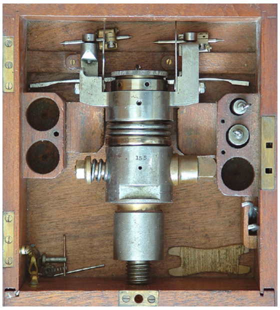
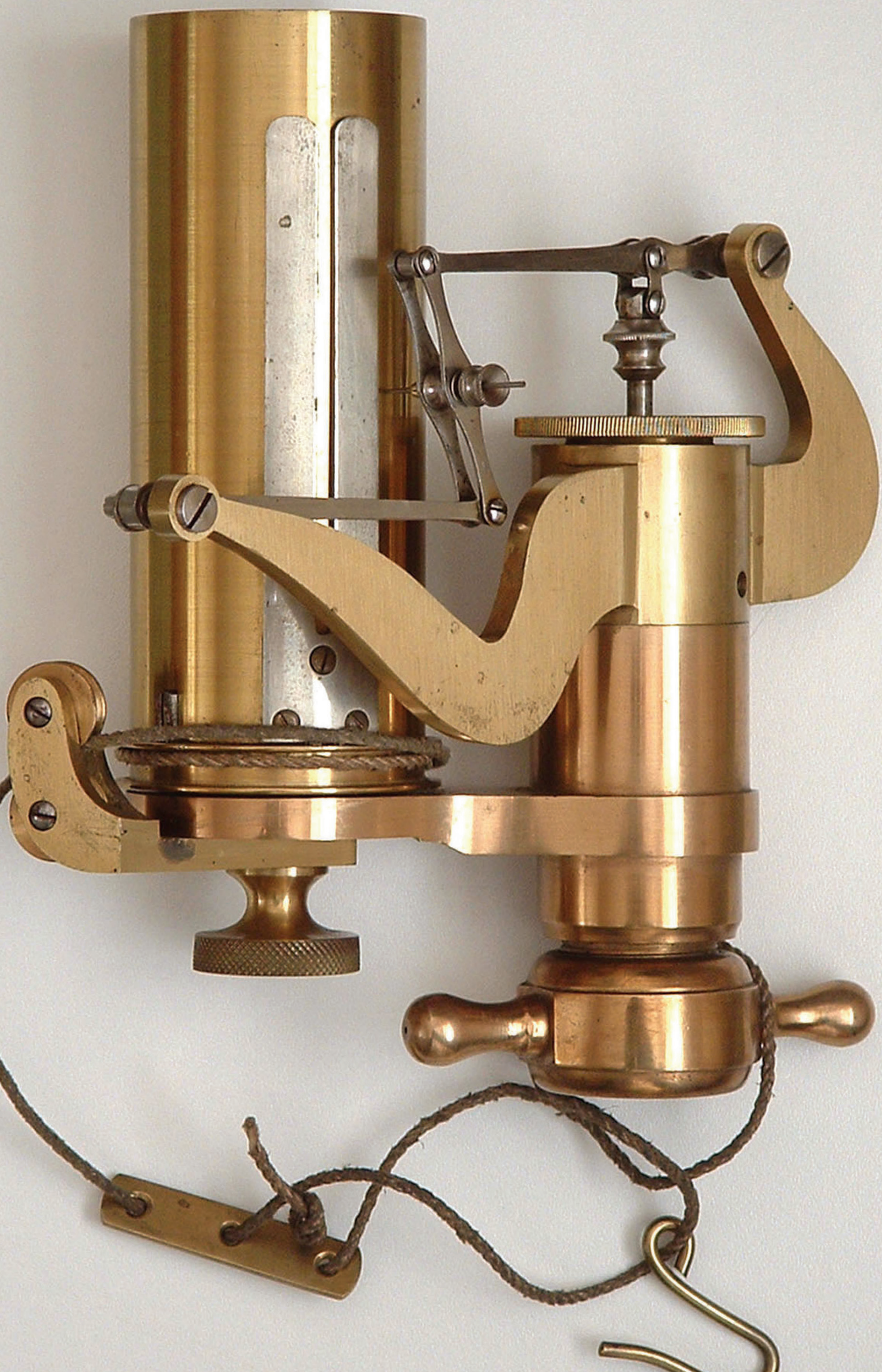


THE ENGINE INDICATOR

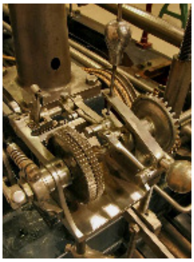


THE ENGINE INDICATOR

A CONCISE GUIDE TO THE IDENTIFICATION OF AUTOGRAPHIC INSTRUMENTS

JOHN WALTER

THE CANADIAN MUSEUM OF MAKING
in association with
NEVILL PUBLISHING



First published in 2008 by
THE CANADIAN MUSEUM OF MAKING
www.museumofmaking.org

with the assistance of
Nevill Publishing & Design, Hove, England

Updated to 7th July 2011

This chapter has been up-loaded
to allow free access to information as 'work in progress'.
Other chapters will be made available as they are completed:
please check our websites for details.

PRODUCED BY JOHN WALTER
e-mail: johnwalter883@btinternet.com • *website:* www.archivingindustry.com

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 the engines were designed to drain 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, as 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 that 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.

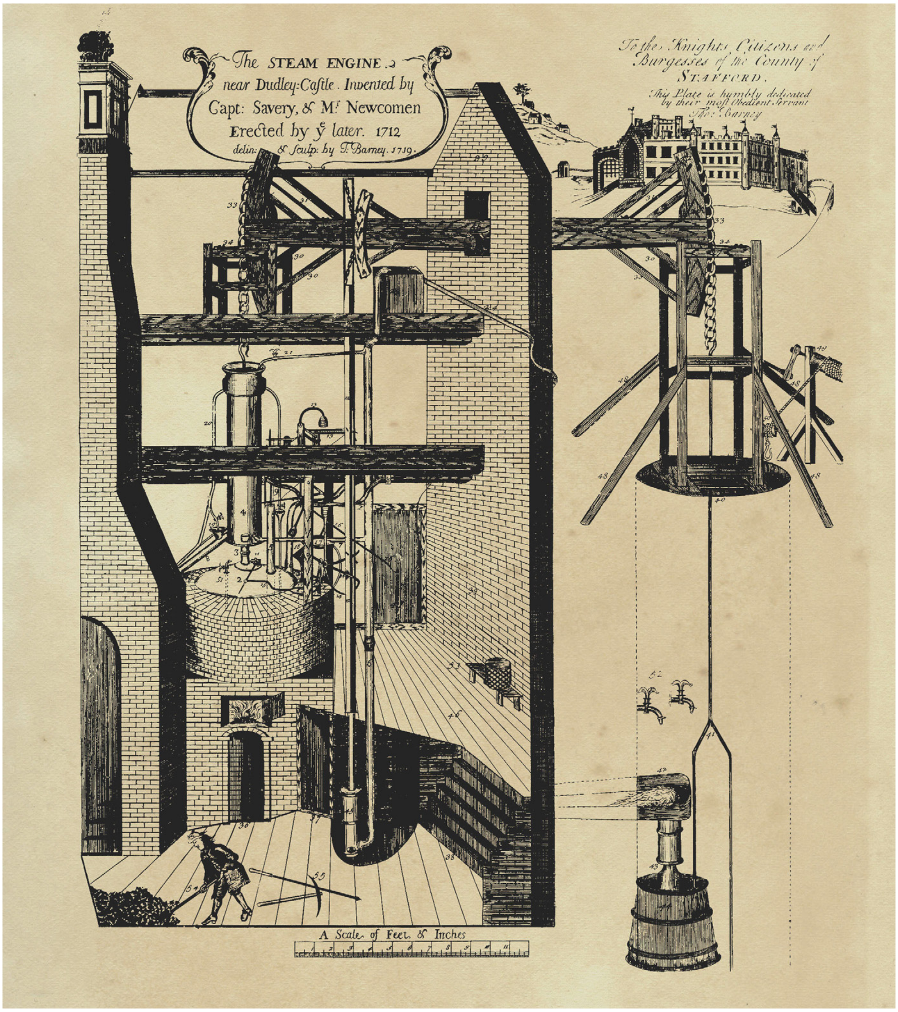


Plate 0-1. This reproduction of an engraving by Thomas Barney, originally dating from 1719, is the earliest known illustration of a Newcomen atmospheric engine—in this case, the so-called 'Dudley Castle' engine erected in 1712. *John Walter collection.*

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

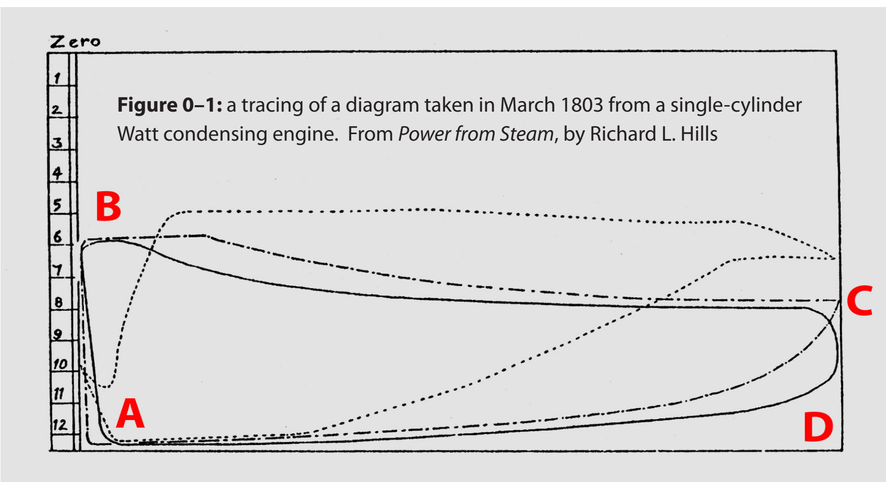


Figure 0–1: a tracing of a diagram taken in March 1803 from a single-cylinder Watt condensing engine. From *Power from Steam*, by Richard L. Hills

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 of the Newcomen engines was only about one per cent, improved by even the

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

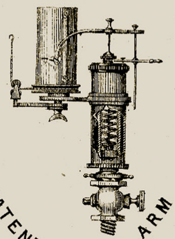
STEAM ENGINE

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 0-2. 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.*

finest of the Watt engines only 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.

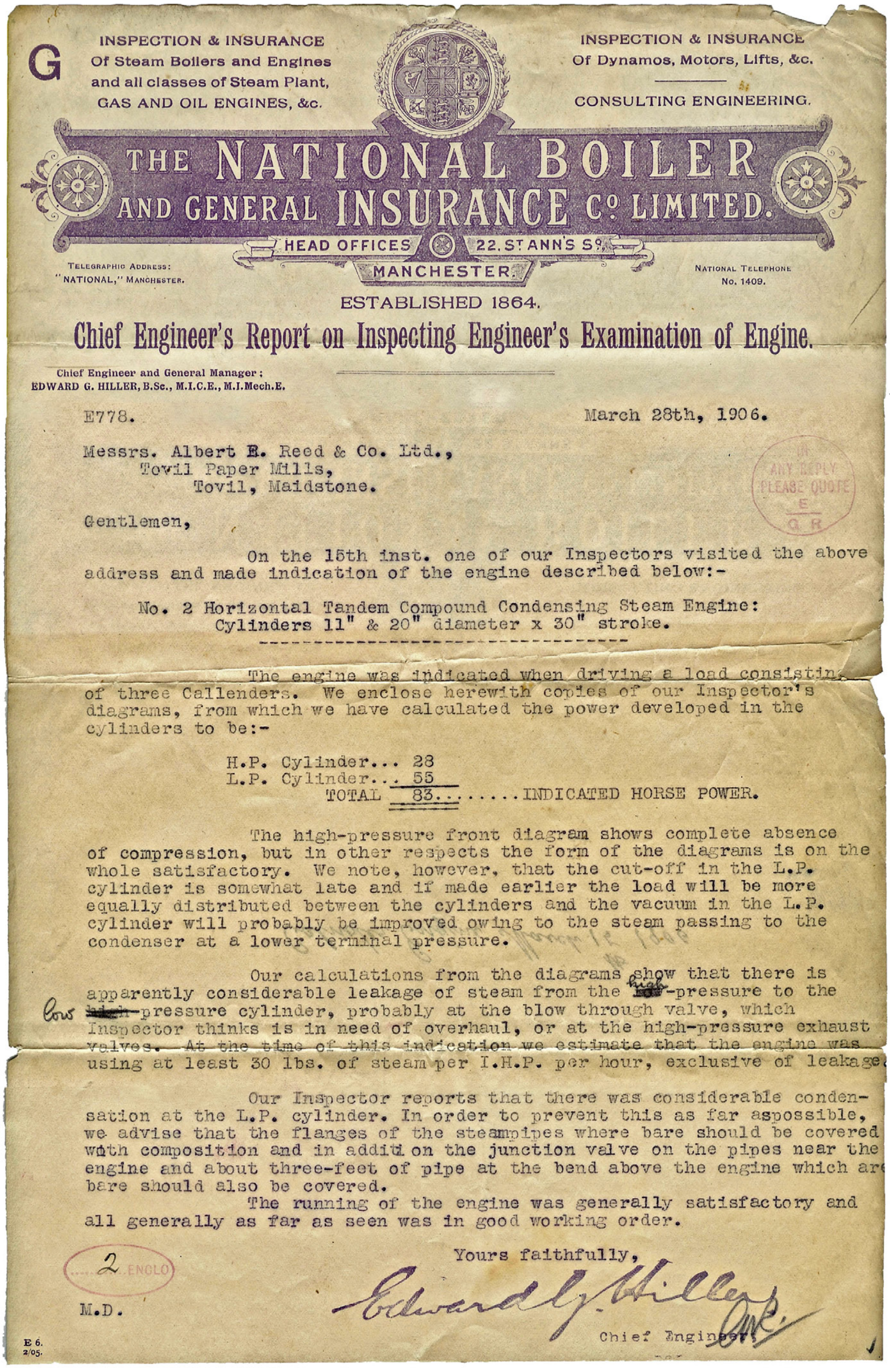
As early as the 1840s, the British engineer Daniel Gooch (1816–89) was indicating railway locomotives—even then running with boiler pressures of 120 lb/sq.in—and Jacob Perkins (1766–1849) had produced boilers capable of withstanding pressures more than ten times higher. The rapid rises in piston speeds 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 Chapter 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 specifically designed for use with high-speed machinery, these included



G

INSPECTION & INSURANCE
Of Steam Boilers and Engines
and all classes of Steam Plant,
GAS AND OIL ENGINES, &c.

INSPECTION & INSURANCE
Of Dynamos, Motors, Lifts, &c.

CONSULTING ENGINEERING.

THE NATIONAL BOILER
AND GENERAL INSURANCE Co. LIMITED.
HEAD OFFICES 22, ST ANN'S SQ.
MANCHESTER.

TELEGRAPHIC ADDRESS: "NATIONAL," MANCHESTER.

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.

IN ANY REPLY PLEASE QUOTE E G R

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

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 ~~low~~ high-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,

2 ENCLO

Edward G. Hiller

M.D.

Chief Engineer.

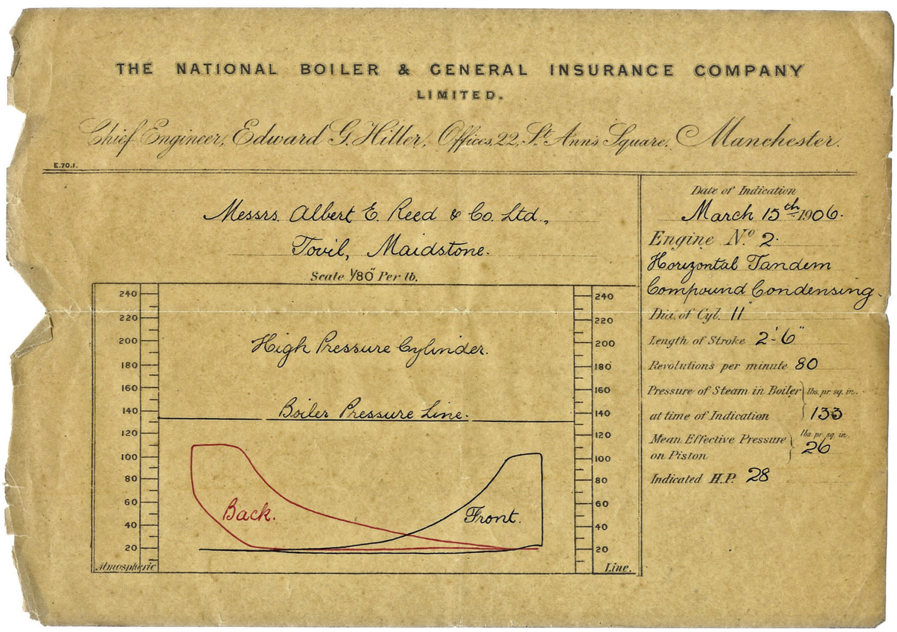
E 6. 2/05.

the principal US patterns: the Thompson of 1875, the Tabor of 1878 and the Crosby of 1882 (all included in Chapter Three).

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. Among the most important catalysts in its success was the introduction in Britain of the Boiler Explosions Act of 1882, the inspiration for later amendments and comparable legislation accepted in France, Germany, the USA and elsewhere prior to 1914.

The increasingly frequency with which boilers failed soon attracted public attention. The earliest attempt at regulation seems to have been a maritime boilermexplosions act pased in the USA on 7th July 1838, seeking to prevent needless loww of life on thr 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.

Plate 0–3 (previous page) and **Plate 0–4**. 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.*



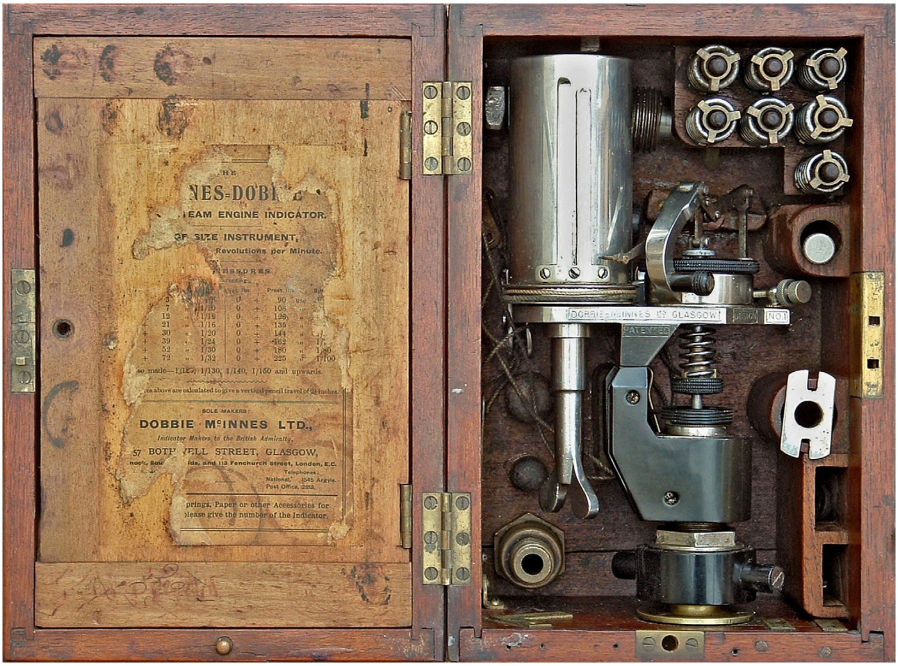


Plate 0–5. This Dobbie McInnes Design No. 1A indicator, no. 16813L dating from *c.* 1917, is known to have been used by a Surveyor employed by the British Engine Boiler & Electrical Insurance Co. Ltd. Unlike standard Design No. 1A instruments, which have the distinctively arched tracer bar, the 'L' type has a straight arm and a large drum intended for use with Richards-type paper. *John Walter collection.*

The British were initially much less keen to hamstring industrial development with restrictive legislation. Eventually, 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 (Victoria 45 & 46, c. 22) and its 1890 amendment (Vistoria 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 camouflages 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, the figures were 56 and five respectively.

Inspections were facilitated by the use of indicators, which could show if engines and boilers were properly matched; if the steam lines were too constricted; or if the valve gear was 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.' 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.

The letter reproduced as Plate 0–3 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 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-yard.

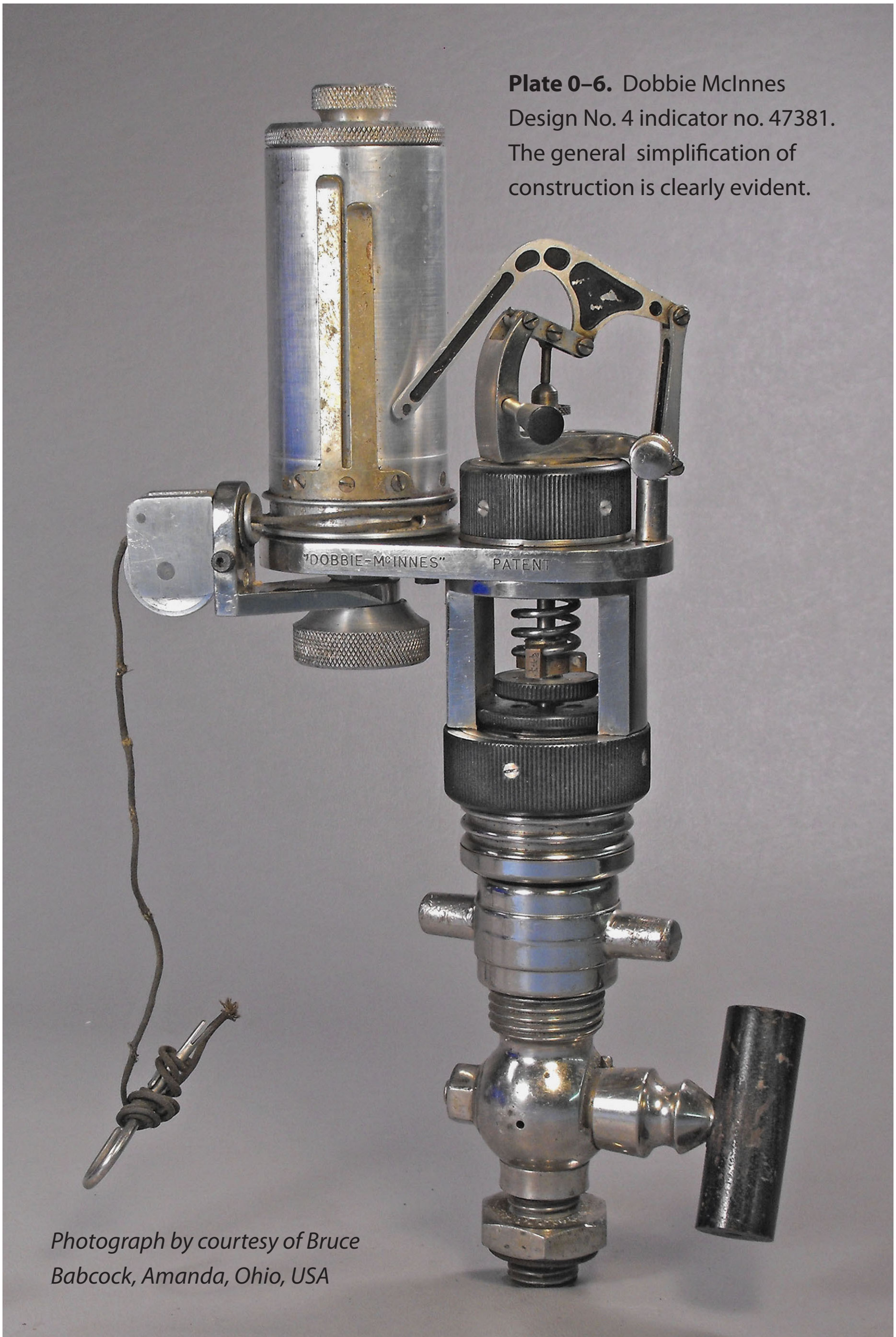


Plate 0–6. Dobbie McInnes Design No. 4 indicator no. 47381. The general simplification of construction is clearly evident.

Photograph by courtesy of Bruce Babcock, Amanda, Ohio, USA

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 (Chapter Seven) 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 from a specialist supplier. 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 then 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.

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

Plate 0–7. 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.*

"Springs were tested on a dummy 'skeleton' indicator rig, using a deadweight 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.

"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.

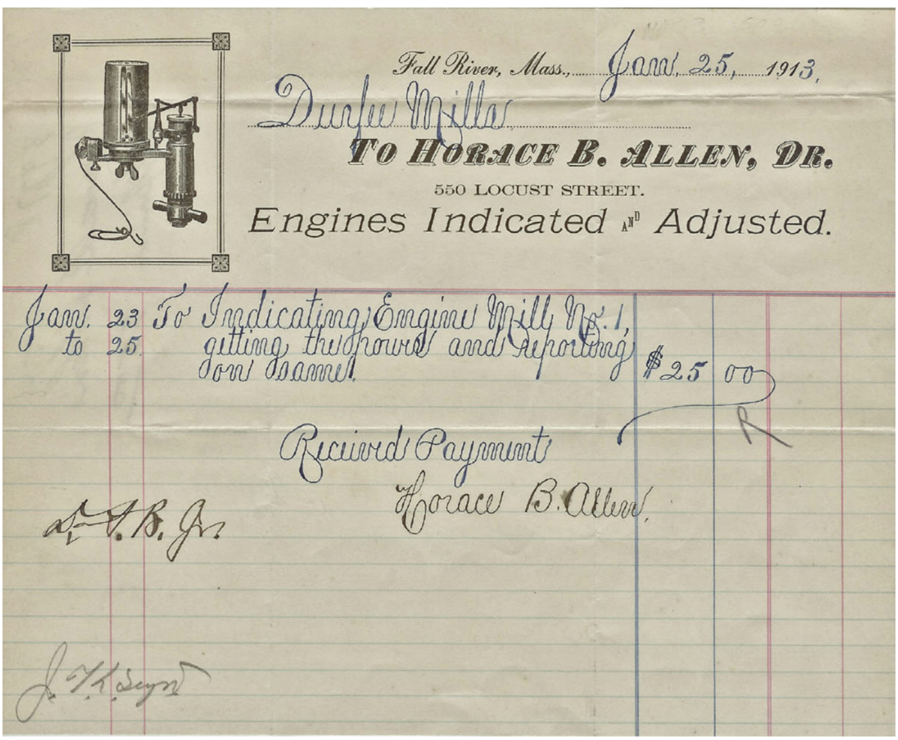
"I think that some of the boxes made during the Second World War, when supplies of mahogany were restricted, were made of marine plywood (perhaps birch). I've seen several boxes of this type, with alternating light close-grain sapwood and dark open-grain heartwood layers crossed for strength.

"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 in this era.

"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 0–8. The indicator provided many engineers with work. This billhead is typical of many. *By courtesy of Bruce E. Babcock, Amanda, Ohio, USA.*



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 USA, 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 PELL 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 0–9. 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, USA.*

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

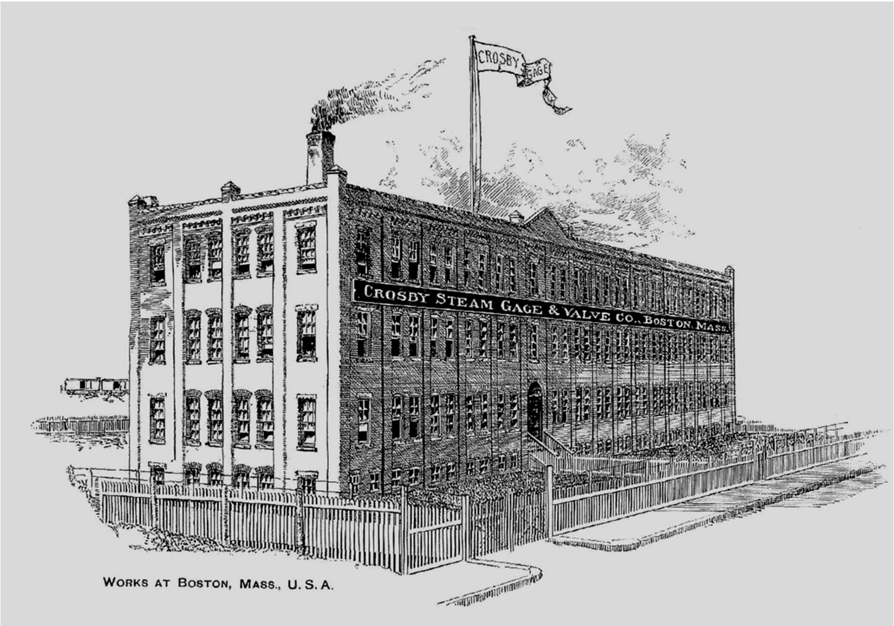


Plate 0–10. The main block of the Crosby Steam Gage & Valve Company factory in Boston, Massachusetts, from a catalogue published by the company in 1897. *By courtesy of Bruce E. Babcock, Amanda, Ohio, USA.*

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

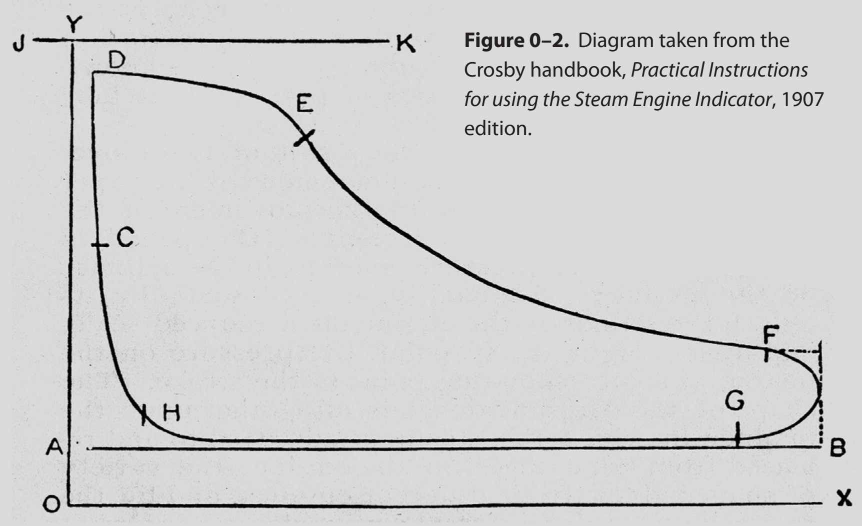


Figure 0–2. Diagram taken from the Crosby handbook, *Practical Instructions for using the Steam Engine Indicator*, 1907 edition.

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.

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:

"[the illustration on the preceding page gives] 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.

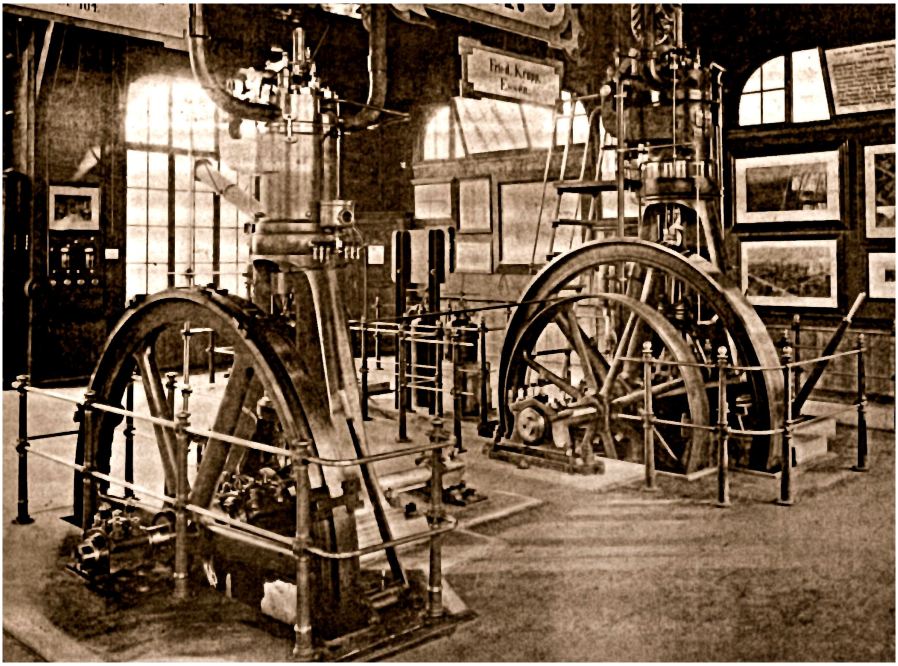
"*The zero line of pressure*, or line of absolute vacuum O X, is a reference line, and is drawn by hand, 14⁷⁄₁₀ pounds by the scale, below and parallel with the atmospheric line. It represents a perfect vacuum, or absence of all pressures.

"*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.

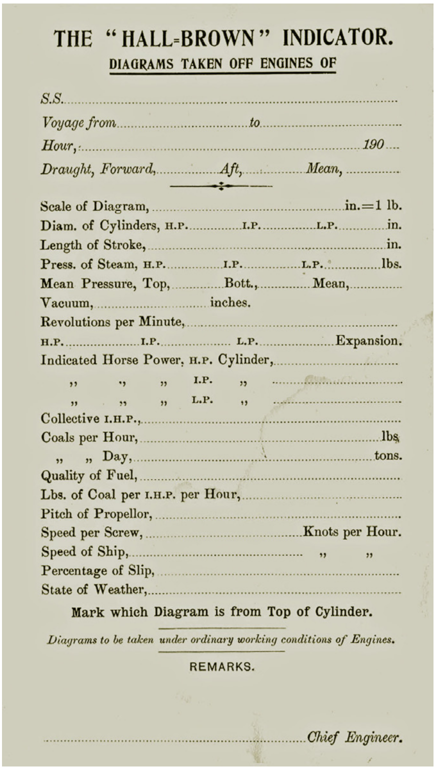
Plate 0-11. Two of the earliest diesel engines to be made by Maschinenfabrik Augsburg–Nürnberg ('MAN'), seen on display in the machinery hall of the international exhibition held in Leipzig in 1900. The design of autographic indicators was rapidly improved to accommodate internal-combustion engines. *John Walter collection.*



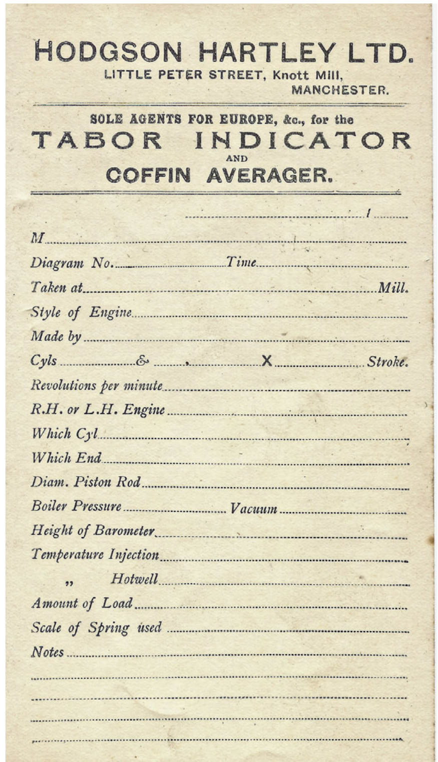
Bibliography

Articles

¶ **Unattributed**: "Darke's Indicator", in *Engineering*, 26th March 1880, pp. 241 and 242.
—'Detent for Indicators' in *Engineering*, 17th December 1875, p. 474.
—"Kenyon's Pistonless Indicator", in *Engineering*, 23rd April 1880.
—"Little's Continuous Recording Indicator", in *Engineering*, 10th December 1879, pp. 720–2.
—'The Accuracy of Indicator Diagrams', in *Engineering*, 16th November 1877, pp. 382–3; 30th November 1877, pp. 420–2; 1st February 1878, pp. 77–8; 19th April 1878, pp. 294–5; and more to add.
—'The Collins Micro-Indicator for High-Speed Engines', in *Engineering*, 9th June 1922, p. 716
—'The Crosby Indicator', in *Engineering*, 29th February 1884, pp. 185–6.
—'The Gale Indicator for High Speed Engines', in *Engineering*, 12th March 1926, p. 350.
—'The Lefebvre Indicator', in *The Practical Engineer*, 16th August 1889.
—'The Mathot Continuous Explosion and Pressure Recorder', in *Engineering*, 30th May 1902, p. 725.
—"The M'Innes Indicator", in *Engineering*, 2nd August 1889, p. 158.
—"The M'Innes-Dobbie Indicator", in *Engineering*, 8th June 1900, p. 748.
—'The Tabor Indicator', in *Engineering*, 7th June 1889, pp. 653 and 654.
—"The Tabor Indicator and Coffin Averaging Instrument", in *The Practical Engineer*, 22nd July 1892, pp. 545–7.
—"Thompson's Indicator", in *Engineering*, 19th October 1877, p. 312.
¶ **Bruce E. Babcock**: 'Engine Analyzers for Steam engines. The Story of the Steam Engine Indicator', in *Old Abe's News*, xix no. iv (autumn 2004), pp. 42–6.
—'The Slide Rule and the Steam Engine Indicator', in the *Journal of the Oughtred Society*, details to add…
¶ **C.F. Budenberg** MSc: 'Steam Engine Indicators'—a lecture given before the Owens College Engineering Society on 4th February 1890. Reported in *The Practical Engineer*, 14th February 1890, pp. 98–100; 21st February 1890, pp. 114–16; 28th February 1890, pp. 139–140; 7th March 1890, p. 151; 14th March 1890, pp. 171–2; and 28th March 1890, pp. 198–9.
¶ **Frederic W. Burstall** (Professor): 'Indicating of Gas Engines'. A paper



THE "HALL-BROWN" INDICATOR.
DIAGRAMS TAKEN OFF ENGINES OF
S.S.
Voyage from ... *to* ...
Hour, ... *190* ...
Draught, Forward, ... *Aft,* ... *Mean,* ...
Scale of Diagram, ... in.=1 lb.
Diam. of Cylinders, H.P. ... I.P. ... L.P. ... in.
Length of Stroke, ... in.
Press. of Steam, H.P. ... I.P. ... L.P. ... lbs.
Mean Pressure, Top, ... Bott., ... Mean, ...
Vacuum, ... inches.
Revolutions per Minute, ...
H.P. ... I.P. ... L.P. ... Expansion.
Indicated Horse Power, H.P. Cylinder, ...
" " " I.P. " ...
" " " L.P. " ...
Collective I.H.P., ...
Coals per Hour, ... lbs.
" " Day, ... tons.
Quality of Fuel, ...
Lbs. of Coal per I.H.P. per Hour, ...
Pitch of Propellor, ...
Speed per Screw, ... Knots per Hour.
Speed of Ship, ... " "
Percentage of Slip, ...
State of Weather, ...
Mark which Diagram is from Top of Cylinder.
Diagrams to be taken under ordinary working conditions of Engines.
REMARKS.
... *Chief Engineer.*



HODGSON HARTLEY LTD.
LITTLE PETER STREET, Knott Mill, MANCHESTER.
SOLE AGENTS FOR EUROPE, &c., for the
TABOR INDICATOR
AND
COFFIN AVERAGER.
... / ...
M ...
Diagram No. ... *Time* ...
Taken at ... *Mill.*
Style of Engine ...
Made by ...
Cyls ... & ... X ... *Stroke.*
Revolutions per minute ...
R.H. or L.H. Engine ...
Which Cyl ...
Which End ...
Diam. Piston Rod ...
Boiler Pressure ... *Vacuum* ...
Height of Barometer ...
Temperature Injection ...
" *Hotwell* ...
Amount of Load ...
Scale of Spring used ...
Notes ...

Plate 0–12. The backs of two typical British cards of the 1890s, used to promote the merits of the Hall-Brown indicator for maritime use and the Tabor indicator for more general purposes. Ephemera of this type was often produced for individual clients—insurance companies, for example. *John Walter collection.*

read before the Institution of Mechanical Engineers, Liverpool, 28th July 1909; summarised in *Engineering*, 6th August 1909, pp. 193–4.

¶ **Thomas Gray**: 'A Continuous Steam-Engine Indicator', in *Engineering*, 22nd October 1897, pp. 515–16. A summary of a presentation to the American Society of Mechanical Engineers in Hartford, Connecticut, in May 1897.

¶ **Loughnan Pendred**: 'High-Speed Engine Indicators', a paper read before the Institution of Mechanical Engineers, London, on 19th January 1923. It was summarised in *Engineering*, 26th January 1923, pp. 119–26. The article also contains detailed descriptions and drawings of the Burstall optical and Collins micro-indicators.

¶ **James G. Stewart**: 'Indicators'. A paper read before the Institution of

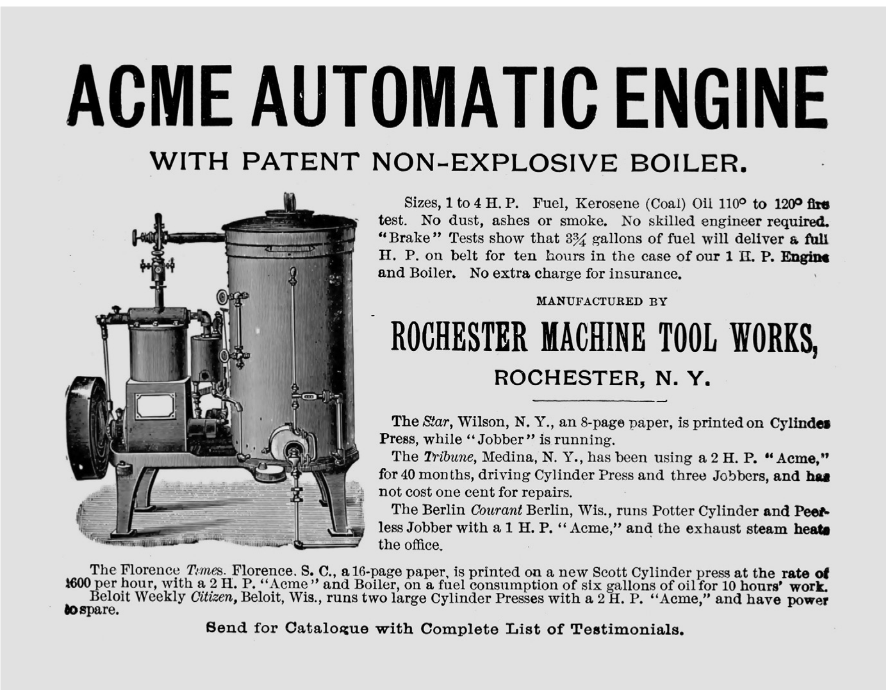
Mechanical Engineers, London, on 17th January 1913. Summarised in detail in *Engineering*, 24th January 1913, pp. 134–9.

¶ **John E. Sweet**: 'A New Steam Engine Indicator', in *Engineering*, 8th August 1879, p. 117, summarising a paper read before the American Institute of Mining Engineers in Chattanooga, Tennessee.

¶ **Charles T. Porter**: 'On the Allen Engine and Governor'. Proceedings of the Institution of Mechanical Engineers (USA), April 1868.

¶ **Paul Zoller**: 'The Steam Engine Indicator: 19th Century Tool of Science and Stethoscope of the Engineer', in the *Bulletin of the Scientific Instrument Society*. No. 67 (2000), pp. 9–22.

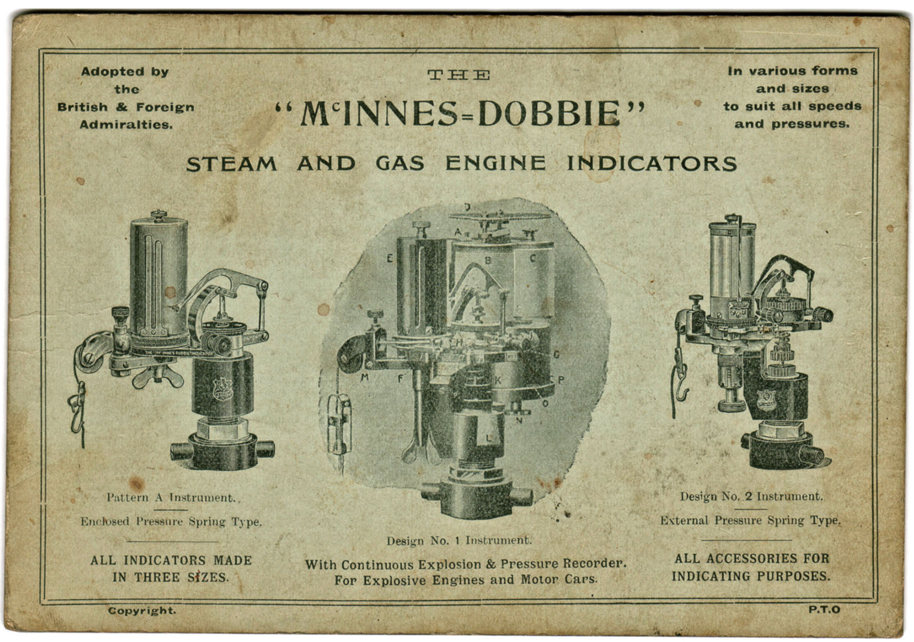
Plate 0–13. This 1894-vintage advertisement from *Cassier's Magazine* draws attention to the introduction of compact steam engines, developed partly to satisfy demands for self-contained power-plants and partly to compete with first hot-air and then internal-combustion engines. *John Walter collection.*



Books

¶ **Anon.**: *Exposition universelle internationale de 1878 à Paris. Rapports du jury international* ('Groupe VI. – Classe 54. Rapport sur les machines et les appareils de la mécanique générale'). Imprimerie nationale; Paris; 1883.
—*Indicators*. The Institution of Mechanical Engineers, London; 'Excerpt Minutes of Proceedings of the Meetings', 1923. A bound off-print version of four articles: Loughnan Pendred, 'The Problems of the Engine Indicator'; Professor F.W. Burstall, 'A New Form of Optical Indicator'; W.G. Collins, 'Micro-Indicator for High-Speed Engines'; and H. Wood RAF, AMIMechE, 'R.A.E. Electrical Indicator for High-Speed Internal-Combustion Engines…'
—*Measurement of Indicated Power* ('Part 8, Instruments and Apparatus, Supplement to ASME Performance Test Codes'). The American Society of Mechanical Engineers, New York; © 1970, 'reaffirmed 1985'.
—*Reciprocating Steam Engines* ['Power Test Codes – 1949'. PTC 5-1949]. The

Plate 0–14. Promotional cards of this type, backed by a radial divider to ease the task of interpreting diagrams, were regularly included with Dobbie McInnes and Dobbie McInnes & Clyde indicators. Though undeniably useful as a guide to products, they are, however, all too rarely dated. *John Walter collection.*



American Society of Mechanical Engineers, New York; 1949.
—*The Engine Indicator. Diesel : Steam.* ('With Specimen Diagrams showing Engine Faults'). Dobbie McInnes Ltd and Dobbie McInnes & Clyde Ltd, Glasgow; various editions, nor dated.
—*The Indicator Book* ('A Description of the Latest Types of Engine Indicators and Accessories, with Information on Taking and Reading of Indicator Cards'). Trill Indicator Company, Corry, Pennsylvania; © 1916.
—*The Pennsylvania Railroad System at the Louisiana Purchase Exposition. Locomotive Tests and Exhibits. Saint Louis, Missouri, 1904.* The Pennsylvania Railroad Company, Philadelphia; 1905.
—*The Record of the International Exhibition, 1862.* William MacKenzie, Glasgow, Edinburgh and London; 1862.
¶ **John R. Allen** and Joseph A. Bursley: *Heat Engines. Steam, Gas, Steam Turbines and Their Auxiliaries.* McGraw Hill Book Co., Inc., New York and London; 1941.
¶ **L[ouis]. Arnal** and Gustave Gauthier: *Traité de Mécanique* ('Chaudières à Vapeur, Moteurs à Vapeur et à Gaz'). Part of the 'Encyclopédie Théorique et Pratique des Connaissances Civiles et Militaires'. Georges Fanchon, Paris; *c.* 1894.
¶ **Bruce E. Babcock**: *Engine Analyzers for Steam Engines. The Story of the Steam Engine Indicator.* Published by the author, Amanda, Ohio; 2001.
¶ **Geo. H. Barrus** SB: *The Star Improved Steam Engine Indicator.* Star Brass Mfg Co., Boston, Massachusetts; © 1903.
—*The Tabor Steam Engine Indicator.* Broun, Green & Adams, New York City. First edition, 1883; second edition, 1888.
¶ **John Bourne** CE: *A Catechism of the Steam Engine* ('in Its Various Applications to Mines, Mills, Steam Navigation, Railways and Agriculture…'). Longmans, Green & Co., London; 'New Edition', 1874.
—*The Steam Engine* ('A Treatise…'). Longmans, Green & Co., London; 1876. First published in 1846, but reprinted many times without revision.
¶ **A. Brown** ME: *Illustrated Catalogue* ('of Vertical Quadruple Expansion Engines, Horizontal & Vertical Triple Expansion Engines, Compound Engines, Simple Engines, Barring Engines, Lancashire Boilers, Globe Safety Boilers, Sectional Boilers, Mill Gearing, Indicators, &c. manufactured by John Musgrave & Sons, Ltd.'). John Musgrave & Sons, Bolton, Lancashire; *c.* 1893–5.
¶ **A.G. Brown**: *The Indicator and Its Practical Working.* The Globe Engineering Co. Ltd, Manchester and London; undated (*c.* 1889)
¶ **J[acques]. Buchetti**: *Guide pour l'Essai des Machines à Vapeur et la*

Production Économique de la Vapeur. 'Chez l'Auteur' and 'Chez Bernard Tignol', Paris; undated (*c*. 1886).
—[Alexander Russell MIEE, etc, translator] *Engine Tests and Boiler Efficiencies*. Norman W. Henley & Co., New York; 1903. An English-language version of the third French edition.
¶ **A.B. Calkins**: *A Treatise on the Calkins Steam-Engine Indicator* ('with Descriptions of Calkins' Improved Graduated Pantograph, Polar Planimeter, Speed Measure, Revolution Counter, Parallel Rule, Indicator Spring Weighing Device, Mercurial Column'). The Engineers' Instrument Company, New York; 1891.
¶ **W.E. Dalby** FRS, AMCINA, MInstCE, MIME, MA, BSc: *Steam Power*. Edward Arnold, London; first edition, 1915.
¶ **Charles Day** WhSc, MIMechE: *Indicator Diagrams and Engine and Boiler Testing*. The Technical Publishing Co. Ltd, Manchester; third edition, 1898.
¶ **Kalman J. DeJuhasz**: *The Engine Indicator. Its Design, Theory and Special Applications*. Instruments Publishing Company, New York; 1934.
—(Professor), and Dr.-Ing. J. Geiger: *Der Indikator. Seine Theorie und seine mechanischen, optischen und elektrischen Ausführungsarten*. Julius Springer, Berlin, 1938.
¶ **Paul H. Frohwein** [collaborating with the 'I.C.S. Staff']: *Steam Engine Testing* ('Indicating Steam Engines. Engine Testing'). International Textbook Company, Scranton, Pennsylvania; textbook no. 583, combined edition, © 1932.
¶ **A.H. Goldingham** ME: *The Design and Construction of Oil Engines* ('With full directions for erecting, testing, installing, running and repairing'). Spon & Chamberlain, New York City, and E. & F.N. Spon, London; 1900.
¶ **Frank D. Graham** BS, MSME: *Audels Engineers and Mechanics Guide 3* ('A Progressive Illustrated Series with Questions–Answers Calculatiuons'). Theo. Audel & Company, New York; © 1921, 1927 and 1940.
¶ **Frederick Grover** AMInstCE, MIMechE: *A Practical Treatise on Modern Gas and Oil Engines*. The Technical Publishing Co., Manchester and London; Simpkin, Marshall, Hamilton, Kent & Co. Ltd, London; D. Van Norstrand Co., New York; E.W. Cole, Sydney and Melbourne; Geo. Robertson & Co. Pty Ltd, Melbourne, Sydney, Adelaide and Brisbane. Fourth edition, 1906.
¶ **William J. Goudie** DSc (reviser): *Ripper's Steam Engine Theory and Practice*. Longmans, Green & Co., London, New York and Toronto; eighth edition, 'revised and enlarged', 1932.

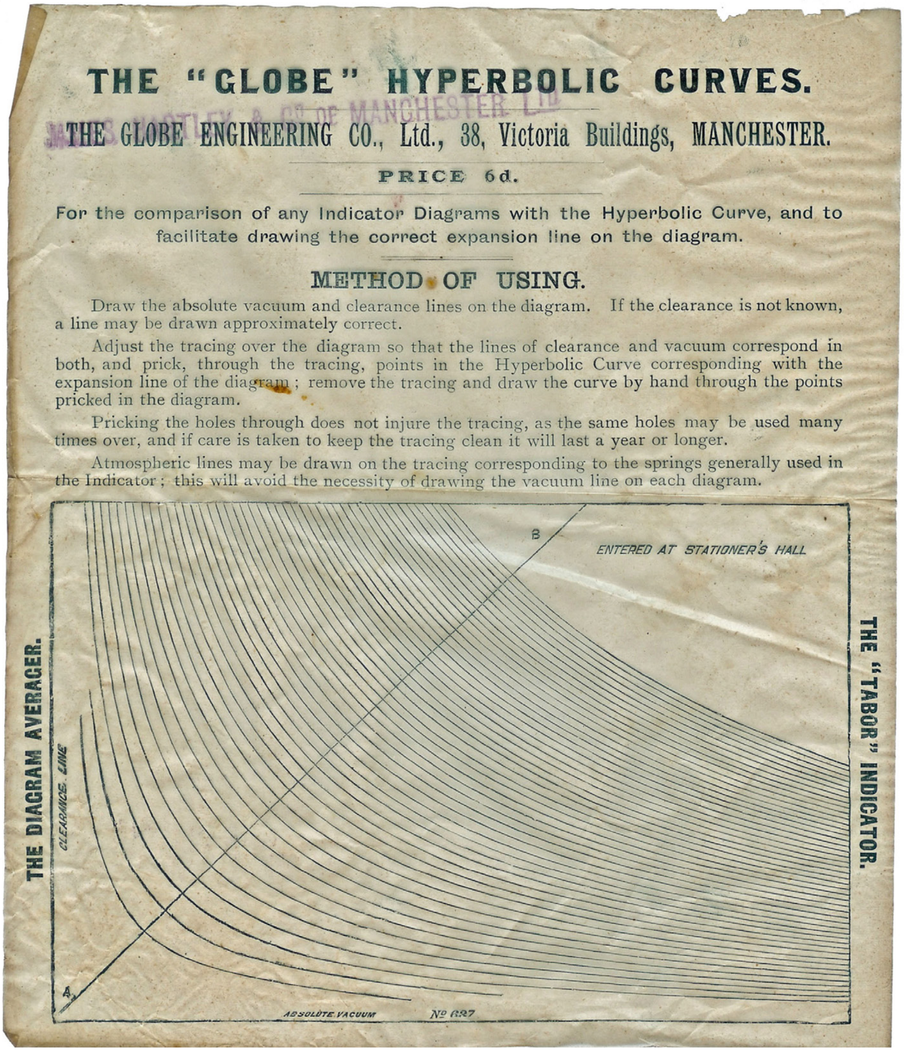
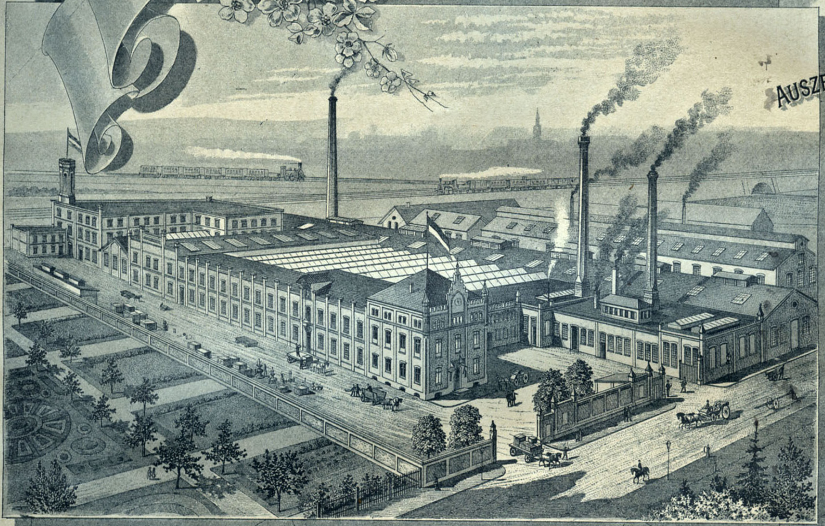


Plate 0–15. Printed on translucent paper, this was prepared partly as a promotional tool (Globe briefly distributed Tabor indicators in Britain) and partly to provide a method of comparing actual performance with thermodynamic theory. *John Walter collection.*

¶ **Hermann Haeder**: *Der Indikator. Praktisches Handbuch für Entwurf, Untersuchung und Verbesserung von Dampfmaschinen, Dampfkesseln etc.* Privately published, Duisburg; third edition, 1900.
—*Der Indikator und die Kraftanlage.* Rich. Carl Schmidt & Co., Berlin; 1928.

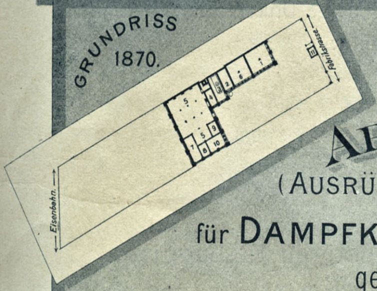
Lohmann

DREYER, ROSENKRANZ & DROOP
HANNOVER.
GEGRÜNDET 1870.

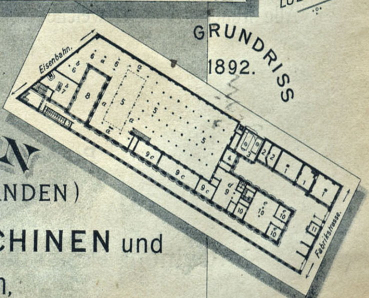


AUSZEICHNUNGEN:
WIEN 1873.
KÖLN 1875.
BRÜSSEL 1876.
KÖLN 1876.
BERLIN 1878.
HANNOVER 1878.
MANNHEIM 1880.
MELBOURNE 1880-81.
FRANKFURT a/M. 1881.
HANNOVER 1881.
CHRISTCHURCH 1882.
HANNOVER 1884.
ANTWERPEN 1885.
LÜBECK 1895.

GRUNDRISS 1870.



GRUNDRISS 1892.



FABRIK
von
ARMATUREN
(AUSRÜSTUNGSGEGENSTÄNDEN)
für **DAMPFKESSEL, MASCHINEN** und
gewerbliche Anlagen,
PATENT-WASSERMESSERN
UND
WASSERLEITUNGS-GEGENSTÄNDEN.

Plate 0–16. The highly decorative title page of the 1899 Dreyer, Rosenkranz & Droop catalogue. Material of this type is often the most important guide to identifying and dating individual instruments. *John Walter collection.*

—CE [H.H.P. Powles AMInstCE, MIME, translator]: *A Handbook of the Steam Engine* ('with especial reference to small and medium sized engines'). Crosby Lockwood & Son, London; 'Second English edition, revised', 1896.

¶ **Thomas J. Hayes** (Colonel, US Army) ['Prepared under the Direction of']: *Elements of Ordnance. A Textbook for the Use of Cadets of the United States Military Academy*. John Wiley & Sons, Inc., New York, and Chapman & Hall Ltd, London; © 1938.

¶ **N. Hawkins** ME: *Hawkins' Indicator Catechism. A Practical Treatise* ('for the use of Erecting and Operating Engineers, Superintendents, Students of Steam Engineering, etc'). Theo Audel & Co., New York City; 1898, 1901, 1903 and 1904 editions. The covers are generally marked 'Practical Treatise on the Steam Engine Indicator', with "Hawkins' Indicator" on the spine.

¶ **Frank F. Hemenway**: *Indicator Practice and Steam-Engine Economy*. John Wiley & Sons, New York; fourth edition, 1890.

¶ **John D. Hines**: *The Engine Indicator For Performance Evaluation*. The Cooper-Bessemer Corporation, Mount Vernon, Ohio, USA; © 1952.

¶ **Joseph Hopkinson**: *The Working of the Steam Engine Explained by the Use of the Indicator*. John Weale, London; Thomson & Son, Manchester; and R. Brown, Huddersfield. First edition, 1854; second edition, 1857; third edition, 'enlarged and improved', 1860; fourth edition, 1864; fifth edition, 1867; sixth edition, 1871, seventh and final edition, 1875.

¶ **Andrew Jamieson** MInstCE: *A Text Book on Steam and Steam Engines* ('Specially Arranged for the use of Science and Art, City and Guilds of London Institute, and other Engineering Students'). Charles Griffin & Co., London; twelfth edition, 1897.

—[Ewart S. Andrews BSc (Eng.), reviser]: *A Text Book of Heat and Heat Engines* ('Specially Arranged for the Use of Engineers Qualifying for the Institution of Civil Engineers, the In-stitution of Mechanical Engineers, the Institution of Electrical Engineers…'). Charles Griffin & Co. Ltd, London; vol. 1, eighteenth edition, 1919.

—[Ewart S. Andrews BSc (Eng.), reviser]: *Elementary Manual of Heat Engines: Steam, Gas and Oil* ('Specially Arranged for First Year Students under all Boards of Education…'). Charles Griffin & Co. Ltd, London; fifteenth edition, 1917.

¶ **W.P. Johnson** MInstAE: "High Speed Indicators" ('[An] Excerpt of Trans-

actions, 1924–25'). Swindon Engineering Society, Swindon; 'Pamphlet No. 144.' ('No. 136' on title page), 1927.
¶ **H.H. Kelley**: *A B C of the Indicator*. W.R.C. Smith Publishing Company, Atlanta, Georgia; 1908.
¶ **J. Langmaid**, Staff Engineer, RN, and H. Gaisford, Engineer, RN: *Elementary Lessons in Steam Machinery and the Marine Steam Engine* ('Compiled for the use of Junior Students of Marine Engineering'). Macmillan & Co, London and New York City; 'New edition, revised and enlarged', 1893.
¶ **David Allan Low** WhSc, MIMechE: *Heat Engines* ('[The] Theory, construction, and performance of steam boilers, reciprocating steam engines, steam turbines, and internal combustion engines'). Longmans, Green & Co., London, New York and Toronto; seventh impression, 1933 (© 1920).
¶ **F.R. Low**: *The Steam Engine Indicator*. McGraw-Hill Book Company, Inc., New York, and Hill Publishing Co. Ltd, London; third edition, 'revised and enlarged', 1910.
¶ **Rankine Kennedy** CE: *Modern Engines and Power Generators* ('A practical work on prime movers and the transmission of power: steam, electric, water, and hot air'). The Caxton Publishing Co., London; vol. IV, undated (*c.* 1925).
¶ **W.C. McGibbon** MIES: *Indicator Diagrams, Steam and Oil, for Marine Engineers*. James Munro & Co. Ltd, Glasgow, and Simpkin, Marshall, Hamilton, Kent & Company, London; first edition *c.* 1906, third edition 1915, fourth edition *c.* 1922, fifth edition *c.* 1929.
¶ **Robert F. McKay** MSc, AMInstCE, AMIMechE: *The Theory of Machines*. Edward Arnold & Co., London; second edition, 1925.
¶ **John McNaught**: *Description and Use of Macnaught's Improved Indicator and Dynamometer for Steam Engines.* J.H. Cowan, Glasgow; the original edition of 1828, and a later version of 1834. The monograph was subsequently reprinted and enlarged several times to become a book.
¶ **Thomas J. Main** MA, FRAS, and Thomas Brown: *The Indicator and Dynamometer* ('With Their Practical Applications to the Steam Engine'). Herbert, London, and Woodward, Portsea, Hampshire; second edition 1850, fifth edition 1864.
¶ **John George Mair** MInstCE: *On the Independent Testing of Steam Engines and the Measurement of Heat Used.* The Institution of Civil Engineers, London; 1882. Extracted from *Minutes of the Proceedings of The Institution of Civil Engineers*, vol. lxx (1881–2), part iv.
¶ **Edward F. Miller** [Ed.]: *Practical Instructions relating to the Construction and Use of the Steam Engine Indicator…* Crosby Steam Gage & Valve Company, Boston, Massachusetts, U.S.A.; many editions—1905, 1910, 1911

Plate 0–17. The introduction of the autographic indicator allowed the performance of steam engines to be assessed under many conditions. The wooden hoarding on the running plate of this London, Brighton & South Coast Railway locomotive, photographed in the early years of the twentieth century, protected engineers endeavouring to take diagrams at high speed!. *John Walter collection.*

and 1917 versions have been among those that have been consulted.

¶ **J.A. Moyer**: *Power Plant Testing*. McGraw-Hill Book Co., New York; 1926.

¶ **Max de Nansouty**: *Chaudières et Machines à Vapeur*, in the series 'Les Merveilles de la Science'. Ancienne Librairie Furne, Boivin & Cie, Paris; 1911.

¶ **H[enry]. Northcott**: *The Theory and Action of the Steam Engine* (For Practical Men). Cassell, Petter & Galpin, London, Paris and New York; undated (Preface is dated 1876).

¶ **J[ohn]. Okill** MEng, MIAE: *Autographic Indicators for Internal Combustion Engines*. Edward Arnold & Company, London; 1938.

¶ **Cecil H. Peabody**: *Manual of the Steam Engine*. John Wiley & Sons, New York, and Chapman & Hall Ltd, London; first edition, 1900.

¶ **John Perry** DSc, FRS: *The Steam Engine and Gas and Oil Engines* ('A book for the use of students who have time to make experiments and calculations'). Macmillan & Co. Ltd, London, and The MacMillan Company, New York City; 1904 and other editions.

¶ **Alan Platt**: *The Life and Times of Daniel Gooch*. Alan Sutton Publishing, London; 1987.

¶ **Charles T. Porter**: *Description of Richards' Improved Steam Engine Indicator. With Directions for its Use*. Elliott Brothers, London; undated (probably *c*. 1864).

—*A Treatise on the Richards Steam-Engine Indicator with Directions for Use* ('Revised, with notes and large additions, as developed by American Practice'. D. Van Norstrand, New York, 1873.

—*A Treatise on the Richards Steam-Engine Indicator, (Manufactured by Elliott Bros., London,)* 'and the Development and Application of Force in the Steam Engine'. Longman, Green, Reader and Dyer, London; third edition ('revised and enlarged'), 1874. Fourth, fifth and sixth editions by E. & F. Spon, London, 1888, 1894 and 1902 respectively

¶ **Thomas Pray**, jr.: *Twenty Years with the Indicator* ('Being a Practical Text-Book for the Engineer or the Student, with no Complex Formulæ"). American Steam Gauge & Valve Mfg. Co., Boston, Massachusetts, USA; 'newly arranged and complete in one volume', 1917 (originally published separately: Volume I © 1882, Volume II © 1885, and combined in 1888.)

¶ **W.W.F. Pullen**: *The Testing of Engines, Boilers and Auxiliary Machinery* ('A Treatise on the Construction and Use of the Instruments and Methods Employed in the testing of Prime Movers in the Laboratory and Workshop'). The Scientific Publishing Company, Manchester, England; second edition, 1911.

¶ **P[hilipp].H. Rosenkranz**: *Der Indikator und seine Anwendung*. R. Gaertners Verlagsbuch-handlung, Berlin; third edition, 1879; fifth edition, 1893; twelfth edition, 1912.

¶ **D. Scott** and A. Jamieson LL.D: *The Engineer and Machinist's Assistant* ('Being a Series of Plans, Sections and Elevations of Steam Engines, Spinning Machines, Mills for Grinding, &c…'). Blackie & Son, Glasgow, Edinburgh and London, no date (*c*. 1850?).

¶ **John Sothern**: *Verbal Notes and Sketches for Marine Engineers* ('Specially arranged to suit the Board of Trade Regulations, and intended as a General Reference Book for Marine Engineers'). James Munro & Co. Ltd, Glasgow; sixth edition, 'revised and enlarged', 1908. The eighteenth and nineteenth editions (J.K. Bowden, Ed., *"Verbal" Notes and Sketches for Marine Engineer Officers*, 'A Manual of Marine Steam Engineering Practice), each by Munro and each in two volumes, are undated.

¶ **Anton Staus**, Dipl.-Ing.: *Der Indikator unde seine Hilfseinrichtungen*. Julius Springer Verlag, Berlin; 1911.

FIG. 1.

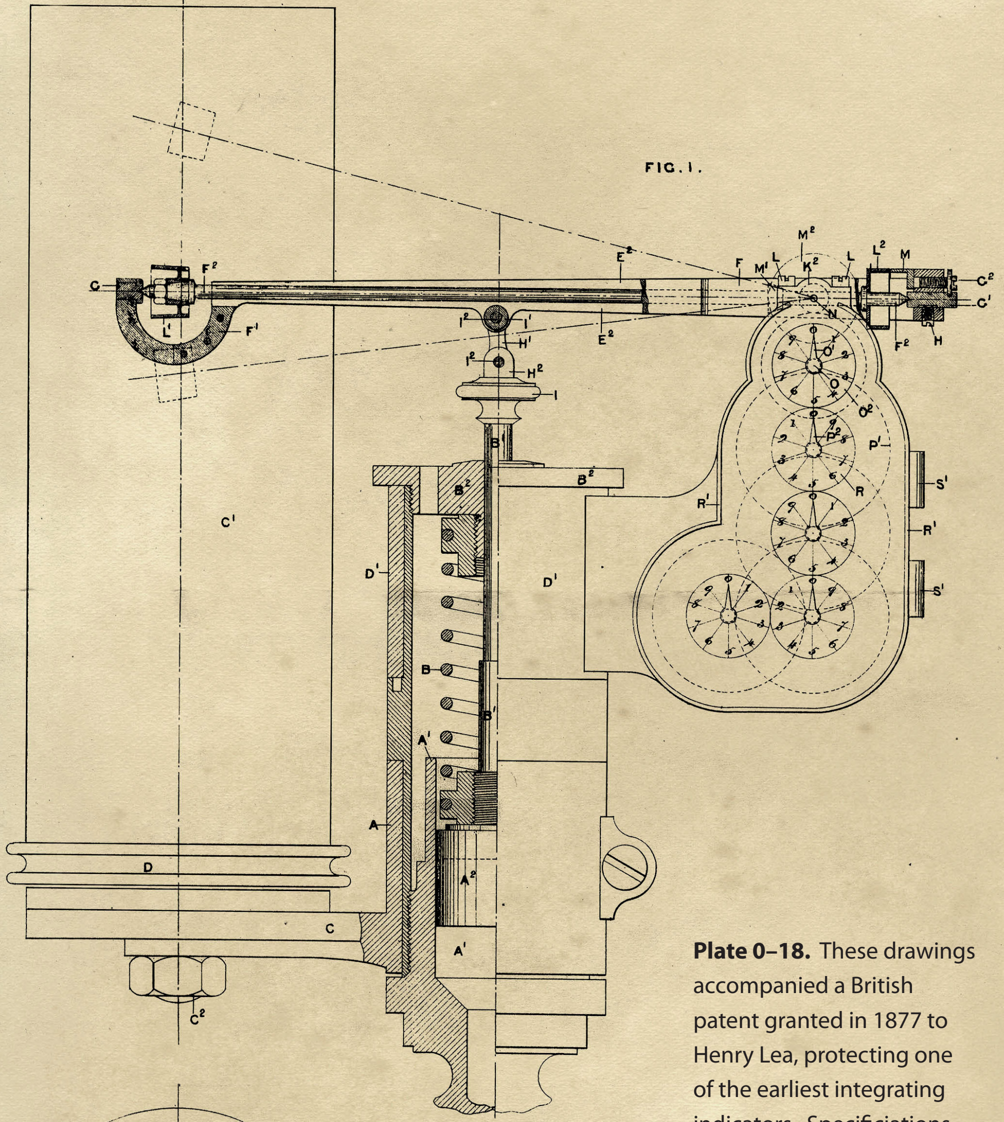


FIG. 2.

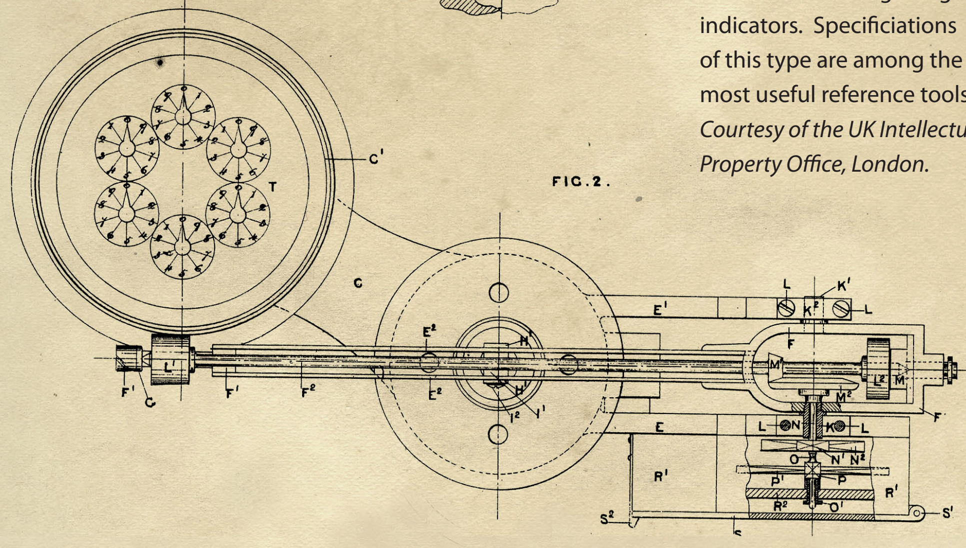


Plate 0–18. These drawings accompanied a British patent granted in 1877 to Henry Lea, protecting one of the earliest integrating indicators. Specificiations of this type are among the most useful reference tools. *Courtesy of the UK Intellectual Property Office, London.*

¶ **H[einrich]. Steuding**: *Messung mechanischer Schwingungen*. VDI Verlag, Berlin; 1928
¶ **Calvin F. Swingle** ME: *Twentieth Century Handbook for Steam Engineers and Electricians* ('A Practical Nontechnical Treatise on the Care and Management of Steam Engines, Boilers and Electric Machinery…'). Frederick J. Drake & Co., Chicago, Illinois; several editions, 1903–22.
¶ **C.H. Thirkell**, Extra Chief, and Edward Ingham AMIMechE: *Engines and Boiler Accessories* ('Edited by the Staff of the Bennett College for the use of Students'). The Bennett College, Sheffield; *c*. 1913.
¶ **R[obert]. H. Thurston** MA, LL.D, DEng: *A Handbook of Engine and Boiler Trials and of the Indicator and Prony Brake* ('For Engineers and Technical Schools'). John Wiley & Sons, New York; 'second and revised edition', 1891.
—*A Manual of the Steam Engine* ('Part II. Design, construction and operation for engineers and technical schools'). John Wiley & Sons, New York City; 'second edition, revised', 1893.
¶ **A.E. Tompkins** CBE (Engineer-Captain, 'Royal Navy [Retired]'): *Marine Engineering (A Text-Book)*. Macmillan & Co., Ltd, London; fifth edition, 'entirely revised', 1921.
¶ **Louis Toft** MSc, and A.T.J. Kersey ARCSC, MIMechE, MIAE: *Theory of Machines*. Sir Isaac Pitman & Sons Ltd, London; 'second edition reprinted', 1934.
¶ **J.Y. Wheatley**: *The Polar Planimeter*. John Wiley & Sons, New York; revised edition', *c*. 1932.