A PROJECT REPORT

ON

"ACTUAL INDICATOR DIAGRAM MECHANISM"

Submitted to

UNIVERSITY OF MUMBAI

In Partial Fulfillment of the Requirement for the Award of

BACHELOR'S DEGREE IN
MECHANICAL ENGINEERING

BY

ANSARI FARAAZ	12ME05
BAIG ARSHAN	13ME17
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UNDER THE GUIDANCE OF
PROF. UBAID SHAH

Anjuman-I-Islam's Kalsekar Technical Campus
SCHOOL OF ENGINEERING & TECHNOLOGY
Plot No. 23, Sector - 16, Near Thana Naka,
Khandagaon, New Panvel - 410206

2018-2019

AFFILIATED TO

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CERTIFICATE

This is certify that the project entitled

"ACTUAL INDICATOR DIAGRAM MECHANISM"

submitted by

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is a record of bonafide work carried out by them, in the partial fulfilment of the requirement for the award of Degree of Bachelor of Engineering (Mechanical Engineering) at ***Anjuman-I-Islam's Kalsekar Technical Campus, Navi Mumbai*** under the University of MUMBAI. This work is done during year 2018-2019, under our guidance.

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I am grateful to him/her for his timely feedback which helped me track and schedule the process effectively. His/her time, ideas and encouragement that he gave is help me to complete my project efficiently.

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ANSARI FARAAZ
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Project I Approval for Bachelor of Engineering

This project entitled ***"ACTUAL INDICATOR DIAGRAM MECHANISM"*** by ***Ansari Faraaz, Baig Arshan, Aadil Ateeque, Khan Sakib, Singh Divya*** is approved for the degree of **Bachelor of Engineering in Department of Mechanical Engineering**.

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Declaration

I declare that this written submission represents my ideas in my own words and where others ideas or words have been included; I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

The main aim of this project is to understand the mechanism of actual indicator diagram and its working principle. Furthermore to design and fabricate a low cost mechanical indicator prototype with the help of available non-expensive materials using comprehended studies done previously. Such type of indicators is mainly found to be used by steam and diesel engine manufacturers to enable them to work out horsepower ratings for the products. They are also a useful diagnostic tool to show problems with injection, valves, leaking piston rings etc.

The engine indicator work on the principle of showing cylinder pressure plotted against piston movement (indicator diagram), and the resulting trace is marked onto a piece of treated paper to give a permanent record. The pressure is taken from the cylinder on test into the indicator. The indicator has a small cylinder with a piston which operates against a spring which sets the operating range. The indicator diagram is very important to know the combustion in the cylinder and also to adjust the engine. The diagram is taken periodically from the indicator valve equipped on the cylinder head and combustion condition is to be confirmed. The compression pressure and maximum pressure in the cylinder can be presumed from the indicator diagram. Engine indicator is the device used to take the indicator diagram, which can be considered as a 'stethoscope' for diesel engines. This diagram give efficiency of combustion in the cylinder, condition of the running gear, irregularities in fuel pumping and injection and a lot of things. The present work is aimed at learning the principle working of an actual indicator diagram and thereby designing and fabricating a low cost prototype engine indicator.

Contents

List of Figures

Chapter 1

Introduction

1.1 An Indicator

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

1.2 Steam Engine Indicator

A common form of steam engine indicator is shown in Fig. 1.1. It consists of a cylinder C which is placed in communication at E with one end of the engine cylinder by a proper pipe connection, provided with a quick opening and closing cock or valve. The cylinder C contains a piston, above which is placed a coil spring of such strength that a given pressure per square inch acting upon the lower side of the piston will compress the spring a definite and known amount. Extending through the cap or head of cylinder C is a stem attached to the piston below, and connected by suitable levers with a pencil point P. The arrangement of the levers is such that a certain rise of the piston causes the point P to move upward in a vertical line a proportional amount.

The hollow drum D rotates back and forth upon a vertical stem at its center, its motion being produced by the string H, which is attached by means of a suitable reducing motion to the cross-head of the engine. The return motion to the drum is obtained from a coil spring contained within it and not shown. The paper upon which the diagram is to be drawn is wound around the drum D, and held in place by the spring clip F.

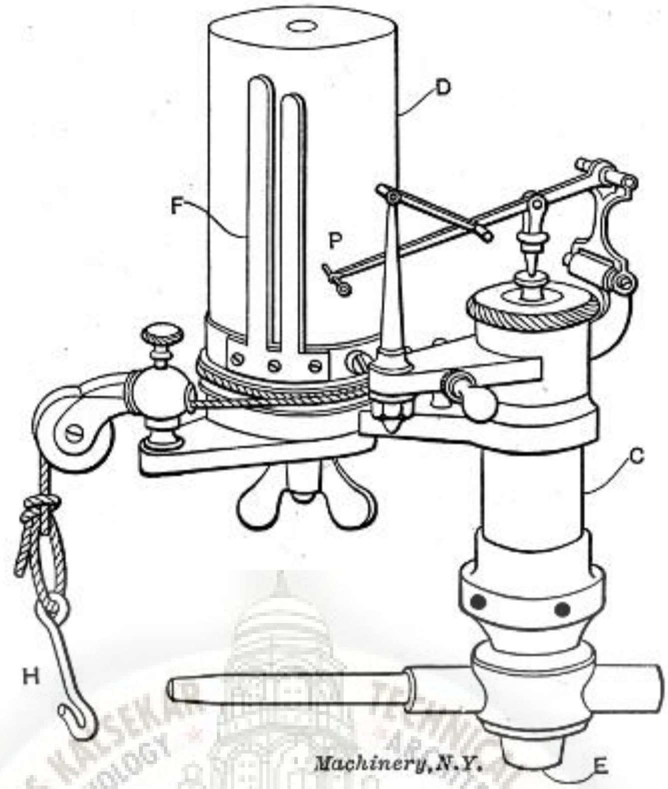

Figure 1.1: Steam Engine Indicator.

In taking an indicator card, the length of stroke must be reduced to come within the limits of the drum, that is, it must be somewhat less than the circumference of drum D. In practice, the diagram is commonly made from 3 to 4 inches in length. There are a number of devices in use for reproducing the stroke of the engine on a smaller scale. The most accurate consists of a series of pulleys over which the cord passes on its way from the cross-head to the indicator drum.

The indicator is connected with the engine cylinder by means of special openings tapped close to the heads and either plugged or closed by means of stop-cocks when not in use. In some cases two indicators are used, one being connected to each end of the cylinder, while in others a single indicator is made to answer the purpose by being so piped that it can be connected with either end by means of a three-way cock. After the indicator is connected and the cord adjusted to give the proper motion to the drum, a card is attached, after which the three-way cock is opened and steam allowed to blow through the indicator to warm it up. The cock is now closed and the pencil pressed against the drum to get the so-called atmospheric line. The cock is again opened, and the pencil pressed lightly against the drum during one complete revolution of the engine. The cock is then thrown over to connect the indicator with the other end of the cylinder and the operation is repeated.

1.3 Types of Indicator (Based on Motion)

Following are the various engine indicators which work on the straight line motion mechanism.

1.3.1 Simplex Indicator

It closely resembles to the pantograph copying mechanism, as shown in Fig. 1.2. It consists of a fixed pivot O attached to the body of the indicator. The links AB, BC, CD and DA form a parallelogram and are pin jointed. The link BC is extended to point P such that O, D and P lie in one straight line. The point D is attached to the piston rod of the indicator and moves along the line of stroke of the piston (i.e. in the vertical direction). A little consideration will show that the displacement of D is reproduced on an enlarged scale, on the paper wrapped on the indicator drum, by the pencil fixed at point P which describes the path similar to that of D. In other words, when the piston moves vertically by a distance DD_1, the path traced by P is also a vertical straight line PP_1, as shown in Fig. 1.2.

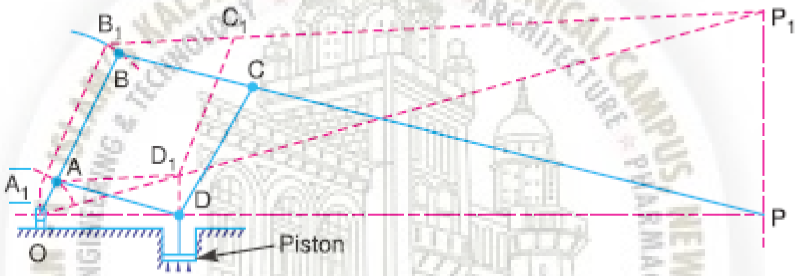

Figure 1.2: Simplex Indicator.

From the practical point of view, the following are the serious objections to this mechanism:

1. Since the accuracy of straight line motion of P depends upon the accuracy of motion of D, therefore any deviation of D from a straight path involves a proportionate deviation of P from a straight path.

2. Since the mechanism has five pin joints at O, A, B, C and D, therefore slackness due to wear in any one of pin joints destroys the accuracy of the motion of P.

1.3.2 Cross-by Indicator

It is a modified form of the pantograph copying mechanism, as shown in Fig. 1.3. In order to obtain a vertical straight line for P, it must satisfy the following two conditions:

1. The point P must lie on the line joining the points O and A, and

2. The velocity ratio between points P and A must be a constant.

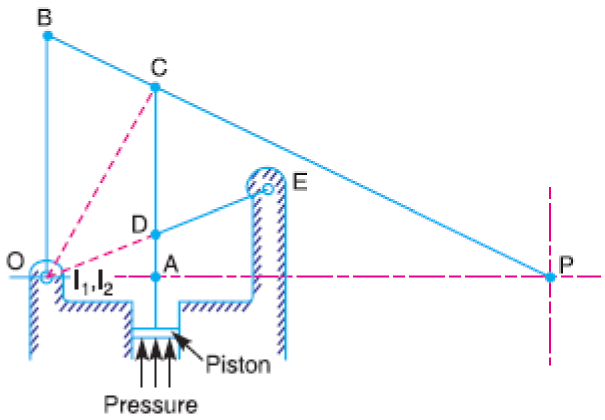

Figure 1.3: Cross-by Indicator.

In the Fig 1.3, I_1 and I_2 is the instantaneous centre of the link AC and BP, respectively.

1.3.3 Thompson Indicator

It consists of the links OB, BD, DE and EO. The tracing point P lies on the link BD produced. The link BD gets the motion from the piston rod of the indicator at C which is connected by the link AC at A to the end of the indicator piston rod. In the Fig 1.4, I_1 and I_2 is the instantaneous centre of the links BD and AC respectively.

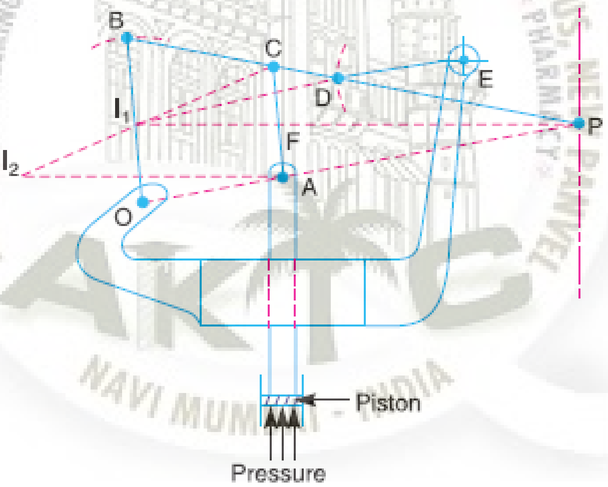

Figure 1.4: Thompson Indicator.

1.3.4 Dobbie McInnes Indicator

It is similar to Thompson indicator with the difference that the motion is given to the link DE (instead of BD in Thompson indicator) by the link AC connected to the indicator piston as shown in Fig. 1.4. In the Fig 1.4, I_1 and I_2 is the instantaneous centre of the links BD and AC respectively.

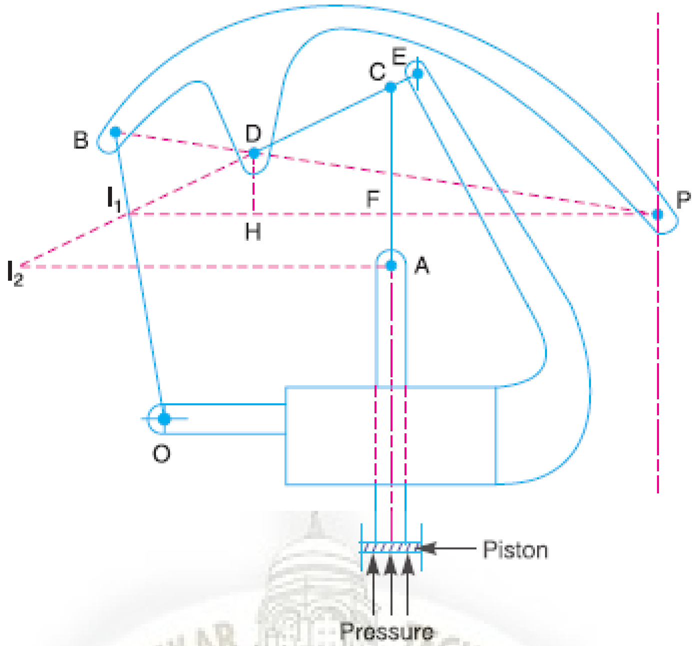

Figure 1.5: Dobbie McInnes Indicator.

1.4 Limitations of Mechanical Indicators

The mechanical indicators possess some limitations due to which they are inadequate to be used for high speed engines due to the following reasons:

1. The inertia of the piston of the indicator and its linkages and springs cause a lag in response of the indicator to the pressure changes. Thus there is a time lag between the change in pressure and its recording on the paper by the indicator. At high speeds, the pressure changes occur at very high rate and the indicator is unable to respond.

2. The effective clearance volume of the engine is affected by the passages connecting the cylinder to the indicator. Change in clearance volume changes the compression ratio and thus affects all parameters which change with the compression ratio.

3. There are severs pressure fluctuations in the passages between the cylinder and the indicator. The indicator, therefore, finds it difficult to sense the true and exact value of the instantaneous pressure.

4. The carbon particles from the products of combustion may enter into the connecting passages and cause error in the pressure values in the cylinder.

1.5 Purpose

Indicator diagram, now called as the pressure–volume diagram (or PV diagram), were developed in the 18th century as tools for understanding the efficiency of steam engines. Indicator diagrams indicate, simultaneously, the pressures and the relative position of the piston for a particular engine cylinder. It is based on the indicator diagram that the overall performance of the engine is assessed. Indicator diagrams are taken at regular intervals of time and matched with that of the trial diagrams to check if there is any significant difference in performance. If there is any difference, it is important that the problem is rectified before starting the engine. The indicator diagrams are used mainly for following purposes:

1. To calculate indicated power of the engine
2. To determine peak pressures and compression pressures
3. To evaluate the process of combustion inside the engine
4. To evaluate scavenging and exhausting conditions

1.6 Project Goals and Objectives

The goals of this project are:

1. To fabricate a prototype of an engine indicator using available and non expensive material.
2. To comprehend the mechanism of actual indicator diagram.

Chapter 2

Literature Survey

2.1 The Development of the Indicator

When a mechanic attaches an engine analyzer to the engine of your vehicle he may be using state-of-the-art equipment, but what he is doing has been done by mechanics for more than 200 years. The first instrument for analyzing the performance of an engine, and even recording the results on paper, was invented some time shortly before 1800.

The first instrument for analyzing the performance of an engine, and even recording the results on paper, was invented some time shortly before 1800. Most writers attribute the invention to James Watt, but others (Kalman DeJuhasz and The Victoria and Albert Museum) attribute it to John Southern, an engineer who worked for Watt. This instrument was named the steam engine indicator by its inventor, a name that continues to be used today. Bolton and Watt, the steam engine manufacturing company that employed Southern, realized the tremendous competitive value of owning such an instrument and consequently kept the existence of the invention so secret that they did not even attempt to get a patent on it. It appears that the secrecy surrounding Watt's indicator outlived Watt by nearly a hundred years.

2.1.1 Watt, c. 1793

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

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

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

Figure 2.1: Watt Steam Engine Indicator (Replica).

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

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

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

2.1.2 Watt & Southern, c. 1796

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

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

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

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

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

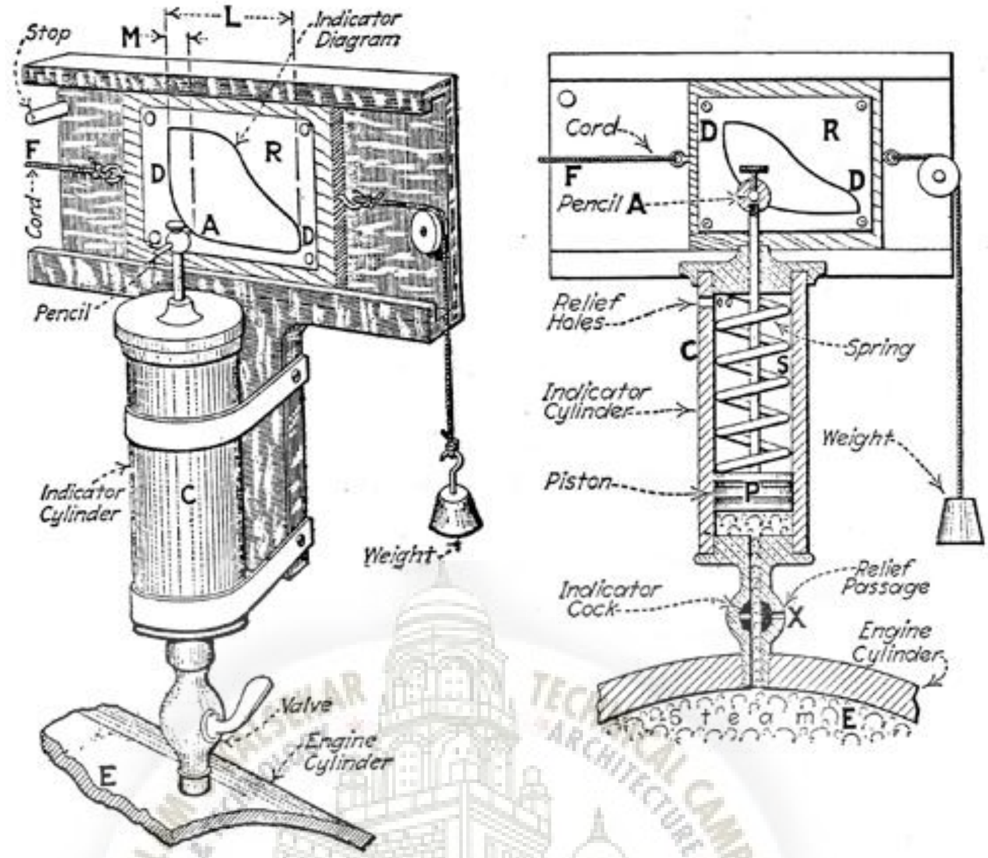

Figure 2.2: Watt & Southern Steam Engine Indicator (Steam Engine Principles and Practices, 1922).

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

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

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

However, the Wayne instrument could also be fitted with a detachable limiting mechanism (later known as a 'liner'), enabling it to be used in circumstances

— e.g. on railway locomotives — where vibration hindered the creation of a single diagram. The limiting mechanism allowed the operator to produce a continuous line-by-line summary of performance as the tablet reciprocated. The movement applied to the piston by the worm gear ensured that each line was drawn at slightly greater pressure than its predecessor.

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

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

2.1.3 McNaught, c. 1827

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

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

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

Figure 2.3: McNaught Steam Engine Indicator (Replica).

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

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

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

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

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

Figure 2.4: McNaught Parallel-Axis Steam Engine Indicator (Replica).

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

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

Figure 2.5: Hopkinson Indicator.

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

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

Chapter 3

Engine Indicators

3.1 Engine Indicator

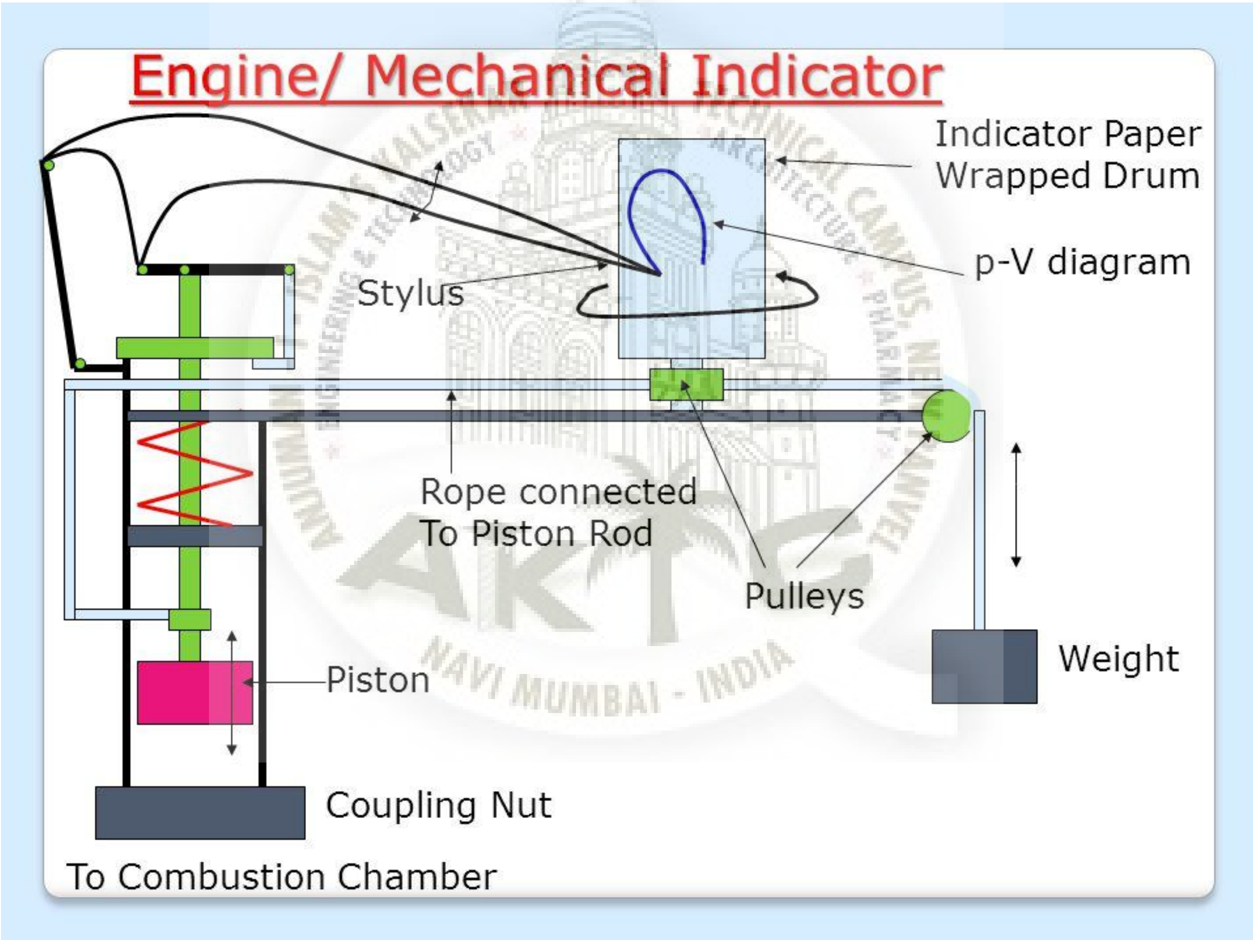

Figure 3.1: Typical Engine Indicator.

Engine indicators are instruments which record the pressure and volume of the gases within the engine cylinder on a diagram, and make possible a study of the entire cycle with alterations or modifications to the air/fuel ratio, ignition timing, speed and load characteristics being recorded.

It consists of a small piston of known size which operates in a cylinder against a specially calibrated spring. The engine cylinder pressure is applied against indicator piston which reciprocates an amount depending on calibration of spring. The vertical motion of piston is recorded by a stylus on a recording device on a paper wrapped around the oscillating drum.

The drum oscillates, i.e. swing from front to back due to the cord pull. The cord is moved by a reciprocating (up and down) mechanism which is proportional to the movements of the piston in the cylinder. At different points of the stroke the stylus draws out indicator diagram representing the gas pressure on the engine piston and the area of the indicator diagram represents the power developed in the cylinder.

3.2 Types of Engine Indicators

The main types of engine indicators are:

1. Drum/piston type indicator
2. Balanced diaphragm type indicator
    a. The Farnborough balanced engine indicator
    b. Dickinson-Newell indicator
    c. Capacitance-type balance pressure indicator
3. Electronic indicator

3.3 The Drum Type Indicator

A good deal of the design and development work in the early part of this century was made possible as a direct result of information gained from the use of drum type indicators on steam, gas, surface ignition and slow speed oil engines. A line diagram of such an instrument is shown in Fig. 3.2.

The piston stroke of the engine is reproduced to scale by an oscillating spring-loaded drum upon which is clipped a sensitive sheet of paper. The small indicator piston of an exact face area and its cylinder are connected to the test engine by means of a screwed adaptor. The motion of the indicator piston is multiplied by levers and links similar to a pantograph and produces a vertical movement to scale representing the gas pressure within the engine cylinder, and at the same time the drum is oscillating according to the position of the engine piston. The instrument is only suitable for engines up to 500 rev/min, but is more accurate around 200 rev/min.

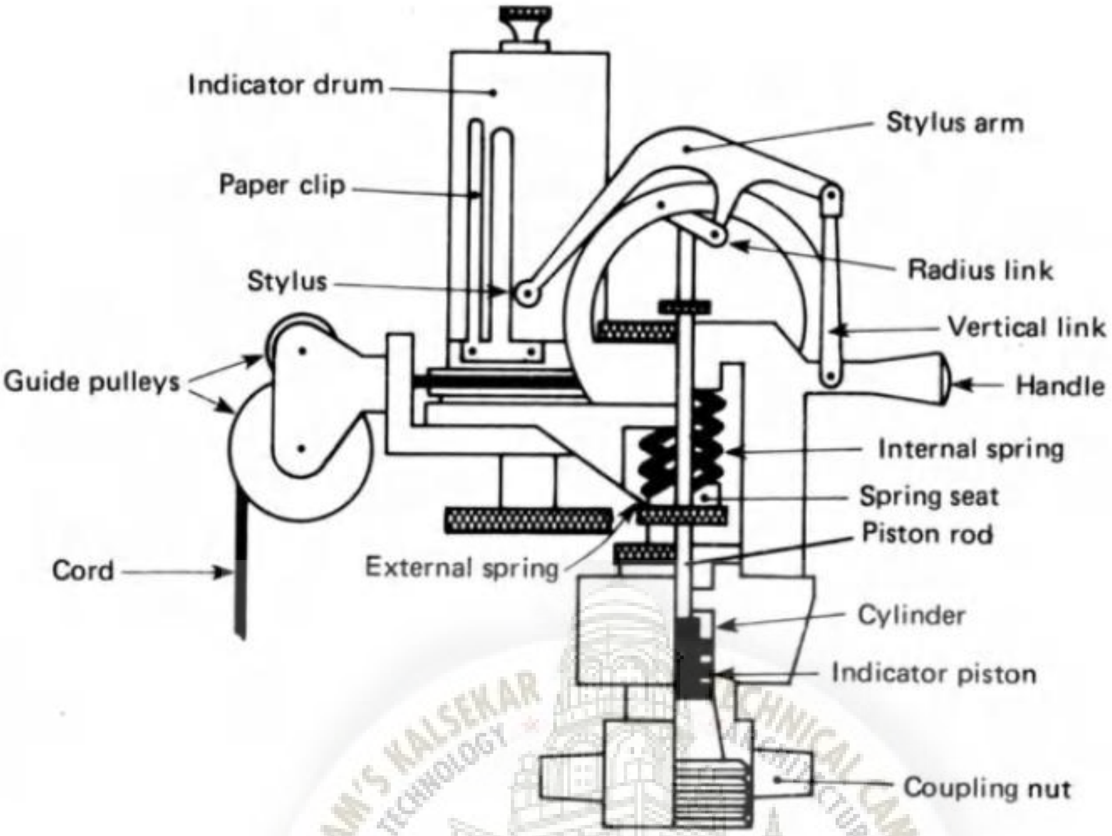

Figure 3.2: Drum Type Engine Indicator.

The limitations of such an indicator become obvious to any person who has used one, but inertia of the moving parts, friction and heat from the engine are the main problems.

3.4 The Farnborough Balanced Indicator

The method adopted with this engine indicator is that of recording the time at which a certain cylinder pressure balances a standard known pressure. A revolving drum driven at engine speed is used, driven through a dog clutch so that the drum may be stopped while the engine is still on test. A special paper is fitted to the drum to receive the diagram. The indicated diagram shows cylinder pressure on a crankshaft angle basis.

3.4.1 The Indicator Unit or Pick-up

The pick-up unit consists of a disc valve (see Fig. 3.3) which is guided by an insulated spindle. The disc only moves about 0.2 mm in between two seats both of which form the earth return for a primary low voltage circuit connected to an high tension coil, or, in later units, to a mains electronic HT relay unit. One side of the disc valve communicates with the combustion chamber, and the other side to the standard nitrogen pressure via a regulating valve.

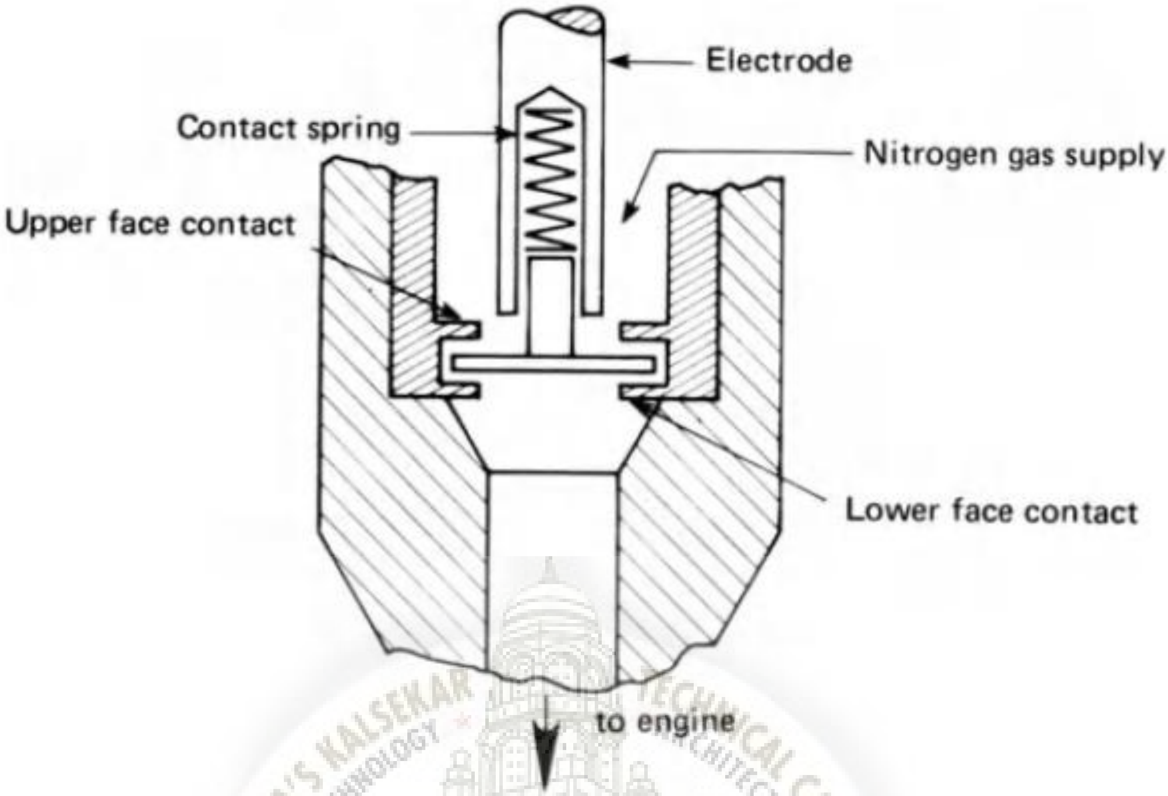

Figure 3.3: Disc Valve Pressure Pick-up (Diagrammatic).

A modified pick-up unit is available which consists of a light unstressed metal diaphragm of low elasticity which replaces the disc. No pressure can escape past the diaphragm which is earthed. A small electrode connected to the low voltage primary circuit is situated on the nitrogen side of the diaphragm and together with the diaphragm forms a simple make-and-break switch transmitting low tension signals to the mains operated HT relay unit. This unit is capable of producing a stronger stream of high tension sparks for better paper perforation.

3.4.2 The Recording Mechanism

A piston and cylinder unit is connected to the nitrogen supply. The piston is 'loaded' by two springs suitably rated for the engine under test and connected to a multiplying parallel link motion, which has a sparking point attached through which the high tension voltage is passed. The spark jumps the gap between the point and the revolving drum and perforates the paper. At the same time the piston of the recording unit is subjected to the same pressure as the disc valve or diaphragm; therefore the distance at any point along the drum represents the cylinder pressure. The drum will be in a precise position relative to one of the engine piston's dead centre, so that the perforation in the paper on the drum will record the pressure and the angle of the crankshaft. Fig. 3.4 is a simple line diagram of the Farnborough balanced high speed engine indicator.

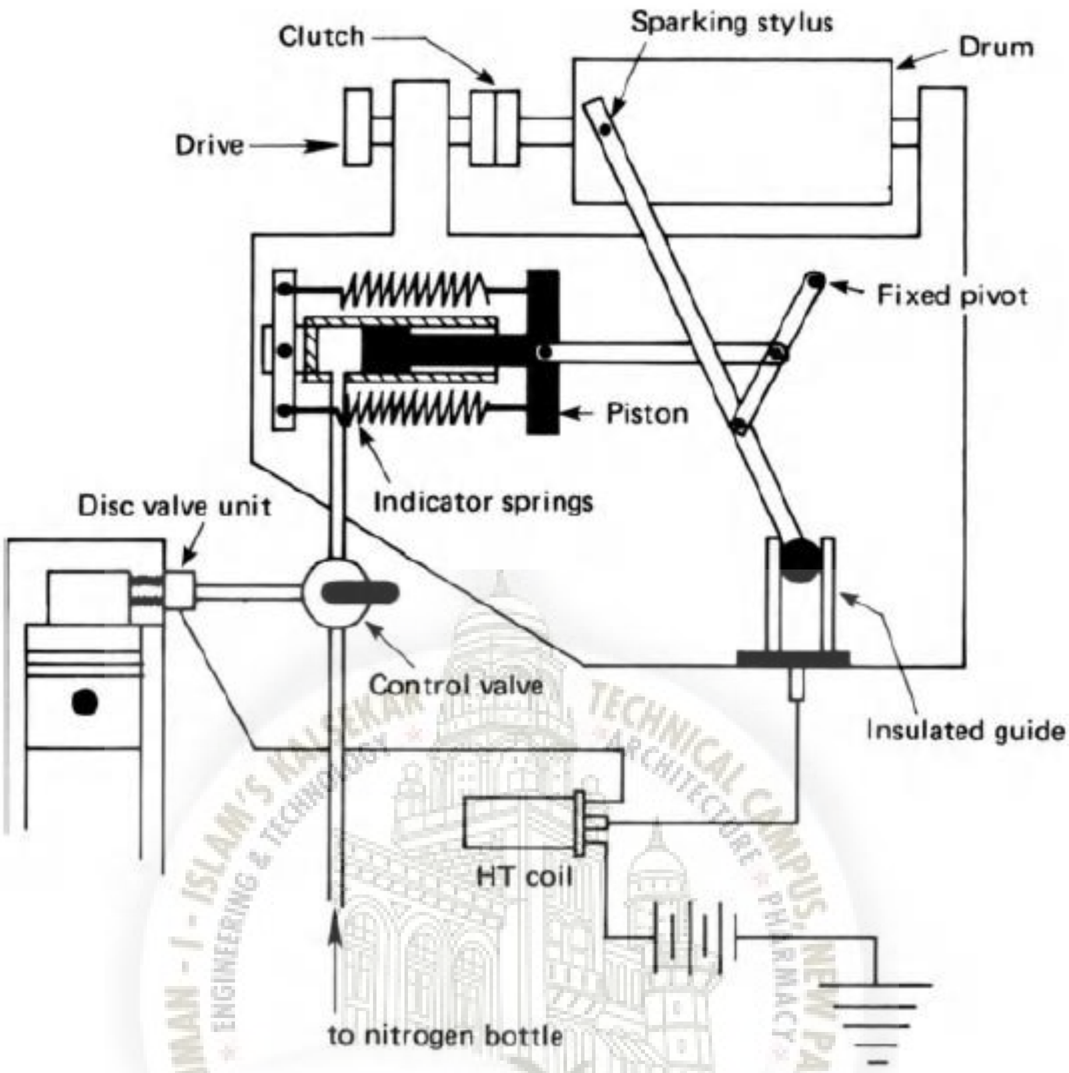

Figure 3.4: Farnborough Balanced High Speed Engine Indicator.

3.5 The Electronic Indicator

With this system a diagram is produced on the screen of a cathode-ray oscilloscope (CRO) and if a record is required it can be traced (if the image is a steady one) or a photograph taken. The Polaroid camera and its almost instant pictures has revolutionized this method of recording results.

The main units of the system are:

1. The cathode-ray oscilloscope (CRO)
2. The pick-up or transducer
3. The time-sweep unit
4. The camera for recording if required.

3.5.1 The CRO

This will be provided by a reputable company to accommodate the frequency range for all engine speeds and graticules, enabling measurements and calibration of the trace to be made.

3.5.2 The Pressure Transducer

There are numerous types of transducers or pick-ups, but the usual one fitted to record cylinder pressure is the piezoelectric transducer which incorporates a crystal of quartz which is capable of giving a weak electrical signal, the strength of which varies with the pressure produced upon it. This weak signal is amplified before it is passed to the CRO unit. There is one very important problem to be overcome before the cylinder pressure can be recorded, and that is to find a convenient position to insert the pressure transducer. In the modem engine cylinder head there is little room between the valves and sparking plug to allow a drilling to be made and clear the coolant passages.

If, like piston aircraft engines, the automobile engine was fitted with two sparking plugs per cylinder the problem would be solved, as one plug could be replaced by a transducer. A plugged screwed passage supplied by the engine manufacturer would be useful for engine test tune diagnostic equipment. Sparking plugs which have the dual role of igniting the charge and transmitting pressure pulses are used in certain research work, but they are very expensive and have rather a short working life.

3.5.3 The Time-Sweep Unit

An engine-controlled signal is required for the time base or crankshaft angle to ensure a steady trace. The unit is driven direct from the crankshaft. An inductive transducer is the most common sweep device. A rotating cam operates a spring loaded make-and-break device, which, on the closing of the contacts at some point such as TDC, signals the CRO. a rotating disc carries a series of notches at certain degree intervals. The deeper the notches the taller is the trace; TDC and perhaps So, 10° and 20° may be identified on the screen by this method, see Fig. 3.5.

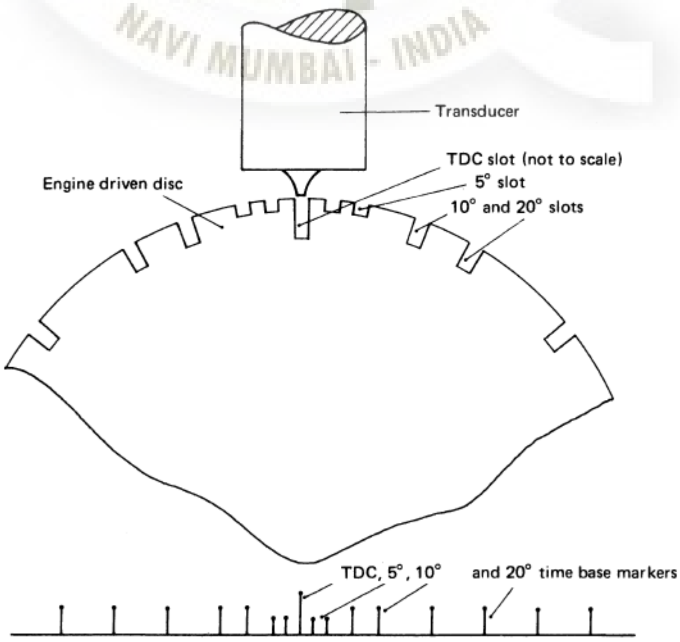

Figure 3.5: Time Sweep Unit.

Chapter 4

Indicator Diagrams

4.1 Collecting Indicator Data

Theoretical work diagrams are balanced by taking actual readings from a working steam engine via a device called an engine indicator. This device causes a pen to move as pressure in the cylinder rises or falls. The device is a delicate construct of springs and linkages so as to scale the pressure range to a graphical output.

An alternative approach might be to buy a digital pressure sensor and interface it to a data gathering computer. This has the advantage of being able to collect all data and average the results. It can be also be trigger to collect data once the engine has reached operating speed and temperature.

4.2 Indicator Diagram Information

The main value of the indicator diagram is that it shows the mean effective pressure exerted on the piston during an entire engine cycle and thus shows the power of the engine. It also shows information about the engine's design and performance including:

1. Valve Performance:
    a. Properly set
    b. Admission of steam is late or early
    c. Initial pressure is unduly lower than the boiler pressure
    d. Degree to which pressure is maintained up to the cutoff point
2. Point in the stroke at which steam is cutoff and if the cutoff is sharp or gradual.

3. Point in the stroke where release takes place and steam pressure at that point.
4. Exhaust Characteristics:
    a. Amount of back pressure opposed to the exhaust
    b. Point that exhaust is closed
    c. Amount of compression at the end of the stroke
5. Whether the steam ports are of adequate size
6. Whether the valve or piston leaks
7. Appropriate amount of steam is consumed in a given time
8. Several vital features concerning the balance of the engine

4.3 Indicator Diagram Analysis

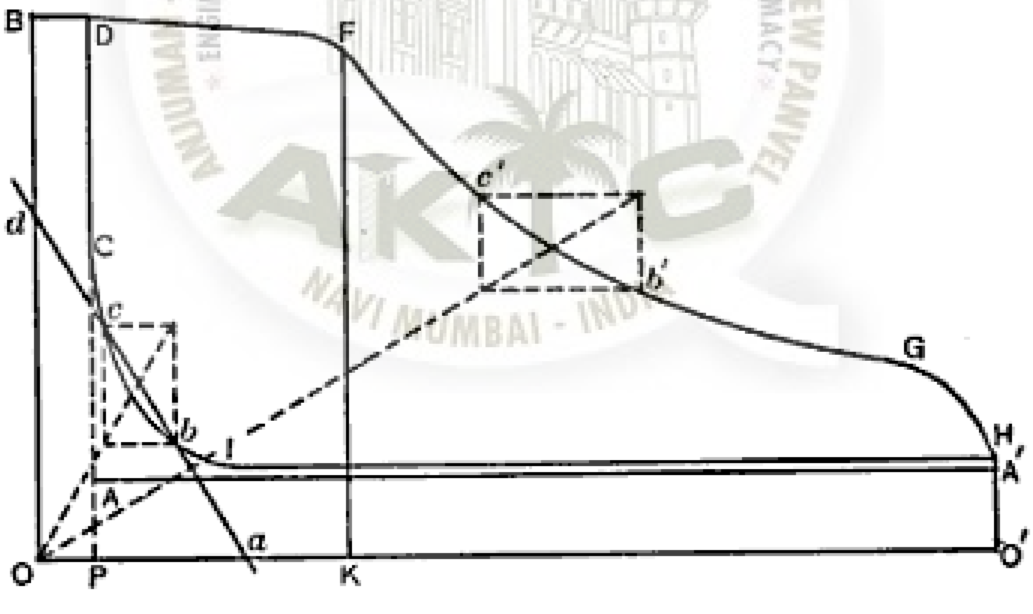

Figure 4.1: Indicator Diagram.

Once the indicator diagram is plotted, a diagram similar to the figure CDFGHI is produced as shown in Fig. 4.1. The lines of this diagram and certain points have specific names, described below.

4.3.1 The Engine Cycle

Immediately on admission of steam, the admission line CD is traced, its height above the atmospheric line, measured to scale, showing the initial gauge pressure of the steam admitted to the engine cylinder.

The engine piston starting on its stroke, the steam line DF is traced during the time steam is being admitted into the engine cylinder.

At the point of cut-off, F, the valve closes, preventing any further admission of steam into the cylinder. The exact point of cut-off, when affected by the valve, is difficult to locate, owing to the fall of steam pressure due to the gradual closing of the port by the valve, shown by the curving of the diagram about F.

The expansion curve FG represents the fall in pressure of the steam confined in the cylinder after cut-off in forcing the piston to the end of the stroke.

A G, the point of release, the valve opens to the exhaust (or exhaust vent is reached), releasing the steam from the cylinder. The higher the rotational speed of the engine the earlier the steam must be released to enable it's pressure to fall to that of the back pressure before the piston commences it's return stroke (hence the use of vacuum on the exhaust vent in the White Cliff's engine).

The exhaust line GH is traced in the interval between release and the end of the stroke, the pressure falling rapidly to that of the back pressure opposed to the exhaust.

In order that the exhaust steam may flow from the cylinder of a condensing engine to the condenser, or into the atmosphere from the cylinder of a non-condensing engine, the actual back pressure must be greater than atmospheric pressure in the other and this excess of pressure depends largely upon the freedom of passage fro the exhaust steam from the cylinder to the condenser or atmosphere. The release of steam from 88 to 90 per cent of the stroke assists materially in the freedom of the exhaust; this is necessary in a condensing engine to insure a nearly complete vacuum when the piston starts on its return stroke and with a non-condensing engine it enables the exhaust steam to begin it's flow into the atmosphere before the return stroke commences.

The back-pressure line HI shows the pressure opposed to the piston on its return stroke. In non-condensing engines this line is slightly above the atmospheric line and in condensing engines it is below the atmospheric line a distance corresponding to the vacuum obtained; but in either case it is back pressure. Vacuum is expressed in inches of mercury and since one cubic inch of mercury weights 0.491 pound, the inches of vacuum multiplied by 0.491 will give the pressure equivalent to the vacuum in PSI.

A I, the point of exhaust closure, the valve closes the port to the exhaust (or the exhaust vent is covered) and the compression of the steam trapped in the cylinder begins.

The compression curve IC represents the rise in pressure of the trapped steam due to its compression into the clearance space by the piston. The advancing piston compresses the steam, its pressure rising to some point C where the valve opens to lead, the pressure rising suddenly to D and a new stroke commences.

4.3.2 Locating the Vacuum Line

For the study of the diagram and for computations involving pressures, it is necessary to locate the vacuum line OO', or line of no pressure, from which all pressures must be measured to make them absolute. The vacuum line is parallel to the atmospheric line and at a distance below ti equal to the pressure of the atmosphere measured scaled appropriately to the diagram. The average atmospheric pressure is 14.7 pounds, but this will vary by altitude above sea level and the weather.

4.3.3 Locating the Clearance Line

Of equal importance to the vacuum line in computations involving the indicator diagram is the clearance line OB. it is perpendicular to the atmospheric line and at a distance from the end of the diagram equal to the same percentage of the length of the diagram that the volume of the clearance space of the cylinder bears to the volume displaced by the piston.

The diagrams from the two ends of the cylinder should be taken simultaneously if two indicators are used, or one immediately after the other if only one be used (this refers to continuous flow engines vs. uniflow engines).

4.4 Theoretical Differences Compared to Actual Diagrams

Diagrams taken from the engines of proper design and adjustment do not differ very materially from the theoretical diagram, but it requires careful study and discriminating judgment to make proper use of the information presented by them, a fact that may be appreciated when it is considered that the only absolute information a diagram gives is the varying pressure of the steam in the cylinder.

The full-line diagram of this figure would indicate a very satisfactory performance. The gradual fall in pressure in the steam line from *a* to *b* indicates wire-drawing, the technical name given to the reduction pressure due to friction in the passages. Improper design of the ports may cause this loss to be excessive.

The dotted lines illustrate some possible defects of an engine which would readily be detected by the indicator. The line *cd* would show that the release was too early and the life *ef* that it was too late; the inclination of the admission line to the left at *ga* would show the lead to be too great and its inclination to the right at *hi* would show insufficient lead.

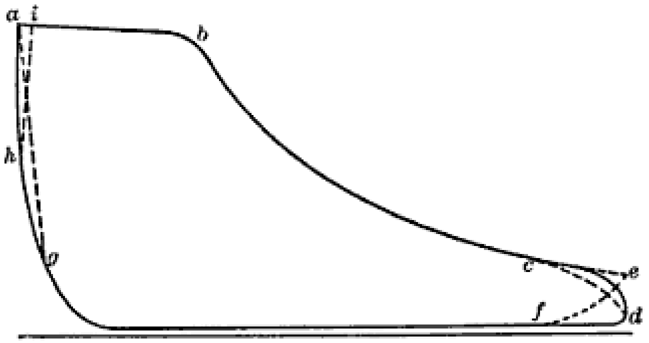

Figure 4.2: Comparison Between Actual and Theoretical Indicator Diagram.

Should a diagram be looped (as in the illustration below), the area *adc* represents a negative work and in obtaining the mean pressure from such a diagram, the lengths of the ordinates included in the loop must be subtracted from the total length of those within the area *eba*. A loop like this is the result of excessive expansion. At the point a, where the expansion curve crosses the back-pressure line, it is evident that the pressures on both sides of the piston are equal and a cut-off which would occasion an expansion so excessive as to reduce the steam pressure to a point below the back pressure opposed to the piston would be manifestly too early. The theoretical limit of expansion is such that the terminal pressure should be just equal to the back pressure, but practical considerations make it exceed this, varying from 24 to 28 pounds absolute in non-condensing engines and from 10 to 15 pounds in condensing engines. In actual practice, a loop in the diagram would very likely indicate that the engine was overloaded.

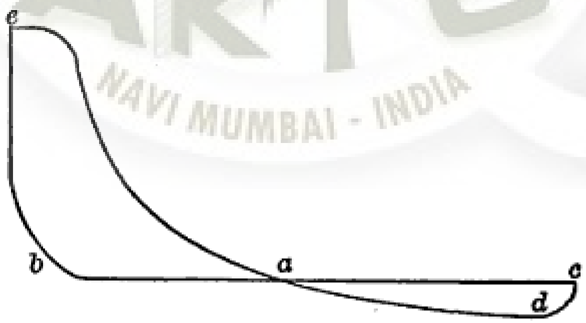

Figure 4.3: Looped Indicator Diagram.

It has been shown that the mechanical work is produced by a force working through a distance. In the case of any gas working within a cylinder against a piston, the force will be the mean value of the pressure of the gas multiplied by the area of the piston and the distance will be the stroke of the piston. In order that the work may be expressed in food pounds, the force must be expressed in pounds and the distance in feet. it is seen then that the area of an indicator diagram is the measure of the work performed on one side of the piston during one revolution; for this area is the product of the length of the mean ordinate of the diagram and the length of the diagram, the first factor expressing the mean effective pressure on the piston in pounds per square inch and the second factor expressing the length of the stroke in feet.

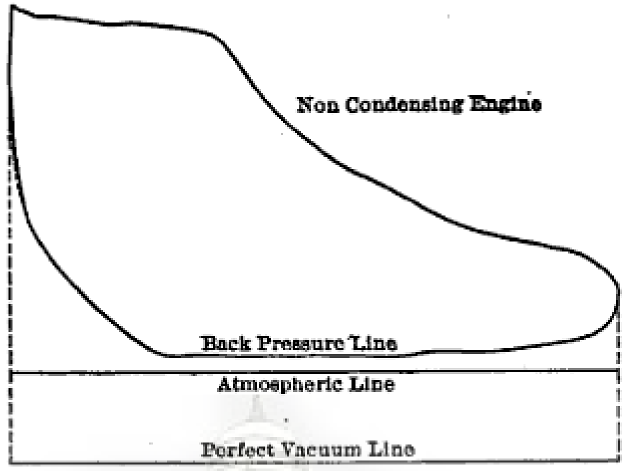

Figure 4.4: Indicator Diagram for Non-Condensing Engine.

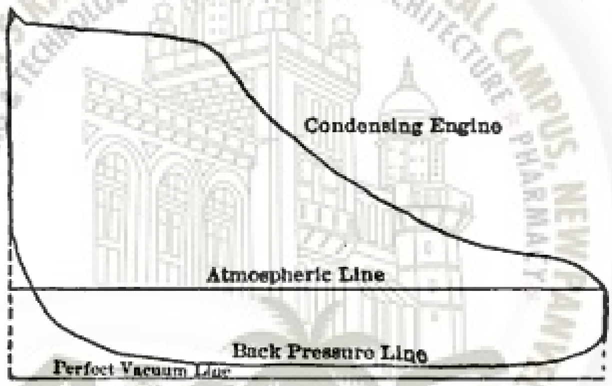

Figure 4.5: Indicator Diagram for Condensing Engine.

4.5 Mean Effective Pressure

There are broadly three methods to obtain the mean effective pressure from the indicator diagram, which are as described below.

4.5.1 Method of Ordinates

To obtain the mean effective pressure from the indicator diagram by the method of ordinates, erect perpendiculars to the atmospheric line touching the extreme ends of the diagram. Divide the space between these perpendiculars into ten equal parts and at the middle points between these divisions erect ordinates to the diagram perpendicular to the atmospheric line. The first and last of the ordinates will be 1/20 of the length of the diagram from the ends and the common interval between the ordinates will be 1/10 of the length of the diagram. One-tenth of the sum of the lengths of the ordinates will be the length of the mean ordinate and the length of the mean ordinate multiplied by the scale of the indicator spring gives the mean effective pressure on the piston throughout the stroke in pounds per square inch.

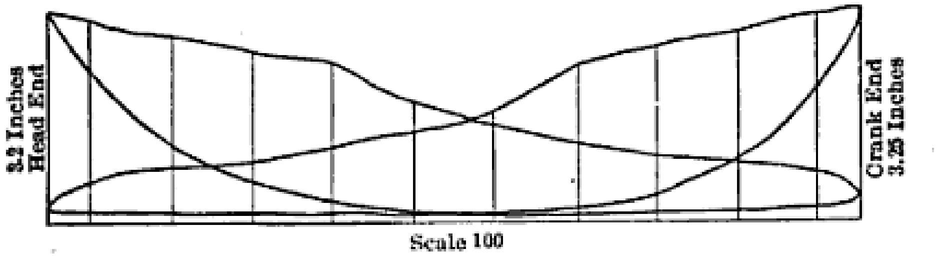

Figure 4.6: Typical Indicator Diagram for High Speed Engine.

This diagram was taken from a high speed engine of the Harrisburg type. The sum of the lengths of the ordinates of the diagrams from the two ends of the cylinder is 3.2 inches and 3.25 inches and the scale of the indicator spring is 100 pounds to the inch. Then for one revolution: M.E.P. = (100(3.20+3.25))/20 = 32.25 pounds.

4.5.2 Method of the Planimeter

The planimeter is an instrument designed primarily to measure the areas of plan figures. its application to finding the area of an indicator diagram, from which the length of the mean ordinate is readily obtained, enables the main effective pressure to be found more quickly and accurately than by the method of ordinates.

The instrument most commonly used is some form of the polar planimeter of Amsler. Here is one manufactured by Keuffle and Esser (K&E):

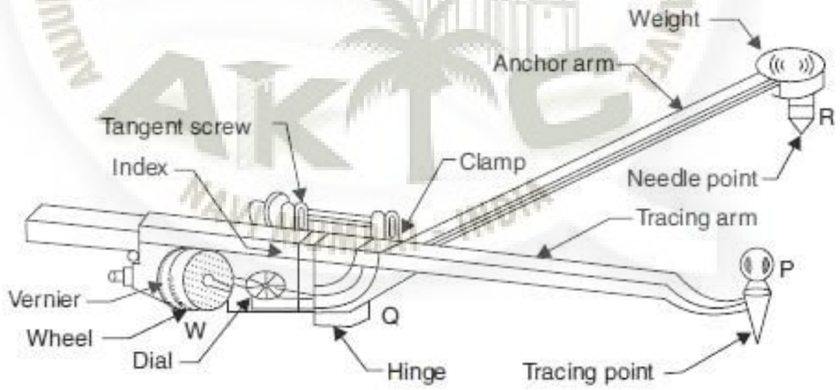

Figure 4.7: Planimeter.

The perimeter of the indicator diagram is traced by the device and the result is modified by the indicator diagram scale.

4.5.3 Computational Method

Given a set of pressure readings collected by a digital pressure sensor, the Method of Ordinates could be expressed as an algorithm implemented in a software function that would calculate the mean effective pressure. M.E.P. and engine power should be calculated and included in the output plot of a digitally created indicator diagram.

4.6 Engine Power

Having found from the indicator diagram the mean effective pressure in pounds per square inch acting on the engine piston throughout one revolution, the product of this pressure and the area of the piston in square inches will be the total pressure acting on the piston in pounds. If this total pressure be multiplied by the distance in feet moved through the piston in one minute, the product will be an expression in foot-pounds of the work performed by the engine in a minute and this product, divided by 30,000 will be the horse-power of the engine.

The mean effective pressure having been found from the indicator diagram, the power thus obtained is called the indicated horse-power, usually denoted by the initials I.H.P. and is equal to the useful work delivered by the engine and the work expended in overcoming the friction of the engine itself.

The factors in the determination of the indicated horse-power of an engine are:
p_e = M.E.P. = mean effective pressure on the piston in pounds per square inch,
L = length of stroke of the piston in feet,
A = area of piston in square inches,
N = number of revolutions of the engine per minute.

$$I.H.P. = \frac{2p_e LAN}{33{,}000} \tag{4.1}$$

4.7 Clearance

The volume of all the space between the piston when at the end of its stroke and the value face is known as clearance of the engine. Clearance is expressed in terms of percentage of the volume proper of the cylinder, that is, of the volume displaced by the piston in one stroke. The amount of clearance varies in the different types of engines. In engines of slow speed and long stroke, the variation is from 2% to 4%; in engines of high rotational speed and short stroke, it may be as much as 8%; as in maritime engines a clearance of 15% is no uncommon.

Clearance can be measured from an indicator diagram. The clearance space at each end of the cylinder must be filled with steam from each revolution of the engine (in a continuous flow engine) and this steam must come from the boiler or from the steam left in the cylinder by the exhaust closure or from both. since the piston does not traverse the clearance space, the clearance steam performs no initial work; it does no work during the period of admission, but after cut-off its effect is to raise the pressure during the expansion and thus increase the area of the expansion part of the diagram. If there were neither expansion nor compression, the clearance steam would perform no work at all and would be a total loss in the exhaust. On the other hand, if the expansion curve were carried down to the back pressure and the compression curve carried up to the initial pressure, there would be absolutely no loss from clearance.

Such conditions are never realized in practice, there for there is always a loss from clearance and this loss is greater as the clearance is proportionally large.

One effect of cushioning is that it reduced the loss from waste of steam in the clearance space, but its most important effect is that it provides for smooth running of the engine by preventing shocks at the end of the stroke. it is especially desirable that the diagram of an engine of high rotational speed have its compression curve well rounded.

Clearance in the engine occasions a loss when the consumption of steam per unit of power is considered, but there are practical considerations which make its existence highly desirable, if not necessary. The clearance space between the piston and the cylinder head, when the piston is at the end of its stroke, give space for the variable amount of water which is always present in a cylinder and doubtless prevents serious accidents which might otherwise occur.

4.8 Ratio of Expansion

The ratio of expansion of the steam used in an engine is he quotient derived from dividing the final volume of steam found in the cylinder by the initial volume admitted. By initial volume is meant the volume of steam admitted to the cylinder up to the point of cut-off, plus the clearance volume, and by the final volume is meant the volume of the volume of the cylinder, plus the clearance volume.

Since the cross-section area of the cylinder is uniform, the volume displaced by the piston at any point is directly proportional to the fractional part of the stroke completed at the point, so that the volumes may be represented by their corresponding fractions of stroke. In like manner, the clearance volume, when divided by the cross-section area of the cylinder, will be expressed as fractional part of the stroke. Then, if we denote the full stroke of the piston by unity, it may also represent the volume displaced by the piston in one stroke, in which case the fraction of the stroke denoting the cut-off will represent the volume displaced up to the point of cut-off.

Neither the volume of the receiver nor the cut-off in the L.P. cylinder has anything to do with the question of the total ratio of expansion in stage-expansion engines. The effect of the receiver is to make the initial pressure lower in the L.P. cylinder than it otherwise would be if the exhaust from the H.P. to the L.P. cylinder were direct, and this reduction in pressure is due to the drop occasioned by the unrestricted expansion of the steam when it enters the receiver space. The receiver only plays the part of a large clearance space.

The low-pressure cut-off will increase the receiver pressure and therefore the power of the L.P. Cylinder, as has been shown, and this increase in the receiver pressure increases the back pressure on the piston of the next proceeding cylinder in the expansion and therefore decreases the power of that cylinder. So it is seen that the function of the L.P. cut-off is to equalize the power between the cylinders and has nothing to do with the total ratio of expansion. Whether the steam is or is not cut off in the L.P. Cylinder, the same weight of steam must find its way into that cylinder at each stroke, and if, by means of the cut-off, a less space be provided the reception of the steam, the pressure will increase accordingly.

4.9 Construction of a Work Diagram

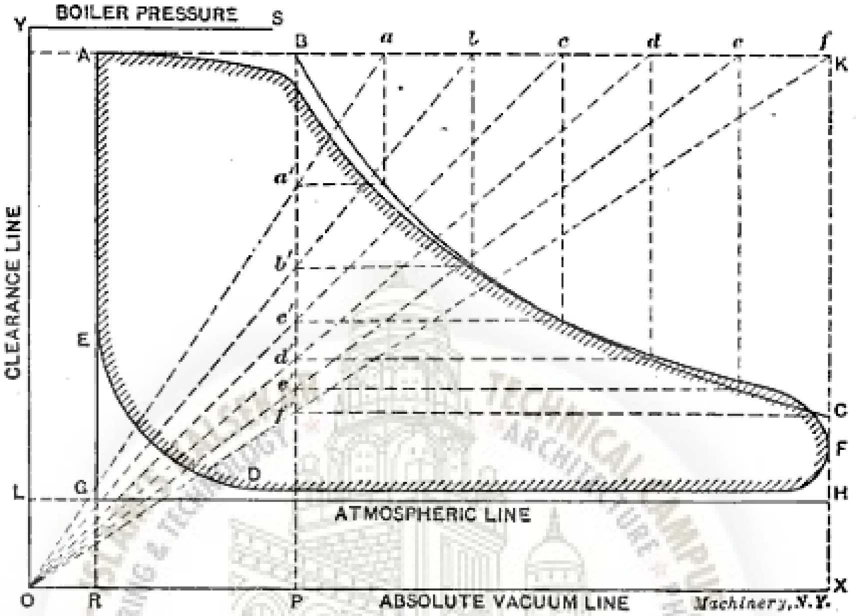

Figure 4.8: Constructing a Steam Engine Work Diagram.

The procedure for constructing a steam engine work diagram is as follows:

1. Determine the initial pressure, ratio of expansion, and percent of clearance.
2. Draw lines OX and OY at right angles.
3. Make OR the clearance displacement percent.
4. Make RX the length of the stroke
5. Draw RA perp. at the clearance displacement length to represent 3-8% (med. speed engine) of the total displacement.
6. Draw AK at 0.98 of the boiler pressure
7. Draw KX at the stroke length.
8. Draw LH at 14.7 psi for atmospheric pressure.
9. Locate cutoff point B for expansion ratio (1/8, 1/4, etc. of stroke length)
10. Divide BK into equal distances (a,b,c, etc)..
11. Connect them to point O
12. Extend horizontals from the points where diagonals meet with line BP.
13. Extend verticals down from (a,b,c, etc)
14. Connect these points to form the expansion curve.
15. Back pressure curve at FD about 2psi above atmospheric
16. Compression curve at DE, rounded up to start of cycle.

4.10 Types of Indicator Diagrams

Indicator diagrams are taken at regular intervals of time and matched with that of the trial diagrams to check if there is any significant difference in performance. If there is any difference, it is important that the problem is rectified before starting the engine. The taking of indicator cards, allows the engineer to receive more information about the combustion process (via the draw or out of phase card), measure the cylinder power output of the engine (via the power cards), and check the cleanliness of the scavenging process (via the light spring diagram).

There are five types of indicator cards, which can provide the following information:

4.10.1 Power or In-Phase Cards

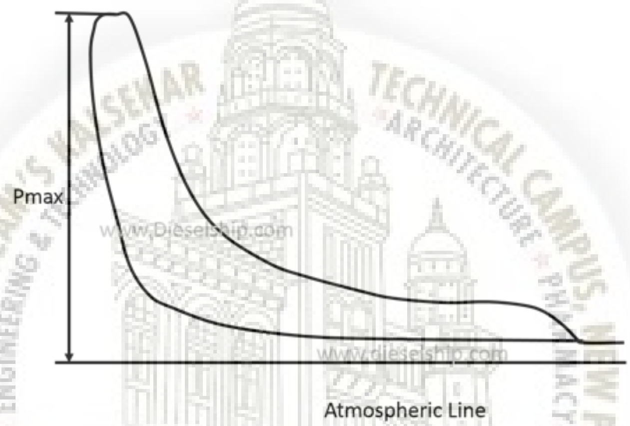

Figure 4.9: Power Card Indicator Diagram.

Cylinder power, calculated from the area within the P-V diagram, indicates after burning present when card shape enlarged during the expansion stroke.

4.10.2 Draw or Out-Phase Cards

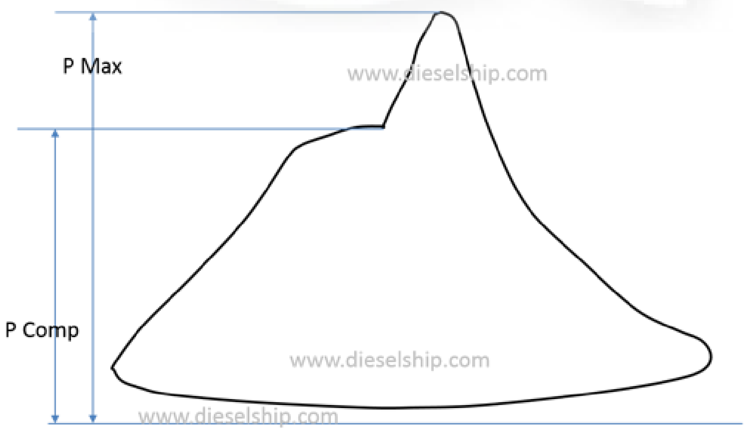

Figure 4.10: Draw Card Indicator Diagram.

This diagram is used for the measurement of the compression pressure and the point of fuel ignition.

4.10.3 Light/Weak Spring Card

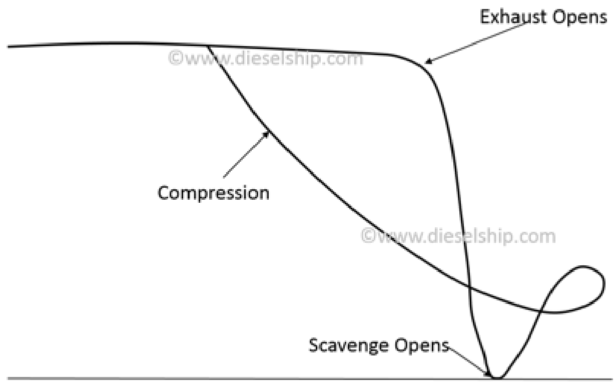

Figure 4.11: Light Spring Card Indicator Diagram.

This diagram is used for determining the fouling of exhaust or scavenges gas flows.

4.10.4 Compression Card

Figure 4.12: Compression Card Indicator Diagram.

This diagram is used for the measurement of the compression pressure and timing check of the indicator.

4.10.5 Pressure Derivative Card

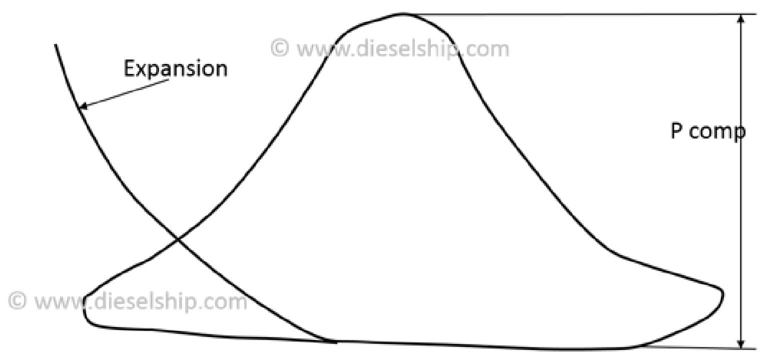

Figure 4.13: Pressure Derivative Card Indicator Diagram.

This diagram is used for the measurement of the point of fuel ignition and maximum rate of pressure rise following initial combustion.

Chapter 5

Prototype and Conclusion

5.1 Prototype Indicator

The prototype consists of indicator drum, stylus, stylus arm, vertical link and handle. It is connected to piston cylinder. The actual fabricated prototype of the indicator is shown in Fig, 5.1.

Figure 5.1: Prototype Engine Indicator.

5.1.1 Piston Cylinder

It is the one of the important part of the prototype. The frame is being made considering the weight it has to bear and vibrations produced by the engine. The piston cylinder is made up of PVC pipe.

Figure 5.2: Piston Cylinder with Handle.

5.1.2 Stylus, Stylus Arm and Vertical Link

Figure 5.3: Stylus Arm and Vertical Link Assembly.

Two wooden plates are used as the horizontal and vertical members of frame to form a strong mechanism as a stylus arm and vertical link respectively.

5.1.3 Piston Rod

Figure 5.4: Piston Rod for Connecting Cylinder with Indicator Drum.

A mild steel bar is used as a connecting medium between the piston cylinder and the indicator drum to act as a piston rod.

5.2 Conclusion

In this project work, we were able to apprehend the mechanism of actual engine indicator diagram by performing exhaustive studies related to it. And furthermore we were able to successfully design and fabricate a prototype of mechanical engine indicator using the concepts learned based on exhaustive studies.

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