.

air pumps, hydraulic systems and even large guns. Inherent inaccuracy was, perhaps, less of a problem than some commentators claimed (as long as the errors were comparatively small); in few instances did an discrepancy of a few horsepower matter. Much more important was the ability of an indicator to detect operating problems before they became critical. At sea, damage to a valve could be potentially catastrophic if it led to the failure of a ship's only source of motive power. It is no surprise to record that mechanical indicators

Plates 20 and 21. Typical cards from *Belle of Louisville*: mechanical (top) and electronic. Different vertical scales prevent a direct visual comparison, but the overall similarity of form is clear to see. *By courtesy of Bruce Babcock and Keith Baylor.*





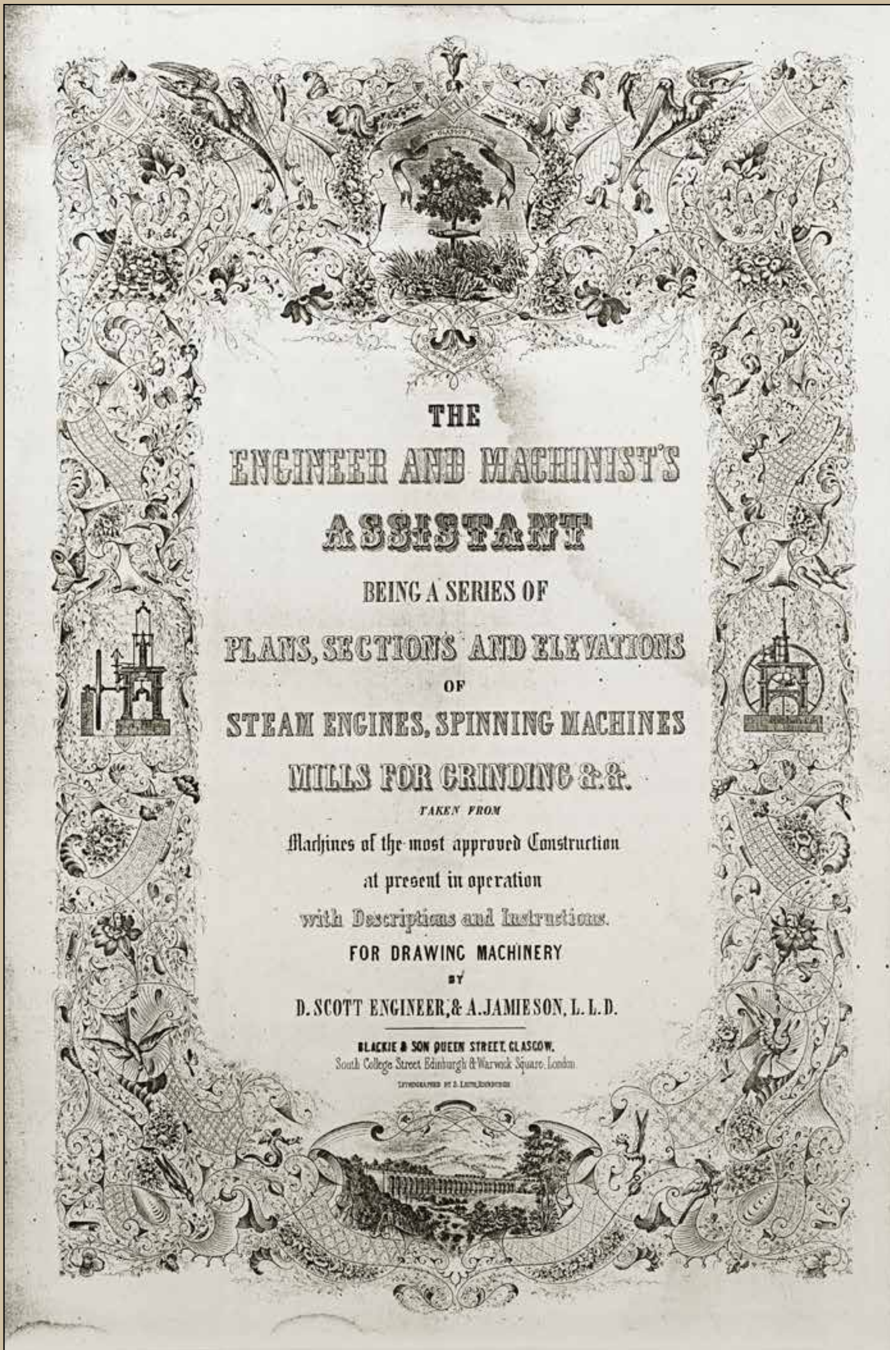
which would not been unfamiliar to Osborne Reynolds are still being made for use with marine- and comparable large-scale diesel engines.

The opportunity has also been taken to compare results obtained with mechanical indicators with those generated by electronic means. For example, a South African Class 26 4–8–4 railway locomotive was tested in the 1980s with a Dobbie McInnes No. 4 indicator on one cylinder and an electronic system on the other. Unfortunately, the chance to use both systems on the same cylinder could not be taken; though the results were broadly comparable, differences in response inevitably provided results which differed in detail. In addition, indicator diagrams obtained the cylinders of locomotive engines—particularly when running at speed on something other than level track—are notoriously difficult to reconcile.

The same caveats apply to trials undertaken in May–July and October 2005 on the engines of *Belle of Louisville*, a 1914-vintage Mississippi stern-wheel riverboat. Mechanical indication was undertaken by Bruce Babcock, with unrivalled experience of using a hunded-year-old Robertson-Thompson indicator, and the electronic datalogger system was created by Keith Baylor.[11] Though tests were made separately, there was surprisingly good agreement between diagrams taken under comparable parameters. Keith Baylor has stated his belief that 'the electronic approach captures some detail that is masked by the inertia of the mechanical units, but…otherwise they exhibit remarkable agreement'. The cards shown here are generally similar; in addition, the indicated horsepower, 66·5 (electronic method) and 66·6 (mechanical method), deviates by merely 0·15 per cent.

It is to be hoped that someone, somewhere, will eventually provide an unarguable demonstration of the abilities of the mechanical indicator by direct comparison with simultaneous electronic data-gathering. It seems likely that results will be closer than many critics have allowed.

11. Though the Robertson-Thompson indicator was in good condition, and performed admirably, the 100lb spring had weakened with age. Tests suggested that it should be re-rated at 87lb, the figure that was subsequently employed in the calculations.



THE

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Plate 22. The decorative title page of
The Engineer and Machinist's Assistant (1845), a text book containing details of the
McNaught and Morin indicators. *John Walter collection.*

1. Simple beginnings

The Scottish engineer James Watt (1736–1819) is customarily accorded credit for defining the 'horse power', and was also the first (as far as we know) to produce a 'stand alone' method of indicating steam pressure within a cylinder.

Pressure gauges based on the mercury barometers of the 1780s proved to be not only too susceptible to vibration to give a true guide to the strength of the vacuum in the condenser of the Boulton & Watt beam engines, but also too difficult to read accurately. Something more robust was clearly needed if proper investigation was to be made of a cycle which had previously been the subject of guesswork and speculation.

According to Robison, in *Steam and Steam Engines*, Watt himself stated: 'The barometer being adapted only to ascertain the degree of exhaustion in the condenser where its variations were small, the vibrations of mercury rendered it very difficult, if not impracticable, to ascertain the state of exhaustion in the cylinder at the different periods of the stroke of the engine; it became therefore necessary to contrive an instrument for that purpose that should be less subject to vibration and should show nearly the degree of exhaustion in the cylinder at all periods…'

He answered his problem, probably about 1790, with an indicator in which a small piston, travelling within a brass cylinder, moved a pointer; the greater the pressure, the greater the deflection, which, as the engines of the day were slow running, could be seen by an observer. A skilled man could note the progress of the pressure during the entire stroke, not only of the steam phase but also the vacuum produced by the condenser.

Watt recorded the details of his design: "A cylinder about an inch diameter, and six inches long, exceedingly truly bored, has a solid piston accurately fitted to it, so as to slide easy by the help of some oil; the stem of the piston is guided in the direction of the axis of the cylinder, so that it may not be subject to jam or cause friction in any part of its motion. The bottom of this cylinder has a cock and a small pipe joined to it, which, having a conical end, may be inserted in a hole drilled in the cylinder of the engine near one of the ends,

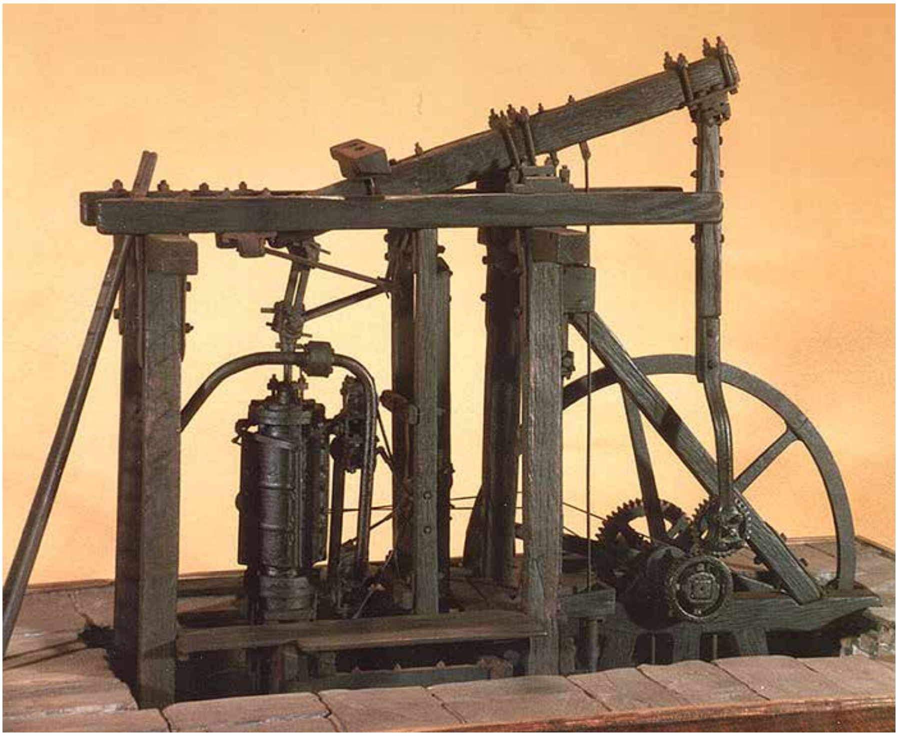


Plate 23. A model of a Watt-pattern rotative beam engine with sun-and-planet motion, introduced in the 1780s to circumvent a patent granted to an entrepreneur named Pickard to protect crank-drive. Comparatively few machines of this type were made. *Formerly in the collection of the British Engineerium, Hove, England.*

so that by opening the small cock, a communication maybe effected between the inside of the cylinder and the indicator.

"The cylinder of the indicator is fastened upon a wooden or metal frame, more than twice its own length; one end of a spiral steel spring, like that of a spring steelyard, is attached to the upper end of the frame and the other end of the spring is attached to the upper end of the piston-rod of the indicator. The spring is made of such a strength, that when the cylinder of the indicator is perfectly exhausted, the pressure of the atmosphere may force its piston down within an inch of its bottom. An index being fixed to the top of its piston rod, the point where it stands, when quite exhausted, is marked from an observation of a barometer communicating with the same exhausted vessel, and the scale divided accordingly."

Exactly when this machine was made remains in dispute, and it has been suggested that it dates from the development of the first engines to work expansively. The Boulton & Watt Papers, now in the care of the Birmingham Museum of Science & Industry, contain a variety of references to the indicators dating back to 1794. They include a paper entitled ‘Experiments made with the Steam Engine constructed by Boulton & Watt at Salford Cotton Mill’, which is endorsed ‘G. Lee’s Experiments with Indicator, 1796’.

Watt’s primitive gauge worked well enough to enable the operating characteristics of individual engines to be determined, but the method of recording changes in pressure 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 has an embrionic Watt indicator 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 a long 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.

This indicator was soon adapted to provide a written record of each individual application instead of merely a transient observation that could only be recorded separately. 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’. However, it seems as though the first design relied on a static sheet of paper (or, perhaps, a roll) on which the pressure/time trace could be drawn. This may have been nothing more than a line (or possibly an arc) from which the maximum pressure and the strength of the vacuum could be deduced.

In the summer of 1796, Southern suggested adapting the ‘recording indicator’ by adding a recording-board or tablet that slid within a supporting frame. A cord attached to the beam—often indirectly—pulled the tablet sideways as, simultaneously, the pencil-pointer recorded the rise of pressure in the cylinder on a sheet of paper.

On 13th August 1796, in a letter to a Boulton & Watt erector named Lawson, Southern expressed doubts that diagrams 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. The shape of this diagram remained characteristic of indicators made into the twentieth century, the earliest datable survivor being made in January 1803.

On 16th March 1797, Coke & Billingsley, proprietors of Pinxton China Clay Works (near Alfreton), enquired whether 'the machine for calculating the power of engines' could be used to investigate the poor performance of a newly-installed engine. By the early 1800s, the design of the moving-tablet indicator had been stabilised; on 5th February 1806, William Murdock asked Boulton & Watt, his employers, if an indicator could be supplied to 'Mr. Wedgwood [who] wishes you would make him an Indicator for his own use that he may try his Engine under different parts of the Machinery'.

A description of an indicator taken by James Watt the Younger to Paris in May 1839 was prepared for submission for the British Admiralty at a time when trials were to be undertaken with the paddle-frigates *Salamander* and *Hydra*. The perfected moving-tablet instrument had: "a cylinder full 1⅛ inch in diameter, so that its area is exactly 1 square inch, the length is 10⅛ inches. The spring has a tension of 1 lb. avoir. Per ¼ inch, and is capable of extending downwards about 4 inches, and of being compressed 1 inch or more. This range being considered ample for the purposes of low pressure steam. It is however customary to fit the cylinder with two pistons having springs differing in strength, one for low, the other for high pressure purposes. The scales of each being formed from the extension of the respective springs by a given weight. The upper end of the spring is attached to a washer under its cover, its lower end to the piston, the rod of which moves freely through the centre of the spiral, and also through the washer and cover.

"The piston is solid, fitting the cylinder tolerably tight without any packing, it being customary to pour a little oil in previous to immediate use, to render it airtight for the moment of experiment. The piston rod is formed

Plate 24. This copy of a Watt moving-tablet indicator was made from details supplied from the National Museum for Science and Industry ('Science Museum') in London.

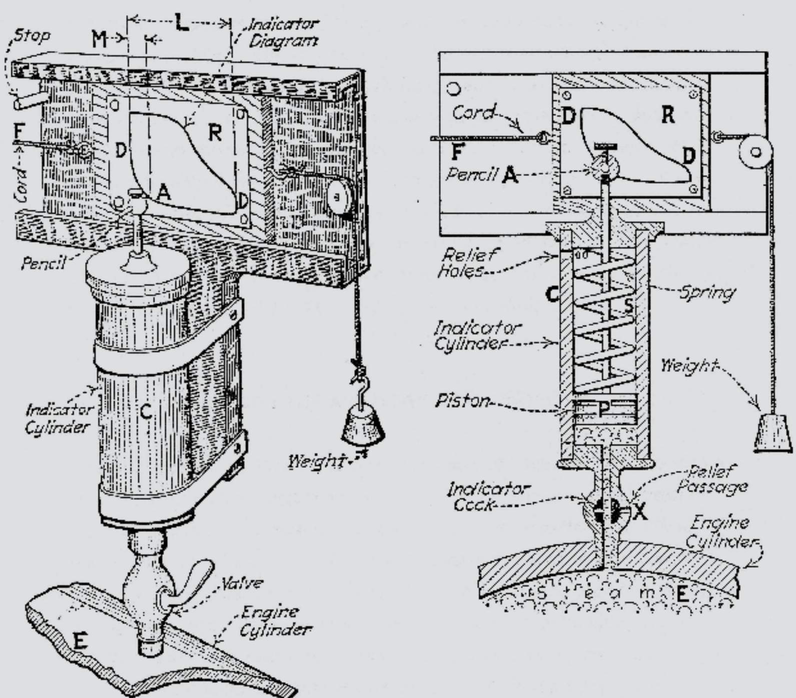
By courtesy of Bruce E. Babcock, Amanda, Ohio, U.S.A.

of a tube, for lightness and with a view to lessen its momentum when in action; on its upper end is fixed a brass tube containing a small & weak brass wire spring to push the pencil with which it is connected forwards at pleasure, the pencil being of a soft description to produce as little friction as possible while its point is passing over the paper.

"To the top of the indicator cover is fixed an iron frame by means of a thumb screw. In this frame is a sliding board or pannel [sic], made either of wood or iron (the latter is best, not being subject to warp with the heat) which moves freely in grooves. . . and upon which the paper is fixed for receiving the figure produced by the pencil during the period of the engine stroke.

"This sliding pannel [sic] has attached to its middle at the back two cords, also very pliable, one of which is fixed to any moveable part of the engine, such as the parallel motion or working gear, where the motion of the part does not exceed that of the length of the figure required, which is most generally 5 to 5½ inches.

"The other cord has a weight attached to its end for the purpose of overcoming the friction of the sliding board and producing the return motion during the exhaustion part of the engine's stroke. The first mentioned cord moving it during the period of the admission of the steam. The motion of the board is therefore perfectly horizontal, in one direction receiving its impulse



Pate 25: a Watt-type indicator

A Watt-pattern indicator: previous page

Taken from Day's *Indicator Diagrams and Engine and Boiler Testing* (1898), this drawing shows a typical 1840-vintage Watt indicator. It consisted of a vertical tube **C**—approximately 10in high with a diameter of 1.125in—attached to an iron or wood frame **D** at the top and a steam cock **B** at the base. The pipe was usually designed to mate with the grease cock on the cylinder-cap of the engine **A**, but could also sometimes be fitted to the lower end of the cylinder to check the valve settings. The tube contained a tight-fitting piston **F** with a hollow tail rod extending upward through the top cap. A short transverse brass tube, containing a light spiral spring and a pencil or pencil or 'crayon' **L** was fixed to the tail rod to serve as an indicating pointer.

A large spiral spring **I** was contained within the piston-tube, surrounding the tail rod. The spring was anchored in the back of the piston head and either in a bracket on the supporting frame **D** or in the top-cap of the tube, so that it was capable of a limited amount of compression (to register the low maximum pressures of the Watt beam engines) or a larger degree of extension to register the vacuum created in the condenser.

An extra main spring was often provided in the fitted wooden indicator-case, so that 'high pressure' engines (which then rarely exceeded 40lb/in^2) could also be accommodated.

The pencil **L** traced its linear diagram onto a sheet of paper, pinned or clamped in place, as the tablet **K** slid along the under-edge of its supporting frame **E**. A cord **O** attached to the tablet was led around a small pulley on the frame **E** to a suitable moving point on the engine — on the parallel motion, for example — which moved no greater than the six inches required for the diagram. The return stroke of the tablet was undertaken with the help of a weight **N** suspended from another cord running over a pulley on the opposite side of the indicator frame to complete the diagram.

from the part of the engine to which it is attached, and in the other from the preponderance of the weight. The bottom of the indicator cylinder is fitted with a stop cock which terminates in a tube whose diameter is usually made to fit the hole of the grease cock in the top of the engine cover."

Watt moving-tablet indicators were made only in small numbers in the Soho manufactory, remaining in perpetually short supply until the 1820s and were usually jealously guarded by the erectors employed by Boulton & Watt. Construction and design often differed greatly in detail; for example, a long spiral spring was often substituted for the cord and weight. Many of these simple tools were still being used in the 1850s, even though, judged by later standards, excessive friction in the moving parts led to inefficiency.

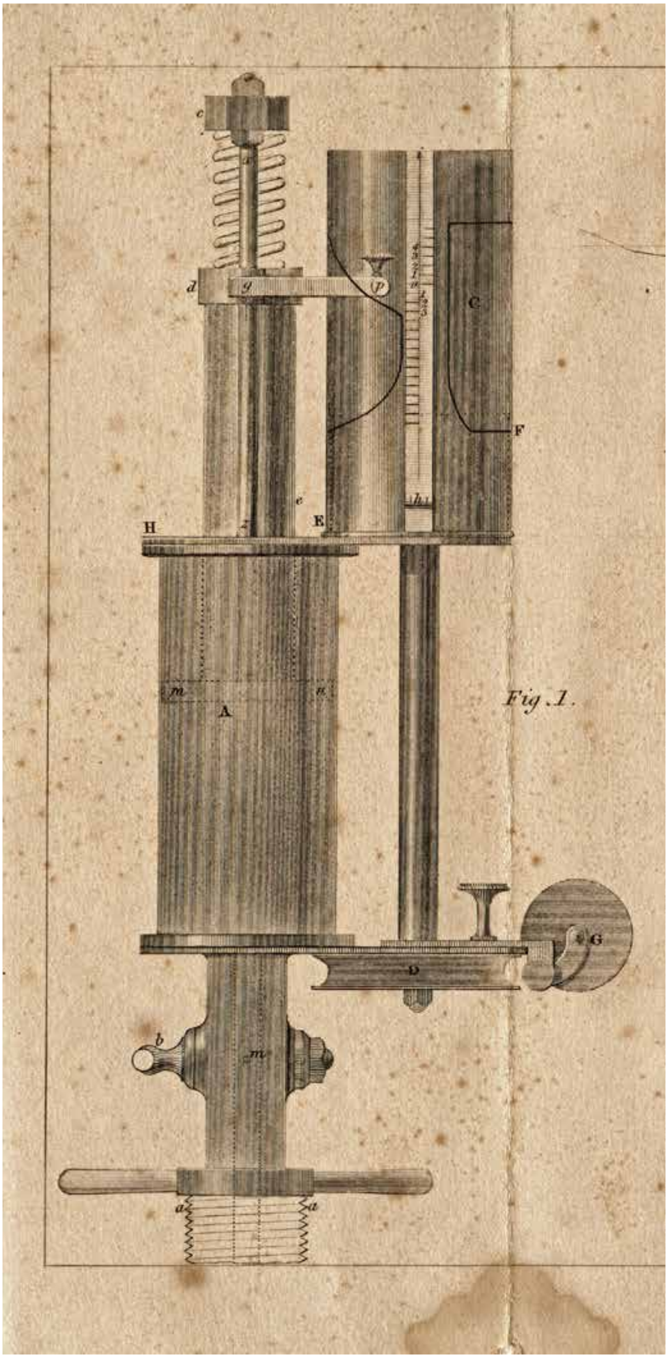
The slow movements of the beam engines and their low operating pressures were just as great inhibitors of accuracy as poor indicator construction, but it soon became clear that improvements could be made. Watt moving-tablet indicators were rapidly eclipsed first by the McNaught instruments and then by the many 'high speed' designs deriving from the Richards pattern.

James Watt was a secretive man, obsessed in keeping his ideas from others, and the development of a recording indicator was kept from the prying eyes of others. In his evidence to the Select Committee on the Law relative to Patents and Inventions, whose report was published in 1829, John Farey claimed that: "Many years ago Mr. Watt invented and applied a small instrument which he called an Indicator, to his steam engine; it indicates what extent of plenum and vacuum is alternately formed within the cylinder, in order to impel the piston when the engine is at work. It is of very important use in giving engine makers true knowledge how to make good engines; and it was of very great use to the inventor just as a hydrometer is to a distiller. He kept it a profound secret for many years, and in 1814 when he published an account of his other inventions he gave only an imperfect description of a part of this one, without any hint of parts which are essential to the successful use. A complete instrument afterwards fell into my hands in Russia [in 1819], where it had been made by some of the people sent out from this country with Mr. Watt's steam engines. At my return to England I made one and also shewed several other engineers [apparently including McNaught] how to make such for themselves and since that time everyone of those persons has very greatly improved his practice by the light it has enabled him to throw upon an obscure part of the operation of steam in an engine. One person who had made an indicator from a sketch that I drew for him, has since printed a description of it in a public journal."

Details were published in an 'Account of a Steam Engine Indicator', a letter submitted by 'H.H. junr.' to *The Quarterly Journal of Science* in 1822 (Vol. XIII, p. 91). The letter credits knowledge of the indicator to Joshua Field of Maudslay, Son & Field, and manufacture to a foundry owned by 'Mr Hutton of Anderston in this City [Glasgow]'. However, progress was slow. As late as 1835, the renowned engineer John Rastrick still had to beg an instrument from James Watt the Younger to test a blowing engine.

The first major advance was made by replacing the reciprocating tablet with a vertical drum, which was much more compact, easier to manage, and

Plate 26. Maudslay & Field's engine indicator, from an engraving published in 1847 in Main & Brown, *The Indicator and Dynamometer*. The age of this instrument is an open question, but dating it to 1822 or even earlier calls the attribution of the rotating drum to McNaught into question. Note also that this lays claim to be the prototype of the exposed-spring indicators of the late nineteenth century.



Appareils de M. Macnaught.

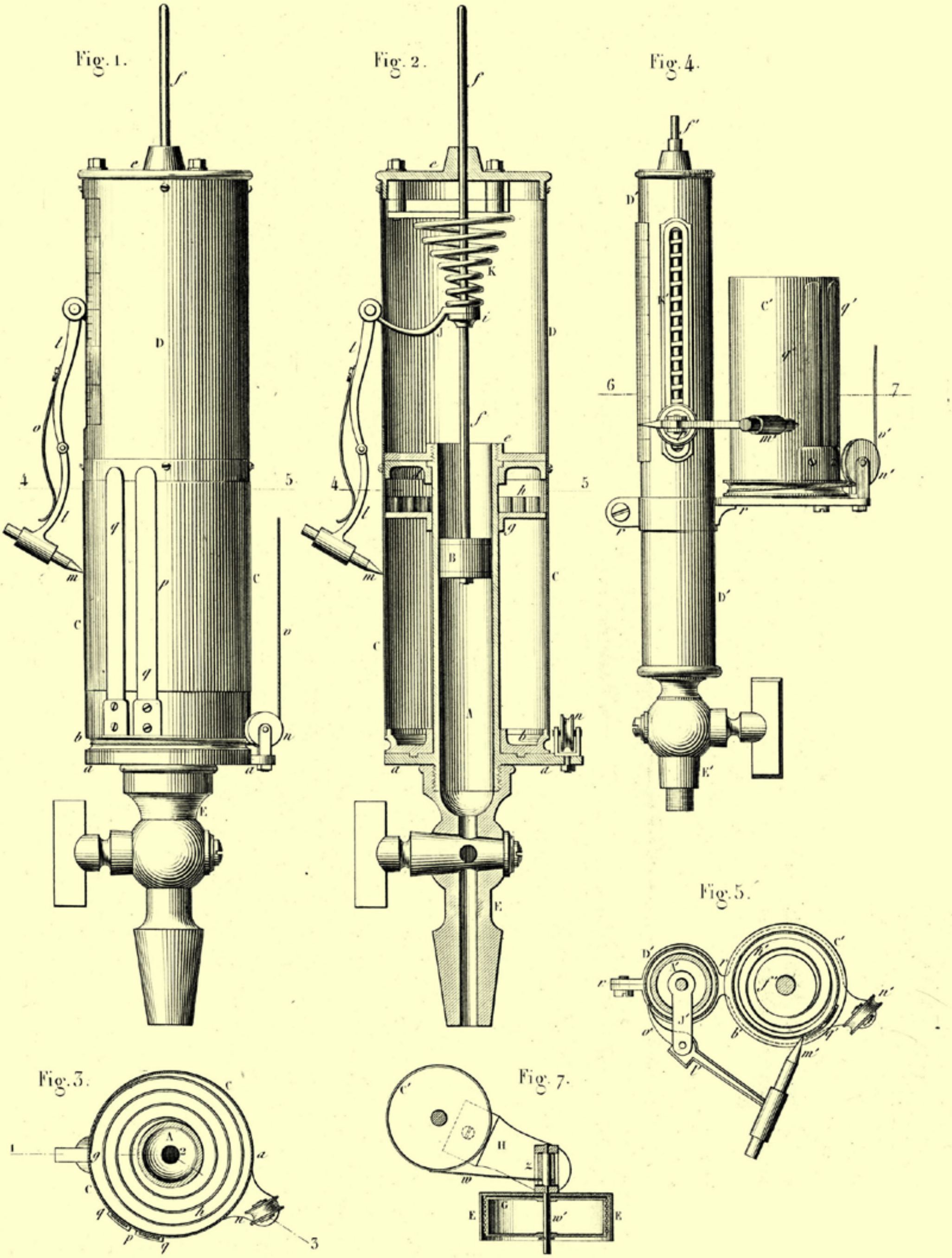


Plate 27, previous page. The McNaught indicators from Armengaude Âiné, *Publication Industrielle des Machines, Outils, et Appareils…* (Paris, 1859). The engravings are copied from 'Description de l'indicateur perfectionée de McNaught, modifié par M. Combes et construit par M. Martin', in Tôme 42 of the *Bulletin de la Société d'Encouragement* (1843) and give a good idea of the construction of the instruments of the late 1830s. *Engravings from the author's collection.*

offered less frictional resistance to the recording stroke. Inertial forces at the end of the stroke were greatly reduced, as the principal force acted at right-angles to the movement—away from the pivot, instead of directly in line with the tablet. The change of direction, therefore, was much less abrupt.

The instigator of this system is generally believed to have been John McNaught (or "M'Naught"), born in the parish of Shaws on 21st April 1771. Little is known about his early life—nor, indeed, how he became a steam engineer, though it is assumed he had served an apprenticeship with either a manufacturer (Cook & Company of Tradeston?) or an independent erector. McNaught married Mary Lindsay in October 1805, among their six children being the promoter of the first system of compounding to be truly successful in Britain: William McNaught (1813–81), whose 1845 English patent protected the addition of an additional high-pressure cylinder to existing single-cylinder engines.[1]

McNaught 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. The oscillating drum of the McNaught indicator relied on the piston stroke to make the first half-rotation 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, seeking recognition not only for the indicator but also for what was called an 'oil test'.

The material included a pamphlet, *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, at the latest, by the winter of 1827.

1. Several earlier attempts had been made in Britain to establish the value of compounding. However, a promising 1780s design by the Cornishman Jonathan Hornblower had fallen foul of James Watt's patent, and engines made to the later patents of Arthur Woolf, though made in England in small numbers (and often surprisingly efficient in use), proved to be much more successful in France.

John McNaught was unable to convince the Society of Arts that his indicator had real merit, the report of a committee chaired by the renowned architect James Milne finding it 'not materially different from that which was invented by the late Mr. Watt [who had died in 1819] and improved by Mr Feild [sic]'. Yet there must have been something of a change of heart: in the summer of 1830, McNaught was awarded the Silver Medal of the Society of Arts for Scotland for his inventions.

It has been claimed that indicators made by Maudslay, Sons & Field pre-dated and possibly influenced McNaught, and that Joshua Field was the first not only to offer an external spring but also to devise a rotating drum. An instrument of this design is pictured in *The Steam Engine* by John Bourne (first edition only, 1846), and in *The Indicator and Dynamometer* by Main & Brown, originally published in 1847; and an oblique reference, quoted above, was made to improvements in the indicator 'made by Mr Feild' detracting from the novelty of the instrument submitted by McNaught to the Society of Arts for Scotland in 1829. However, the case is far from proven.[2]

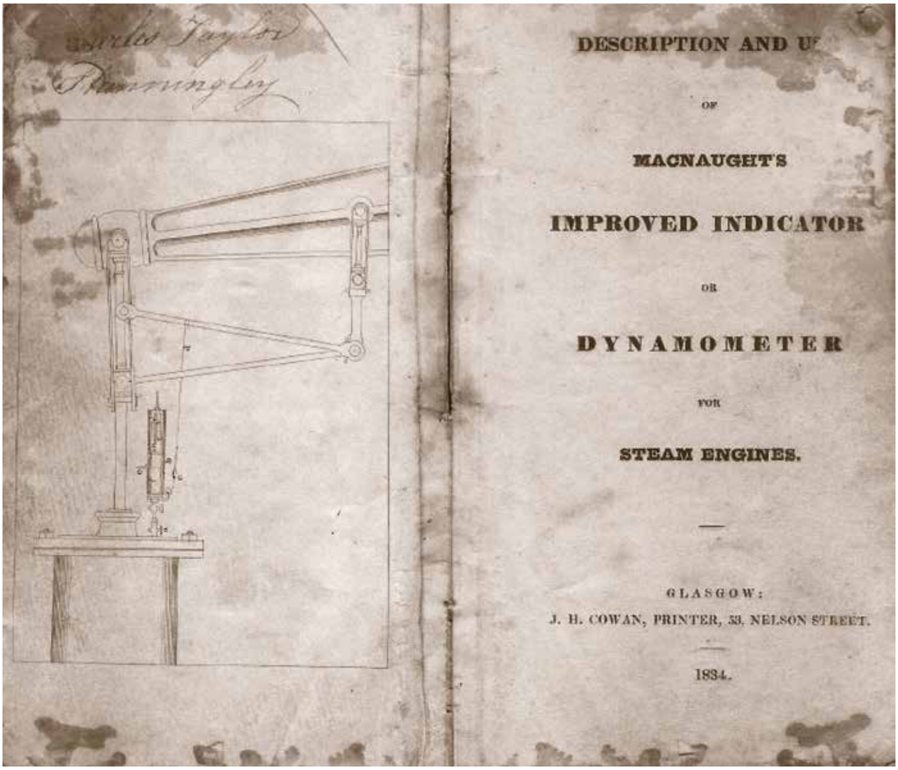


Plate 29. This co-axial McNaught indicator probably dates from the late 1830s or early 1840s, and is generally comparable with the engraving accompanying the article in *The Practical Mechanic and Engineer's Journal* in February 1842. Note the plain tapered plug of the steam-cock, showing that use of this instrument was confined to low-pressure engines. *By courtesy of Bruce E. Babcock, Amanda. Ohio, U.S.A.*

Plate 28, *left*. The title page of this McNaught indicator handbook is dated 1834. Though there is nothing to suggest that the instrument is as old, the design of the spring and the absence of a 'quick release' support for the pencil suggests that it was made prior to the mid 1840s. The indicator was found in a plain tin box (a contrast with the fitted wood case associated with later examples), which the discovery of a similarly equipped 1850s McNaught viscometer suggests was original.

The construction of the earliest McNaughts, the so-called 'co-axial' design, consists of a two-part cylinder of brass, the upper part or 'body' fixed to the two-part cap of the piston cylinder and the lower part or 'drum' free to revolve around a vertical axis formed by the same cylinder. The piston rod, which

2. Illustrations of what is supposed to be the Field indicator date from the late 1840s/early 1850s, quite clearly inspired by the publication of Main & Brown's book. The design and construction seem to owe more to the 1840s than the 1820s, and it is suspected that any indicators made by Maudslay, Sons & Field prior to 1822 may have been modifications of the original Watt pattern. Reliable information is still needed.

Plate 30. The McNaught indicator in its box. *Photograph by courtesy of Bruce Babcock.*

A McNaught-type indicator

The essence of a McNaught indicator, illustrated (Figure 1–2) in Charles Day's *Indicator Diagrams and Engine and Boiler Testing* (1898), was unchanged from Watt's reciprocating tablet system, with a steam-tight piston **P** sliding in a wood-insulated tube **W** beneath a spiral spring **S**, which was capable of extension or compression.

A pencil-pointer, attached to the piston tail rod **p** and controlled by a 'lifting bar' **R**, protruded through a slot in the wall of the tube **W** to trace a diagram on a paper strip held to the drum **B** by brass fingers. The drum contained a coil spring or *fusée*, which was anchored in the drum spindle and worked against a spindle fixed in the supporting bracket or platform.

When the outward stroke of the engine began, a cord **C** running back from the parallel motion, crosshead or suitable movable point, passed over a pulley **G** attached to the drum-support bracket.

This rotated the drum as the increase in steam pressure in the cylinder raised the pencil to begin the trace. As the inward stroke began, the spring rotated the drum back to its starting position as the cylinder pressure dropped. The return stroke thus completed the diagram.

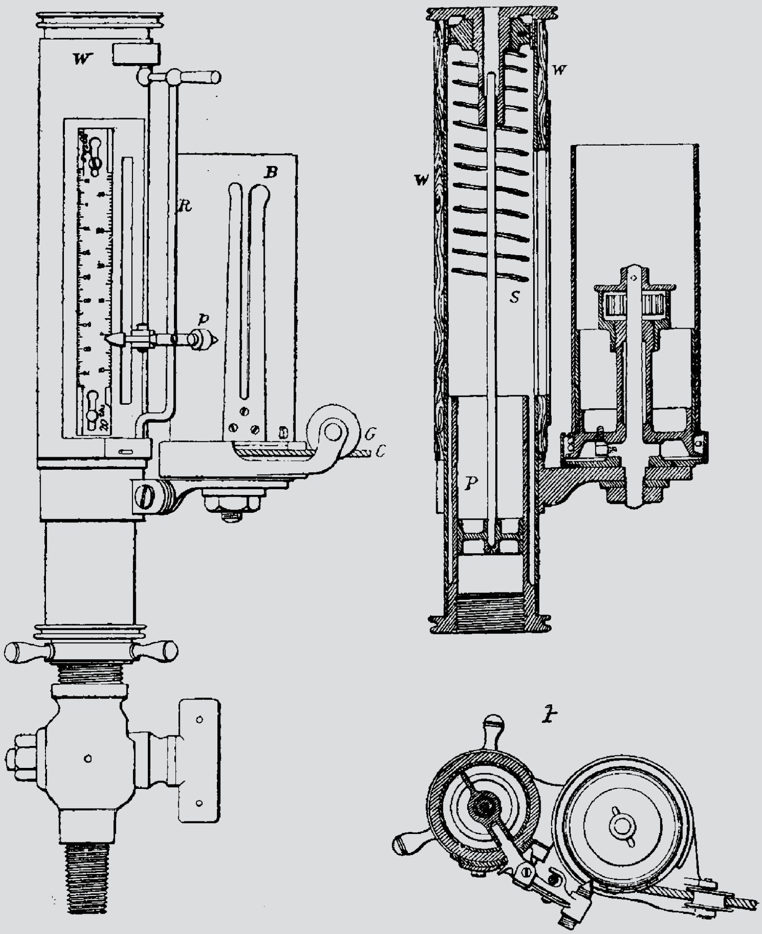


Plate 31: the McNaught indicator

extends upward through the top cap, is concentric with a short coil spring, tapering outward, which is mounted on a three-post bracket inside the cap. A collar at the lower end of the spring not only anchors the spring but also supports a slender finger which protrudes through a slot cut vertically in the body. The original indicator may have had a long slender arm, pivoted to the finger, which held a trace-point at right angles to the drum; later examples had a two-piece arm hinged to the finger, articulated centrally and drilled at the tip to hold a lead (or similar) trace-point at an angle to the drum. A leaf spring on the back of the two-piece arm holds the trace against the rotating drum firmly enough to make an impression—but not so firmly that excessive friction results.

The lower part of the instrument, the drum, can be rotated by a cord from a suitable reciprocating part of an engine, running through a fairlead or pulley on a bracket attached to a base ring made integrally with the piston cylinder. The return stroke is powered by a helical spring inside the top of the drum, which is attached to the piston cylinder at its inner end and tensioned during the outward stroke of the engine. A paper strip can be wound round the drum and held in place by two separate spring-steel fingers, a short distance apart, which are held to the material of the drum by two tiny screws apiece. A cock at the base of the instrument allowed contact with the engine cylinder. These cocks were originally plain-tapered, relying on the considerable weight of the indicator to resist the upward thrust of steam pressures that were barely above atmospheric level. Once higher pressures became commonplace, the plugs were threaded to prevent the indicator being blown from the cylinder.

An engraved scale on the outside of the upper body, alongside the vertical finger slot, showed the pressures for which the instrument had been regulated and (in some cases) allowed a certain amount of adjustment to ensure the readings were accurate. Later instruments, designed to make use of exchangeable springs, had detachable scales held by two screws in short slots so that the scales had a limited amount of vertical adjustment.

Co-axial McNaughts were customarily restricted to low pressures, ranging from 15 lb/sq.in below ('15in. of vacuum') to about 30 lb/sq.in above atmospheric pressure. The vacuum was usually acknowledged by extending the spring, which was set to rest at zero (atmospheric pressure, 14.7 lb/sq.in), and the higher pressures were shown by compression.

The introduction of high-pressure engines in the 1830s soon drew attention to the limitations of the co-axial indicator. This McNaught answered by removing the drum to a platform projecting laterally from the elongated body so that the spring—and the recording arm—could be placed alongside the drum body and the diagram could be traced directly onto the paper. A clamping screw through the platform bracket, which was split vertically, allowed the position of the drum (and of the trace) to be altered if required.

The parallel-axis indicator had been introduced by 1839, when drawings of both types were published in the sixteenth series of the French publication *Annales des Mines*. The information was translated from McNaught's leaflet and an attempt has been made to date the parallel-axis instrument to 1831.

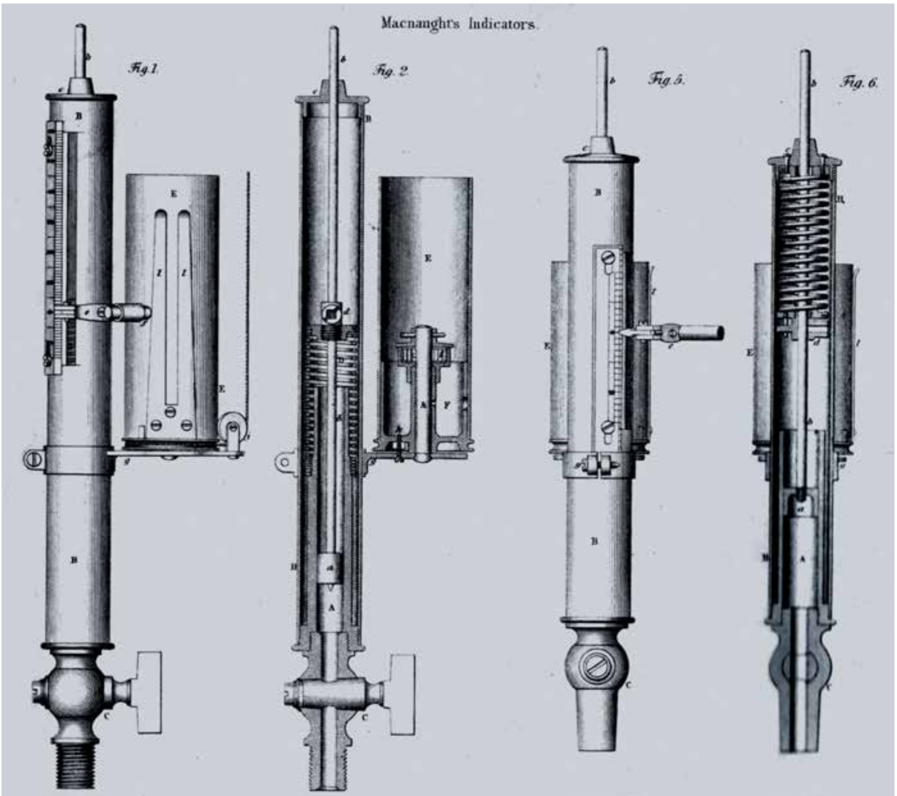


Plate 32. These drawings of the high-pressure (large) and low-pressure (small) McNaught indicators are taken from Scott & Jamieson, *The Engineer and Machinist's Assistant* (1845). Note that these show the earlier form of fairlead, there is a simple pencil holder, and that the springs take the original single-ended 'cap' form. *Author's archives.*

However, the 1834 edition of the McNaught leaflet pictures nothing but the low-pressure co-axial design and it is more likely that the parallel-axis type dates no earlier than the mid 1830s. But the latter had certainly replaced the co-axial type by 1842, when *Description and Use of Macnaught's Improved Indicator; or, Dynamometer for Steam Engines* was printed by David Russell of Argyll Street, Glasgow. Attention has also been drawn to 'Description de l'indicateur perfectionée de McNaught, modifié par M. Combes et construit par M. Martin', in Tôme 42 of the *Bulletin de la Société d'Encouragement* (1843). This article includes illustrations of both types of McNaught indicator attached to a Woolf-type compound engine, a type invented (then largely

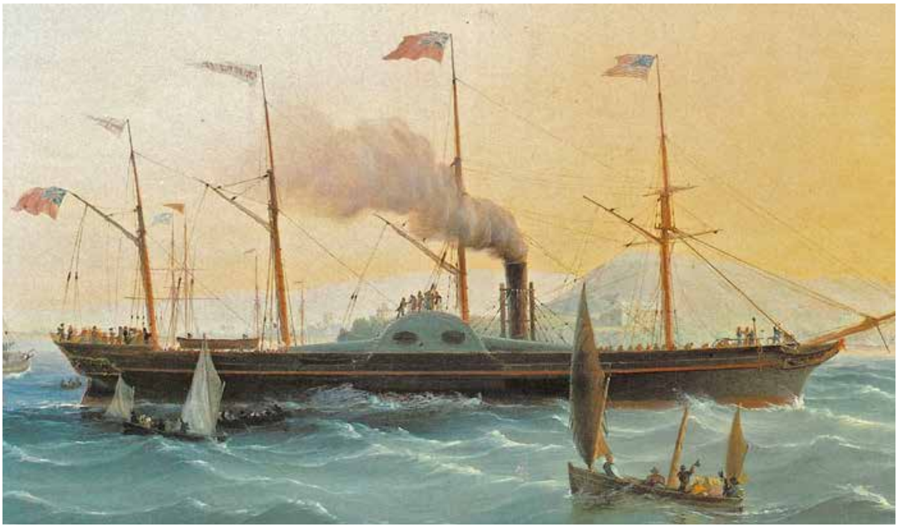


Plate 33. Brunel's historic steamship *Great Western* (1837) was among the first to have had the efficiency of boilers and engines indicated. A Watt-type instrument was used.

overlooked) in Britain but so greatly favoured in France that steam engines were for a time known generically as 'Machines Woolf'.

Not surprisingly, the simpler co-axial indicator is shown on the low-pressure cylinder and the more complex parallel-axis form on the high-pressure cylinder; this accords with McNaught's literature, and also with the graduations on the French drawings. The co-axial indicator has a scale that seems to suggest a maximum steam pressure of 15lb/sq.in and a vacuum of 10lb/sq.in, whereas the scale on the high-pressure machine reaches at least 50lb/sq.in.

Excepting the design and positioning of the drum and the elongation of the body, much of the construction of the 'Improved' or 'parallel axis' design resembled the co-axial design. However, the tapering coil springs were substituted with cylindrical designs and the scales were replaceable. The trace point could still be swung back against spring pressure to prevent a record being taken.

Improved McNaught indicators were made in two basic patterns—for low or high pressures—and in a variety of styles. The major difference concerned the springs. The high-pressure indicator did not register a vacuum, and so the scales run upward from 0 lb/sq.in to 100 lb/sq.in or more; the spring was compressed between the piston-cylinder body and a collar attached to the piston rod. The low-pressure type, though similar in most respects, relied on a spring that was attached to the piston-rod stud and the inside of the top cap. This allowed it to be extended downward to show a vacuum, or compressed upward to indicate pressure above atmospheric level. The two types could be told apart by several features: the engraved numerals on low-pressure scales will show '15' below zero; the finger slot is usually closer to the mid-point of the body in low-pressure instruments; and the low-pressure indicators are usually considerably smaller than that of high-pressure examples. Internally, the low-pressure instruments have a ¼ sq.in piston face; high-pressure pistons measure only ⅛ sq.in. Pressures ranged as high as 130lb/sq.in, which had advanced only to 140lb/sq.in by the mid 1850s. The earliest McNaught indicators, particularly those made prior to 1840, had simple tapered steam cocks. Most of the engines of the day worked at pressures that were only a few pounds above atmospheric level, and the weight of the indicator was sufficient to resist the efforts of low-pressure steam to eject the indicator from its seat. Later examples, made at a time when pressures were beginning to rise, required a threaded plug to ensure that the indicator and the cylinder remained connected.

The indicator made by "Mr John M'Naught, Engineer, 26, Robertson Street, Glasgow", was described in detail in February 1842 in *The Practical Mechanic and Engineer's Magazine*: 'By…[the use of an indicator] a steam engine proprietor can ascertain in one minute the working condition of his engine. He can detect neglect in his engineer, can demonstrate the proportion of power required to overcome the friction in his engine, or give motion to the shafts and mill-gearing, or drive the machinery. He can tell the power expended in driving any part of his works; or if the power is let off, he can at any time prove what power his tenant consumes. He can ascertain the friction of the machinery, when using different oils; and can guide himself with certainty in the choice of that which is best. He can ascertain the expenditure of steam when injecting water of different degrees of temperature, and can compare the saving arising from the use of cold water, with the expense of procuring it. In fact, by this instrument, he can not only find out the most economical way of working his engine , but he can measure the expenditure, and regulate the distribution of his power at all times.'

A description of the indicator "in its improved form, as made by Mr M'Naught" followed: 'A is a cock to form a communication between the cylinder of the steam-engine, and B, the cylinder of the indicator; C, a brass piston accurately fitted and ground into the cylinder B, so as, when oiled, to work easily, and steam-tight without any soft packing. The piston C is attached by its piston rod to a spiral spring contained in the cylindrical case D. While the piston C remains undisturbed, the pencil-holder and pointer F, which are attached to the piston-rod through a slit in the casing D, will remain at the level marked O on the scale.

'But when the communication is formed with the cylinder of the steam-engine; if the cylinder contain [sic] steam above the pressure of the atmosphere, the piston C will, by the action of the steam, compress the spring

Plate 34. An Improved McNaught low-pressure indicator, marked MCNAUGHT and GLASGOW on the piston-cylinder body. The pencil holder, mounted on a slender vertical rod, can be pivoted away from contact with the drum. The fairlead (cord pulley) has been refined compared with earlier examples, but the most important change concerns the design of the springs. These are similar to those associated with the later Richards indicators, with small brass threaded collars at each end. The marks '77. K.F.' and a small Broad Arrow, revealing British government ownership, may denote use in the Kirkee ammunition factory in British India. The factory was mechanised in 1859–61, which could suggest either that Richards adapted a pre-existing type of spring or that the instrument shown here was made in the mid 1860s. *Canadian Museum of Making collection*

Plate 35. A close-up of the ends of the perfected McNaught springs. A comparison with the Richards springs shows that the great similarity cannot be entirely coincidental. *Canadian Museum of Making collection.*

and raise the pointer until it indicate [sic] the pressure per square inch of the steam in the steam cylinder. In the same way, if a vacuum be formed in the cylinder, the spring will be distended by the predominance of the pressure of the atmosphere on the upper side of the piston, and the pointer will denote on the scale the degree…below the pressure of the atmosphere produced.

'The area of the cylinder B, of the instrument in general use, is ¼ of an inch; the weight required to compress or distend the spring is ¼ lb. for each 1⁄10 of an inch it is compressed or distended. The scale is consequently divided into tenths of an inch, and each tenth indicates one pound of pressure on the square inch of the piston…

'G is a cord guided by a small pulley H, and passing round a pulley, to which is fixed a cylinder E. When the cord G is pulled, it turns the pulley and cylinder E on their centre; but on the strain being relaxed, the cylinder and pulley again take up the cord and recover their former position by the action of an internal spring similar to the main spring of a watch. F is the pencil holder, through which the end of a fine pointed pencil is inserted, directed towards the cylinder E. F is connected to the piston-rod and pointer, with a joint which admits of its being turned out clear of the cylinder E; but by relieving a small spring the pencil is made to bear gently on the cylinder. It will appear evident that if, while the pencil is in contact with the cylinder E, the piston be moved up or down, a straight line will be traced on the cylinder E, in the direction of its length; and if the cylinder be made to turn on its axis, by pulling the cord G, while the piston remains at rest, a straight line will be traced round it at right angles to the former. The line formed in this way, when the pointer is at O, is called the atmospheric line—the piston being then undisturbed.' The article concluded with a variety of indicator diagrams, including some taken in 1840–1 from the steamships *British Queen*, *Princess Royal* and *Achilles*, among the most interesting being a seven-trace composite provided by *Achilles* to show the effect of varying the cut-off (the point at which the supply of full-pressure steam to the cylinder was stopped).

Once the value of the McNaught pattern had been universally admitted, steam-engine indicators were made in great quantity by many manufacturers. Writing in 1845 in *The Engineer and Machinist's Assistant*, Scott & Jamieson could state that the indicator was an 'important and useful little instrument which…has very materially contributed to the perfection and efficiency of our modern steam engines; not only by enabling the engineer to ascertain and register the exact values of the forces from which its power is derived, at the point where these forces come into effective operation, but also by pointing out the precise periods, in relation to the different parts of the stroke, at which these elements of power come into action, and thereby conducing to the most economical and perfect combination of them'.

By 1846, when the engineer John Bourne had completed his book *The Steam Engine* (subsequently reprinted many times without alteration), the McNaught indicator had become commonplace. The only major disadvantage of drum-type indicators was that ways had to be found to adapt the engine stroke—which could be several feet long—to the few inches represented by the circumference of the recording drum. This problem was customarily overcome by choosing a part of the motion that moved a very short distance, or by devising linkages to reduce movement to acceptable limits.

A production life of forty years ensures that McNaught-type indicators will not only be found in a variety of styles but also with a variety of adaptations. These included a rod, pivoting in brackets on the body so that it ran the length of the slot, which could be used to lift the trace arm from contact with the drum; improved springs, with Richards-type threaded collars on each end; and coil springs to drive the drums instead of the original helical ribands.

Platforms and fairlead brackets, shaped from solid, often identified individual constructors, as did the milling on the body caps. The design of the paper retainers varied from spring-steel fingers to pivoting rods. Some steam cocks were screwed directly into the base cap, whereas others, generally newer, were attached to the indicator with a captive union; cocks could be turned with elegant butterfly finger-pieces, or with small tommy bars.

The McNaught indicators were sophisticated tools for their day, confining manufacture to a mere handful of specialist instrument makers. McNaught himself made them in Glasgow from about 1830 onward, his address being listed in city directories as 24 and then 26 Robertson Street (1832–40).[3] His profession is usually given as 'Engineer', though the 1835 directory qualifies this: 'Civil Engineer'. In the 1840 directory, he was joined by his son William (1813–81), "Engineer at J. McNaught's, 26 Robertson Street".

John McNaught died in Glasgow on 16th March 1844. Precise details of his death have yet to be found, but his will was proved in Glasgow Sheriff Court on 3rd September 1845. The accompanying inventory shows that McNaught was not a rich man: the value of his estate amounted to merely £275.5.6d, including £85 owed by his son Robert, 'Manufacturer' [of cotton thread], and £40 for the 'Stock in Trade and good Will of business…purchased by… William McNaught by arrangement with the deceased's widow and other children'.

Clearly, the steam-engine indicator had not made John McNaught's fortune. But William McNaught subsequently achieved great renown as the designer of a compound steam engine which allowed many old single-cylinder engines to be upgraded with an additional high-pressure cylinder. Seeing that the burgeoning Lancashire textile industries provided a substantial market for his ideas, which promised (and usually delivered) greater power and better efficiency without the expense of investing in a new engine, William McNaught moved first to Manchester and then, in 1862, to nearby Rochdale.[4] The Robertson Street workshop was maintained in Glasgow for many years: the 1895 Glasgow Post Office Directory, for example, records 'William McNaught & Son' as 'Makers of Steam-Engine Indicators, Steam Gauges, &c.' at 12 Hampden Terrace.[5]

McNaught-made indicators are usually marked simply MCNAUGHT and GLASGOW on the body, though the substitution of the Manchester of Rochdale addresses is possible. Circumstantial evidence suggests that they were made in two patterns, the large high-pressure 'No. 1' and the smaller low-pressure 'No. 2', as the major components of the only two low-pressure instruments available for examination were almost all marked '2'. By 1856, and the final

3. It seems likely that 26 Robertson Street was simply '24' renumbered. Many roads were treated in this way as development and fragmentation of sites occurred.

4. W. & J. McNaught began trading in 1860, moving in 1862 to St George's Foundry, Rochdale, and are estimated to have made 95–100 engines by the time trading ceased in 1914; the last mill engine apparently dated from 1904. However, hundreds of other simple-expansion mill engines were 'McNaughted'.

5. The former 26 Robertson Street, renamed in the late 1880s.

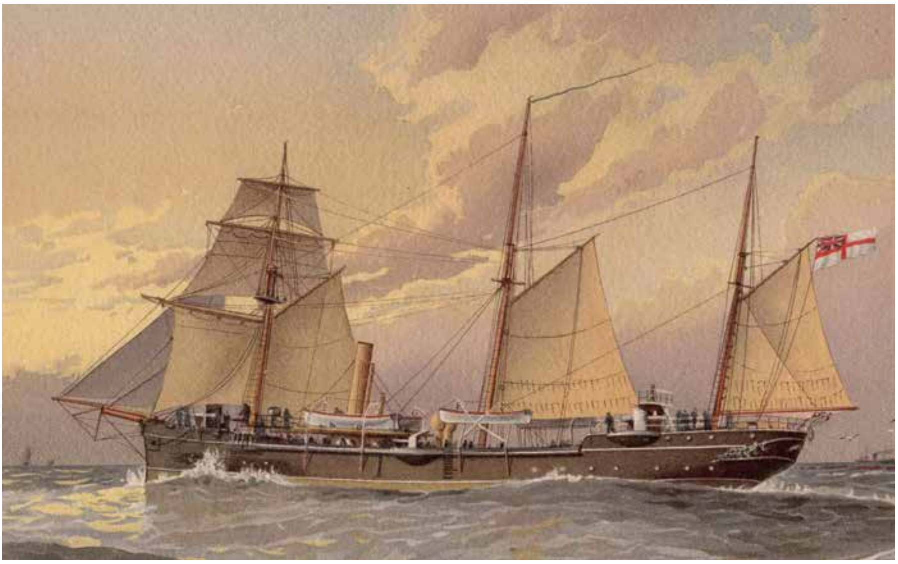


Plate 36. Many nineteenth-century warships were fitted with simple engines operating at comparatively low pressure. Screw sloops of the type pictured were the first to exchange horizontal engines for vertical triple-expansion engines, and the 30–35 lb/sq.in pressures of the 1860s and 1870s (for which McNaught and Hopkinson indicators were ideal) had risen to 130 lb/sq.in by 1885. *From a painting by W. Frederick Mitchell (1840–1914).*

version of McNaught's promotional leaflet (which had become a book), the parallel-axis indicator was being offered for pressures of 60, 100 and 140lb/sq.in. In addition, a specially enlarged version could give a six-inch diagram instead of the customary 3.75in version.

McNaught-type indicators—offering good quality, but little else—were also made by 'Baker' or 'H. Baker' of London. These were probably all the work of Henry Baker of 90 Hatton Garden, who is usually identified in directories as an optician. Baker exhibited barometers and thermometers at the Great Exhibition of 1851, and was still working in 1858. Charles Baker, working from 244 High Holborn in the same era, could also have made indicators alongside barometers, thermometers, odometers and microscopes.

Some of the most interesting variants of the McNaught indicator were made in Manchester by Joseph Casartelli. They included a wood-clad version intended to reduce the transfer of heat to the body during prolonged use. One survivor has the cladding attached directly to the body in the fashion of pre-1850 locomotive boilers; a later version, possibly similar to that illustrated in *Indicator Diagrams and Engine and Boiler Testing* (1898) by Charles Day, concealed the cladding between the body and a thin external case. Casartelli instruments also used an unusually narrow captive union (with three small handles) to connect the indicator and the steam cock.

The Casartelli family originated from the area of northern Italy centred on Lake Como, many individuals fleeing early ninteenth-century famine and economic recession. They included Luigi Antonio or 'Louis' Casartelli, who purchased the barometer-making business of Giovanni Battista Ronchetti when its owner returned to Italy from Manchester in 1811.

In 1815, Casartelli exchanged businesses with Ronchetti's son and moved to Liverpool. His own son, Joseph Louis Casartelli, born in Italy in 1824, then re-acquired the Manchester workshop after his 1851 marriage to Jane Harriet Ronchetti. The Casartelli-made McNaught indicators, therefore, cannot date earlier than the middle of the nineteenth century. Indicators marked 'Joseph Casartelli & Son', acknowledging the participation of Joseph Henry Casartelli (b. 1861) do not date earlier than *c.* 1882, and are unlikely to be McNaughts.

McNaught indicators made in Sheffield were the work of the Chadburns, a well-established family of opticians and instrument makers. According to *A Directory of the Borough and Parish of Sheffield* (1852), Francis and Alfred Chadburn traded as 'Chadburn Brothers, opticians, mathematical, electrical and philosophical instrument makers' from Albion Works in Nursery Street, Lady's Bridge, Sheffield.[6] The inclusion of 'Opticians to H.R.H., The Late Prince Consort' on labels identify instruments made after the death of Prince Albert in 1861. Indicators may also have been made prior to 1861 by Charles Chadburn of 71 Lord Street, Liverpool, 'Optician to Prince Albert', but it seems is more likely that they had come from Sheffield.[7]

John Hannan of Glasgow made McNaught indicators from 31 Robertson Street (1861–5) and 75 Robertson Street (1865 onward), before becoming part of Hannan & Buchanan in 1869. Hannan proposed an improved form of the McNaught to a meeting of the Institute of Scottish Shipbuilders in 1866, but work had ceased in favour of the Richards design by 1877.

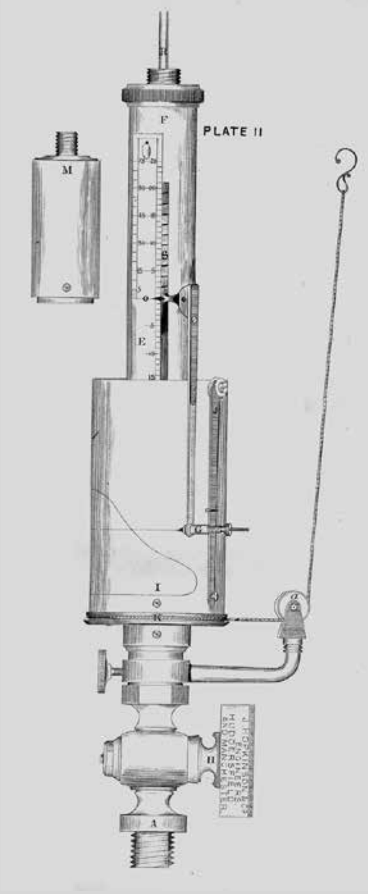
The indicator promoted from the late 1830s onward by Joseph Hopkinson of 'J. Hopkinson & Co., Engineers of Huddersfield and London', was the most interesting variant of the McNaught system. The proprietor of the Britannia

6. Some sources refer to the existence of a partnership of 'Chadburn & Wright' in this period, by mistakenly identifying Francis Wright Chadburn as two people.

7. Charles Chadburn (1815–90) and his son William (1844–1927), trading as 'Chadburn & Son', had specialised in levels, barometers and thermometers before the younger man patented the ship's telegraph that was to make their fortune.

Hopkinson co-axial indicator

Plate 37



From Joseph Hopkinson, *The Working of the Steam Engine Explained by the Use of the Indicator…* (1860 edition).

The plug **A**, screws into the cylinder cover, or grease tap. The tap **H**, forms a communication between the cylinder of the Indicator and the cylinder of the Engine. There is a small hole in the side of the tap, which opens into the tap-plug; and when the tap is open to the cylinder of the Steam Engine and the Indicator, this small hole is closed by the plug being turned with its perfect side against the hole. When the tap is closed, the connection with the Engine cylinder is cut off. The small hole in the tap is then open through the plug to the cylinder of the Indicator, so that any steam remaining between the piston of the Indicator and the plug of the tap may escape into the atmosphere, and allow the pencil attached to the piston of the Indicator to settle down to the atmospheric line.

The cylinder of the Indicator is fitted with a piston, the rod of which is shewn at **R**. This piston is accurately ground into the cylinder, thereby avoiding packing; and, when properly oiled and clean, it is steam-tight, except at very high pressures—where perfect tightness is not required, as any small portion of steam which may escape cannot affect the bulk of the pressure in [the] cylinder. From this construction, the piston works freely with little friction.

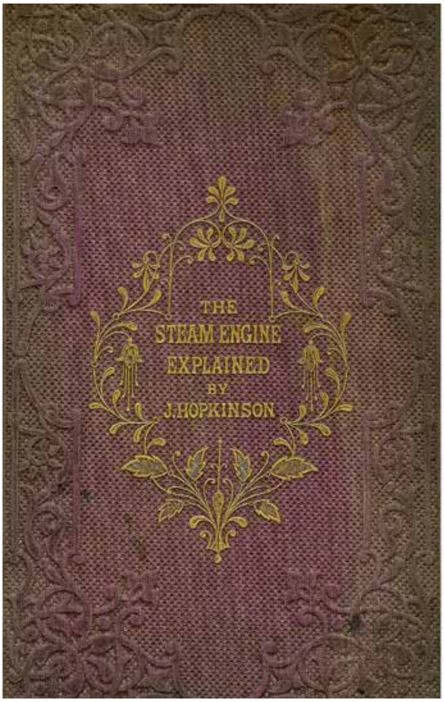
The piston rod **R**. is attached to the spiral spring **S**. within the tube or casing **F.**, placed above the steam-cylinder of the instrument. This spring is so adjusted, that when the piston index is forced one-tenth of an inch above the atmospheric line **O.**, marked on the scale **E.**, it represents 1lb. pressure of steam. The pointer forced upward each tenth of an inch, up to 25 tenths, will represent as many lbs.

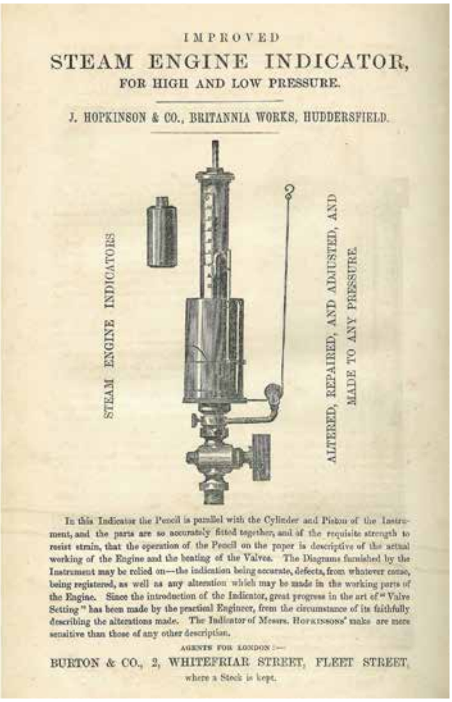
pressure to the square inch. In the same way, when the vacuum is formed the Engine cylinder, the spring will be distended by the pressure of the atmosphere upon the upper side of the Indicator piston, and the piston will be forced downward as many tenths as the degree of rarity, or the quantity of steam extracted from the Engine cylinder, in lbs. per square inch below the pressure of the common atmosphere. Affixed to the casing there is the scale **E.** with the atmospheric line **O.** in the centre. The tenths below **O.** to 15, indicate the vacuum; and above **O.** to 25 tenths, the steam pressure above the atmospheric pressure.

The pencil-holder **G.** is attached to the piston rod **R.** through an aperture cut in the casing **F.**, to allow the pencil holder to move up and down with the piston rod of the Indicator. The pencil can be screwed backward and forward to obtain the exact length required, and is adjusted by a spring to allow it to accommodate itself to any little inequalities there may be on the revolving cylinder or the paper. In all cases a soft and good pencil should be used. The less the pressure upon the paper, the less the resistance to the free action of the piston **I.** is the revolving cylinder outside the casing F. This cylinder revolves on its own axis. The paper on which the diagram is to be taken is fixed around this cylinder, and held in its place by the clip **J**.

On the bottom of the cylinder there is a cord round the pulley **K.**, [mistakenly printed as 'R.' in the book], which, after passing over the swivel pulley **A.**, is then attached to the radius-bar of the Engine... By means of the cord attached to the radius-bar of the Engine, there is produced a regular traversing motion of the cylinder **I.**; and as the pencil presses at the same time against the paper affixed to the cylinder, which also moves up and down with the Indicator piston, which piston is propelled by the same force as the Engine piston, the pencil will describe a diagram according to the circumstances. The area of the cylinder of the Indicator is a quarter of a square inch.

When the steam exceeds 25lbs. to the square inch above the pressure of the atmosphere, there is an additional spring enclosed in a case for higher pressures up to 75lbs to the square inch—or for a still increased pressure if required—which is to be screwed on to the top of the casing **F**. This additional spring is represented at **M**. The piston rod of the indicator passes up the centre of the spring M. when it is fixed to the top of the casing **F.**, and comes in contact with the top attached to the second spring—so that instead of the resistance of only one, there is the resistance of two springs for high-pressure steam. On the scale **E.** for high pressure, the distances are marked thirty to the inch, for steam above 25lbs.; one-thirtieth of an inch representing 1lb. pressure to the square inch.





Plates 38 and 39. The external cover (left) and a typical advertisement (right) from the 1860 edition of Hopkinson's book, *The Working of the Steam Engine Explained by the Use of the Indicator…* Unfortunately, the quantity of indicators that had been sold merits no mention, hindering assessments of popularity. *John Walter collection.*

Works, best known for his steam valves, Hopkinson had a strong opinion of himself and his products, and never under-sold them. In 1854, he published one of the most important of the earliest English-language textbooks on the indicator. In the 1860 edition of this often excessively self-promotional book, after claiming 'though his production may not possess the charm of literary embellishment', Hopkinson continued: 'The commendatory opinions expressed to the Author by individuals of eminence in the Engineering profession, and by distinguished owners of the most powerful and best wrought Steam engines ever constructed, regarding the manner in which he [Hopkinson] has imparted information and conveyed instruction on a subject which concerns the national well-being, has been to him a source of high gratification. If what he has done in this direction shall in any degree be instrumental in adding to the value and efficiency of the great motive-power of our manufactories, mines, ships, and railroad locomotion, he will feel himself amply rewarded by the conscious satisfaction that his endeavours to that end have not been in vain…' Not surprisingly, the indicators, which returned to the co-axial design (which Hopkinson considered to be more resistant to vibration), are treated in much the same vein. Though improvements had undoubtedly been made—and Hopkinson was quick to list them—the basis of his design was not the advance he claimed.

A short introductory history crediting the oscillating drum to John Southern distances Hopkinson from McNaught at a time when the latter's designs were pre-eminent: 'Some makers have this revolving cylinder detached, or apart from the other portions of the instrument; but...[we]… find by experience—the test of all improvement—that it is best to have the revolving cylinder placed upon the steam cylinder of the Indicator, because it is in that place the most convenient and firm for the operation which has to be performed upon it. The pencil holder should be parallel to the cylinder, piston and guide, as by that mode the most sensitive and correct indications are obtained. This improvement, although a minor one in appearance, will hereafter be shown to be of considerable importance. The difference of the indications given by this instrument will be shewn by contrasting its diagrams with those given by that description of instrument called the McNaught, on which the pencil operates at right angles to the traverse of the piston, and where the revolving cylinder is detached from the instrument. It will at once be seen that a tremulous or unsteady motion of the pencil on the revolving cylinder, must impart a corresponding defect to the diagram…'

Ironically, the Hopkinson indicator had the general appearance of the first co-axial McNaught instruments (whose existence Hopkinson does not acknowledge), but was often larger and had a distinctive three-scale graduation plate alongside the pencil-lever slot in the casing. The instruments were all made to the same general pattern, though, as each was made individually, there were often considerable differences in detail.

In the 1860 edition of his book, Hopkinson advertised the merits of products that included the New Patent Compound Safety Valve ('upwards of 2,000 are now in use in the principal firms in Lancashire and Yorkshire') and the Mercurial Steam Gauge ('upwards of 1,000 of which are now in use'). The absence of any claimed total for the sale of indicators may suggest that the quantities involved were comparatively small. Few survivors have been found, as it is suspected that they were concentrated in the textile-making districts of Lancashire and Yorkshire, to be discarded as soon as the mills installed more powerful machinery.

The case-histories given by Hopkinson in 1860, apart from tests undertaken on steamships *British Queen* and *Great Britain*, are largely confined to Bradford, Brighouse, Dewsbury, Halifax, Huddersfield and Sheffield in Yorkshire; Darwen, Oldham and Stockport in Lancashire; Ashton[-under-Lyme] and Stalybridge in Cheshire; and Stafford. They also confirm that McNaught and Hopkinson indicators were commonly used by local insurance associations such as the Hudderfield District or Manchester Associations for the Prevention of Steam Boiler Explosions.

Simple design ensured that 'one-off' indicators could even be made by employees of individual manufacturing companies. Writing in 1860, Joseph Hopkinson remarked that the engineer in charge of four double-acting beam engines installed in the Saltaire Mill of Titus Salt & Sons, near the Yorkshire textile town of Bradford, 'instead of being wedded to the idea…that a small indicator is the best, he prefers, and has had made, a very large one, with which he indicates the working of his Engines…' This special indicator was much bigger than a standard co-axial Hopkinson, which was itself regarded as large compared with a McNaught.

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.

Simple direct-reading indicators retained their popularity in northern England well into the 1880s, when mill and factory engines began to increase in size, speed and power, and there is circumstantial evidence to show that they also remained popular in Cornwall. The McNaught pattern was still regarded as standard in the Royal Navy as late as 1882, as boiler pressures had remained surprisingly low. The advent of compound marine engines then had an important effect: the McNaught pattern was soon being preferred only 'for general use on ordinary service', and the Richards design wasto be used 'for the records of steam trials and other special services'.

THE MCNAUGHT INDICATOR IN EUROPE

Distribution of the indicator may have been comparatively tardy in mid-nineteenth century Britain, but on the Continent of Europe it was painfully slow even though at least one British-made MacNaught had gone to France in 1834, and the Conservatoire des Arts et Metiers added one obtained by Charles Combes to its collection in 1837. Born in Cahors in 1801, Combes studied at the École Polytechnique and then the École des Mines in Paris, eventually rising to become not only the director of the latter establishment but also president of the Conseil Générale des Mines from 1868 until his death in 1872. Nominated to the Academie des Sciences in 1847, he became a member of the Légion d'Honneur in 1860. Renowned for *Traité d'explication des mines* (1844–5), Combes was also a pioneering advocate of the use of the indicator.

Another was taken to Bavaria after the 1851 Great Exhibition in London, to be used by the Maschinenbaugesellschaft Nürnberg, and Charles Brown (who had served his apprenticeship in the shops of Maudslay, Son & Field before being hired by Gebr. Sulzer of Winterthur, Switzerland) ordered an instrument from London in 1853. Though very little interest seems to have been raised in Germany, Brown made particularly good use of his purchase.

The first engine indicators to be used in France were imported from Britain by individual researchers. Much of mid-nineteenth century France, though embracing the compound steam engine with much greater enthusiasm than the British, remained technologically backward. Consequently, the investigation into the performance of the steam engine depended more on the theoretical approach of the Academie des Sciences than the empirical methods employed by British engineers; and the indicator was regarded more as an aid to experimentation than a day-to-day tool. This in turn restricted output: indeed, with perhaps a single exception, the French have never made indicators in quantity.

The first indicator to be designed and made in France was the work of Charles Morin (see Chapter Eight). A few instruments of this general type were made by Bourdon or Saulnier of Paris, one survivor being kept in the collection of the Conservatoire Nationale des Arts et Metiers in Paris. They were followed by a modification of the MacNaught credited to Paul Garnier (1801–69), who had been apprenticed to the great clockmaker Louis Breguet. Garnier had opened his own workshop in Paris in 1825, invented the *coup-balle* ('chaff cutter') escapement in 1830, and was responsible for the first electric clock to be made in France (1849).

The first Garnier MacNaughts resembled British prototypes, but had two springs (one above and one below the piston) and two drums. Paper contained in one drum was wound onto the second, against which a tracer attached directly to the piston provided a permanent record. This continuous-recording pattern is described in greater detail in Part Five.

The original Garnier indicator, soon judged to be fragile and too complicated, was replaced by a simplified version. This relied on a single spring, and the piston was contained in a hollow liner inserted in the base of the body. This avoided the two-chamber design that had characterised the older instruments. Only a single drum was provided, though the pulley-type reducer was retained in a refined form. The double-cock cylinder union was replaced by a single cock with an intermediate union. The advantages of the new model included reduction in weight and complexity, a reduction of oscillations in the trace, and the ease with which the paper could be changed.

Few of these instruments embodied much originality in the arangement of spring and cylinder, as improvements were more usually sought in the drive system. However, Henri Tresca, the deputy director of the Conservatoire des arts et metiers, had experimented as early as 1858 (some years before the advent of the Porter-Allen high speed engine and the Richards indicator) with springs and pistons. His goal was to damp the oscillations that afflicted McNaught and comparable indicators as speed and pressure rose. The greatest problem concerned the mass of the piston and attached rodding, which contributed greatly to what Joseph Hopkinson sneeringly dismissed as the 'unsteady and tremulous motion' of McNaught's pencil.

Tresca replaced the bronze piston of a McNaught-type instrument, which weighed 140 grams, with a 57-gram version that is said to have been made of aluminium. Though the results showed an improvement, the days of the direct-reading indicators were numbered by the advent of high-speed engines and the Richards indicator—the first 'amplifying' design.

THE MCNAUGHT INDICATOR IN NORTH AMERICA

Most probably, a few British-made McNaughts were acquired in the 1830s and 1840s by the leading technical-training establishments and, perhaps, by the first builders of railway locomotives. Among the leading railway engineers was Horatio Allen, and it may not be entirely coincidental that the earliest textbook to be published in the USA highlighting the workings of the steam-engine indicator was the work of the younger brother of Allen's partner, Thomas B. Stillman.

Born in 1806, Stillman had acquired well-honed practical skills long before he and Allen combined their talents in Stillman, Allen & Company — a successor to the engineering business that had built the *Novelty*, a steamship incorporating a boiler designed by Eliphalet Nott to burn anthracite. A small workshop known as 'Novelty Works' was erected on a small wharf in Burnt Hill Point, East River, New York, and operated as 'H. Nott & Company'. In 1837, however, it was sold to James Ward, Thomas Stillman, Robert Stratton and St. John Seymour. Ward, Stillman & Company traded until Ward retired in 1841, then as 'Stillman & Company' until Horatio Allen arrived in 1842. The resulting partnership, 'Stillman & Allen', encountered financial problems in the mid 1850s and, with new shareholders, metamorphosed into The Novelty Iron Works, incorporated in New York at the end of 1855.

The Stillman & Allen indicators were made under the supervision of Paul Stillman (1811–56), who, until he left the company early in the 1850s, 'for several years had charge of the department…devoted to the manufacture of Steam Gauges, Registers, Indicators, Hydrometers, and other instruments used in connection with Steam Engines, Boilers, &c.' Stillman, Allen & Company continued to promote the instruments, which were accompanied after 1851 by a treatise of instructions compiled by Paul Stillman.

The Stillman & Allen steam-engine indicators, the first to be made in the USA (perhaps about 1846–7), were all but indistinguishable from the McNaughts being made in Britain at the time; indeed, it is likely that one of the latter provided the pattern. Paul Stillman made no attempt to disguise these origins, stating in the Preface to his treatise, dated December 1850, that the 'Indicator was the invention of James Watt and…has been variously modified, since he used it. The form in which it is here presented, is that given it by the late Wm. McNaught, of Glasgow, to whom, more than any other person, it owes its present excellence and its general use in Great Britain…'

A line-block engraving shown in the 1857 Novelty Iron Works treatise shows a typical direct-reading McNaught style instrument, with the recording drum on a platform (attached to the barrel with a collar) and a replaceable scale held to the barrel by screws. The drum contains a helical spring pinned at its inner end to the central standard.

The paper clamp consists of a single piece of spring-steel plate formed into two tapering fingers of equal height; three small screws in the base of the plate, placed as though at the points of an isosceles triangle, hold the plate to the paper drum. The lower end of the spring is anchored in a collar, which bears directly on the rim of a cylindrical liner containing the piston, and the upper end bears on a flanged collar attached to the elongated piston rod that protrudes upward through the end cap. The fairlead is a short bifurcated bracket pivoting directly on the outer edge of the platform, and the steam cock projecting from the base of the barrel has a rectangular knob. A large hexagonal nut holds the indicator to the cylinder port of the engine.

Plates 40, *left*. **and 41,** *below*.

A typical Novelty-made McNaught indicator of the 1850s. The number visible on the clamping ring of the platform refers to the pattern, not to an individual instrument.

Bruce E. Babcock collection, Amanda, Ohio, U.S.A.; full-length photograph by Joe Ruh, University Photographer, University of Northern Kentucky.

The illustration suggests that *Stillman* over *New York* was engraved in in flowing script on the platform collar, but no indicator of this precise configuration has been found. The 1857 Novelty Iron Works catalogue offers the indicator in ten differing guises, adapted to specific pressure ranges by altering the area of the piston face (changing the bore of the barrel liner) and the size of the recording drum. All the indicators were designed to work upward from 0 lb/sq.in, about 15 lb/sq.in 'of vacuum' (i.e., below atmospheric pressure). The No. 1 indicator, suited to pressures as high as 100 lb/sq.in, had a piston face of ⅛sq.in and accepted paper measuring 4 × 5in; the No. 2 (to 35 lb/sq.in) had a piston measuring ¼sq.in and the same size of paper drum. No. 3 had a piston measuring ¼sq.in, suitable for pressures up to 120 lb/sq.in, and accepted 4.5 × 7in paper; No. 4 was much the same size, but had a ½sq.in piston and was restricted to pressures less than 35 lb/sq.in. No. 5 and No. 6 had piston faces measuring one square inch, and took 5½ × 9in paper; pressures were restricted by the design of the springs to 35 and 85 lb/sq.in respectively. No. 7, the largest, had a piston face of 2sq.in, took 5½ × 9in paper, and was suited to a maximum pressure of only 30 lb/sq.in. No. 8 was a combination of No. 1 and No. 2, supplied with exchangeable pistons; No. 9 was a similar combination of No. 3 and No. 4; and No. 10 was supplied with two springs allowing it to duplicate the performance of No. 5 and No. 6.

Each indicator was supplied in a mahogany box, with two steam cocks, an elbow, a tap and chaser, a scale for interpreting the diagram, a screwdriver and an instructional treatise. The instruments were exceptionally expensive, prices in 1857 ranging from $60 for the No. l to $120 for No. 7 and No. 10. Additional springs cost $5–10, depending on size; cocks and elbows ranged from $1 to $3.50.

Though a Stillman-marked indicator has still to be found, several survive with platform collars marked *The Novelty Iron Works* and *New York* in a similar formal script. The only visible number identifies the pattern, not the individual instrument, and it is impossible (at this early stage) to make any estimate of production. The Novelty Iron Works is known to have made the Richards indicator exhibited at the Great Exhibition held in London in 1862, but the advent of the American Civil War (1861–5) may have ensured that nothing but McNaught indicators were made until Novelty failed in 1869. The survivors all have an improved union in the form of a captive capstan nut which screws to the steam cock.

The simplicity of the direct-reading indicator was enough to convince a few dedicated, if overly optimistic inventors that they could still compete with the amplifying designs. A U.S. patent granted to William M. Dodd of

Dayton, Ohio (no. 511760 of 2nd January 1894) was typical: though the layout would not have been unfamiliar to John McNaught, a claim to novelty lay in the inclusion of a sealed chamber 'whereby an air cushion is formed to exert pressure against the piston head' and 'counter-balance the pressure exerted by the steam on…[the] piston, whereby the pressure of said steam will be recorded in graduated and uniform lines'.

THE HOPKINSON SWIVEL-ARM DESIGN

This was protected by British Patent 977/69, granted on 31st March 1869 to John Addy Hopkinson and Joseph Hopkinson junior, 'both of Huddersfield, in the County of York, Engineers, for the Invention of "Improvements in Direct-Acting Steam Engine Indicators"…'

Plate 42, *below*. Hopkinson Patent Swivel-Arm Indicator no. 411. The boxes can vary, but this particular example, with the springs in a line, seems to be in its original form. (Compare with Plate 46.) *Canadian Museum of Making collection.*

Plate 43. This view of Hopkinson Patent Swivel-Arm Indicator no. 209 shows the fragility of the non-amplifying trace mechanism and the two-pulley fairlead assembly. *Canadian Museum of Making collection.*

The Hopkinson Patent Swivel-Arm Indicator

Diagram from Hopkinson's book.

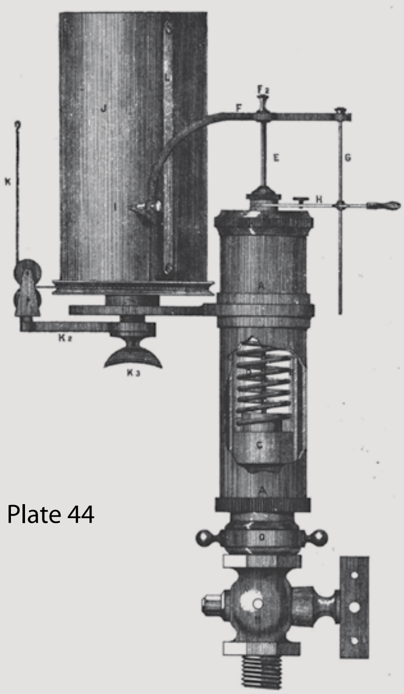


Plate 44

"**A** is the outer barrel, or casing, of the Indicator cylinder **B**, leaving a space between this and the outer casing, thereby keeping the steam cylinder at a more equable temperature than would otherwise be obtained. **C** is the piston, working in the cylinder **B**, and ground to a perfect fit. **D** is the spiral spring, which is fast at one end to the piston **C**, and at the other end to a small block and disc, held firmly in position by the cap **N**, which is screwed on the top of the casing **A**. The piston-rod **E** passes freely through the centre of the cap **N**, which forms its guide, and keeps it parallel with the steam cylinder **B**. The swivel arm **F** turns freely round on the nut **F²**, which screws on the top of the piston-rod **E**. There is a guide-bar **G** fixed to one end of the swivel-arm **F**, which slides freely through a hole (the hole being slightly elongated) in the horizontal arm **H**. The horizontal arm **H** is attached to the cap **N**, and turns on it as its centre, the other end of the horizontal arm **H** having a small handle by which the operator is enabled to apply the pencil **I** to the paper, which is fastened around the paper barrel **J**, whilst the piston-rod and swivel arm are moving up and down by the action of the steam on the piston **C**.

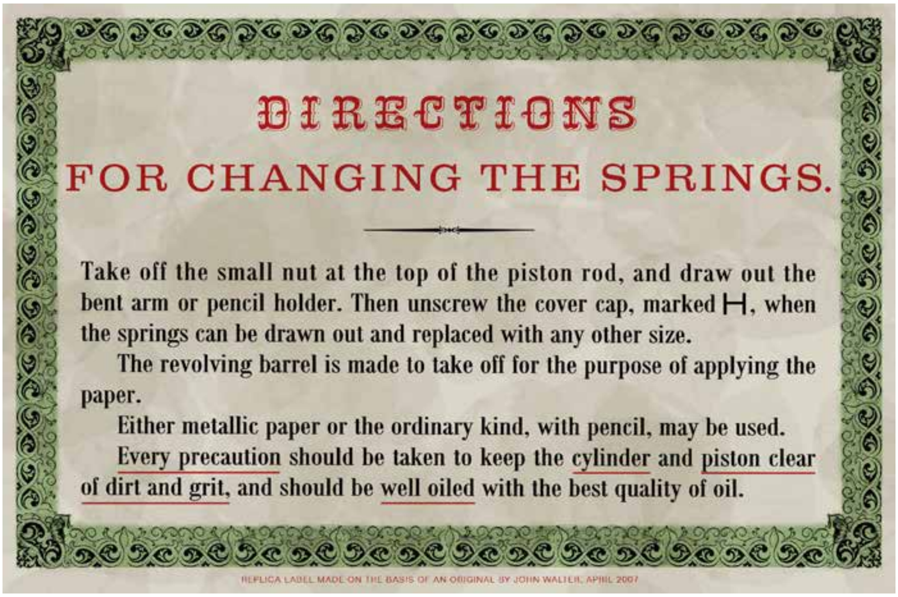
The paper barrel **J** fits accurately on an inner barrel, which contains a helical spring, so that when the cord **K** has been drawn out to its proper length by its attachment to some suitable reciprocating part of the Engine, the paper barrel **J** will then be revolved in the opposite direction by the helical spring already named. The guide pulleys are attached to an adjustable bracket **K²**, which is firmly held in whatever position may be found requisite by the thumb-screw **K³**. This being adjustable, will be found to be advantageous.

The paper on which the diagram is to be taken must be secured to the paper barrel **J** by the bar **L**, which is attached by the screw at **L²** ; the other end being movable, and when put in the position shown, holds the paper fast.

The most convenient way of putting on the paper is to lift off the paper barrel **J**, attach the paper, and then put the barrel in position again. **M** is the Indicator tap, which must be screwed to the permanent cylinder tap. The Indicator **A** is united to the tap **M** by the union coupling **O**, which has two short arms for the purpose of turning it round.

The method of applying the pencil to the paper is quite novel, and is one of the distinguishing features of the Indicator. It enables the operator to take the diagrams with the utmost ease and facility, and reduces the friction to a minimum; indeed, the delicacy of the guide bar **G** prevents any excessive friction. The Indicator is adjustable in every respect necessary for its use; the springs can be changed easily and quickly, and without removing the Indicator from the cylinder; and every part is accessible with the least possible inconvenience."

Plate 45. The labels pasted into many of the early indicator boxes usually suffer far more from the ravages of time than the instruments themselves. This is a modern facsimile of the label customarily accompanying the Swivel-Arm Hopkinson.



DIRECTIONS

FOR CHANGING THE SPRINGS.

Take off the small nut at the top of the piston rod, and draw out the bent arm or pencil holder. Then unscrew the cover cap, marked H, when the springs can be drawn out and replaced with any other size.

The revolving barrel is made to take off for the purpose of applying the paper.

Either metallic paper or the ordinary kind, with pencil, may be used.

Every precaution should be taken to keep the cylinder and piston clear of dirt and grit, and should be well oiled with the best quality of oil.

REPLICA LABEL MADE ON THE BASIS OF AN ORIGINAL BY JOHN WALTER, APRIL 2007

The inventors were the sons of Joseph Hopkinson, who had withdrawn from the day-to-day running of 'J. Hopkinson & Co.' in 1867. The brothers were then 21 and 17 years of age.

Though "Hopkinson's Patent Direct-Acting Swivel-Arm Steam Engine Indicator" gave every appearance of being well made, taking as many hints from the Richards design as it legitimately could, protection afforded to the amplifying mechanism of the latter was not so easily outflanked. The direct-acting method was retained, camouflaging this obvious shortcoming by casting doubts on the efficacy of an amplifier: 'an arm or pencil holder is fixed upon the top of the ordinary piston rod of the indicator, which arm turns on a swivel centre, and at a lower point there is fixed a swivel guiding arm which is so formed as to admit of a drop guiding rod passing through it, so that by turning the swivel arm the pencil can be brought upon the paper which is usually fixed on the revolving barrel, thereby facilitating the taking of diagrams. This arrangement not only dispenses with the ordinary slides, but also with joints and prevents unnecessary friction, together with the liability to derangement… [The] novelty in this instrument consists in the lightness of the arm, and the important feature of having only one joint thereby securing increased steadiness and firmness at the point if the pencil'.

Plates 46, *left,* **and 47,** *above*. The Hopkinson brothers' Swivel Arm indicator of 1869, number 209, with some of its accessories: several of the distinctive double-ended springs, with prominent caps; the steam cock; a small brass container for spare pencil leads; a plug for the steam-line of the engine; and two scale rulers of whalebone, used in the interpretation of diagrams. The case has been re-lined, and it is difficult to judge if the layout is still in its original form *Canadian Museum of Making collection.*

In reality, of course, the fragile-looking design offered little improvement on the preceding Hopkinson axial pattern.

An advertisement appended to *The Engineer's Practical Guide, and the Working of the Steam Engine Explained by the use of the Indicator* (seventh edition, 1875), stated: "Since the introduction of this Indicator it has been steadily and surely growing in favour with all Engineers whose prejudices and prepossessions did not influence them against giving it a fair and impartial trial. Those who have had experience with it have found it to be more reliable than any other Indicator for giving a true representation of the changes of pressure within the cylinder. Such is its superiority in this respect that many of the most skilful Engineers have already adopted it for the most accurate tests of the Steam Engine. The fact that in the face of the great weight of prejudice which it has had to encounter there are now 1200 of them in use, is no slight testimony to its merits... It will be manifest, even to a superficial observer, that the very light, yet rigid, connection between the piston and the pencil, will be free from numerous sources of error which are inevitable in any instruments having a multiplicity of connections, and which have an ever increasing tendency to still greater errors, the longer they are used. Independently of the imperfections inherent in such constructions, their rapid deterioration is a matter of common observation."

The Hopkinson brothers were such certain champions of direct-reading that their method of tracing the diagram on the reciprocating drum was an unsatisfactory compromise. A flimsy curved arm, with a slender cylindrical tail rod, was 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. 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 as pressures and speeds rose to unprecedented heights. Even though Joseph Hopkinson had taken every opportunity in his books to jibe at the Richards indicators being made by Elliott Brothers,[7] the parallel-axis design promoted by his sons was in vogue only for a very few years.

The Hopkinson brothers developed two other variations of the Swivel Arm design, protected by British Patent no. 718 of 11th March 1870. The drawings show one indicator with the trace arm guided by a vertical rod attached to the flat shank of the guiding handle; the other has a short trace arm attached to the head of a piston rod which is additionally guided by passing through a right-angle bracket on the handle shank.

Hopkinson Swivel Arm indicators are rarely encountered. To date, only five 1869-type instruments have been authenticated, numbered between 207 and 711. The existence of another two has been reported, one of which is said to be numbered '1029', and so the 1875-vintage claim by Hopkinson & Company to have made 1200 indicators may not be unreasonable (though old-style concentric-type instruments may represent 150–200 of these). No example of either 1870-pattern direct-reading indicator has yet been found.

7. For example, the 1875 edition says "Any Indicator made with a Multiplying Motion of the Pencil must necessarily have the retarding effect of the friction multiplied in the same degree; and the slackness of the joints will create inaccuracy in proportion to their number..."

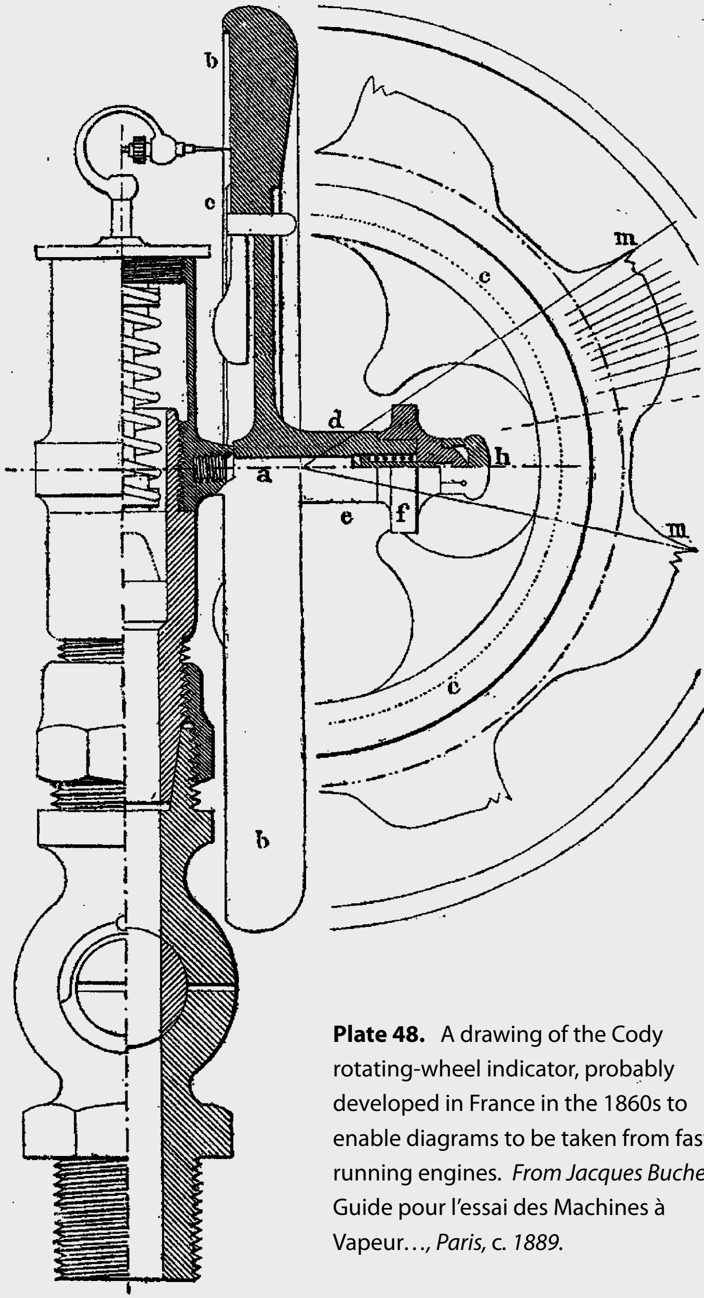


Plate 48. A drawing of the Cody rotating-wheel indicator, probably developed in France in the 1860s to enable diagrams to be taken from fast-running engines. *From Jacques Buchetti,* Guide pour l'essai des Machines à Vapeur…, *Paris,* c. *1889.*

Most of pre-1900 indicators produced conventional closed-loop diagrams, which were easy to interpret. However, there were always maverick inventors prepared to promote something different. These ideas sometimes found their niche: for example, the limiting or 'slice' indicators that built up a composite diagram from small sections of the diagrams that would otherwise have been created many consecutive strokes, or the indicators that registered only peak pressures.

The Cody indicator of the 1860s was one aberrant example. Apparently the work of the eminent French engineer Raymond Cody (1824–1903),[8] it featured a heavy flywheel attached to the body by a horizontal pin. The tracer was attached directly to the tip of the piston rod, protruding through the body cap. A compression spring lay between the upper surface of the piston and the insider of the cap.

To operate the indicator, a paper ring was attached to the inner surface of the flywheel, which was then spun manually. Pressing the operating button for a half-second moved the wheel forward to allow several diagrams to be drawn on the paper disc. Releasing the button moved the wheel back until the tracer left the paper.

It is clear that the Cody indicator worked well enough to provide effectual diagrams, once the operator had learned how to spin the flywheel efficiently. It is also likely that the indicator operated successfully with engines running at more than 300 rpm (which was its stated goal) and perhaps even as high as 1000 rpm. Unfortunately, the lack of amplification limited the pressures that could be indicated, and the diagrams, in the form of a continuous trace above an atmospheric line obtained by operating the indicator with the steam cock closed, were much more difficult to interpret than the closed-loop type. Consequently, the Cody instrument disappeared almost as soon as it had been created.

8. Cody, born in Paris, was 'technical adviser' to Mazeline Frères from the mid 1850s until 1862, when he became chief engineer of Chantiers et Ateliers de l'Ocean (1862-70?) and then successively chief engineer (1872–4) and engineering director (1872–97) of Forges et Chantiers de la Mediteranée.

Please note that the Bibliography, which was originally included here, has been moved to 'Book Five: Aids, Accessories and Overview'.