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Engine: How to Compound Steam Engines?

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For greater *efficiency* and less space per horse power, ***high pressure steam*** is used in steam engine. Now with the use of this high pressure steam the range of expansion is correspondingly increased. If full expansion takes place in single ***cylinder*** the walls of the cylinder to be made very thick to withstand the high pressure and also required a heavy ***flywheel***. All this made a simple steam engine very heavy in construction, large variations of temperature and more leakage past the ***piston***. These are some basic ***engineering*** difficulties mostly observed while ***designing*** the machine.

To overcome these difficulties, the expansion of steam is made in two or more cylinder. This called as "Compounding the expansion of steam". There are three ***different methods*** of compounding of steam engines which is as below,

01) Tandem Compounding

*In this **type**, the cylinders are arranged on common axis and two pistons have a common **piston rod, connecting rod and crankshaft**. The exhaust steam from high pressure cylinder passes directly into low pressure cylinder where it further expands.*
*The turning moment in this type of engine is not uniform due to common crank and piston rod where all the torque acts at the same time. This is the basic disadvantage of such type of engines and requires a large flywheel. Tandem **arrangement** gives constructional economy because of less components of the **engine**.*

02) Woolf Compounding

*In this type, two **cylinders** are arranged side by side while the two cranks are placed at 180 degree to each other. The **pistons** of high pressure and low pressure cylinders begin and end their strokes together respectively.*
*The exhaust of steam from high pressure cylinder coincides with suction of steam in low pressure cylinder. In this case also exhaust steam from high **pressure** cylinder passes directly into low pressure cylinder where it further expands.*
Since the two cranks are at 180 degree to each other, the two cycles are in phase and this causes large variation in the turning moment of crankshaft and necessitating the use of heavy flywheel.

03) Receiver Type Compounding

*In this **type**, two cranks are mounted at 90 degree to each other that is why steam from high pressure cylinder can not exhaust directly into low pressure cylinder.*
A container, known as receiver is used to collect steam from high pressure cylinder while low pressure cylinder draws steam from receiver for further expansion.

*The turning moment in receiver type compounding steam is more uniform therefore a lighter flywheel can be used. With three cylinder **engine**, the cranks are arranged at 120 degree to each other but still small turning moment variation can be achieved.*

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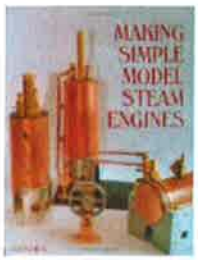

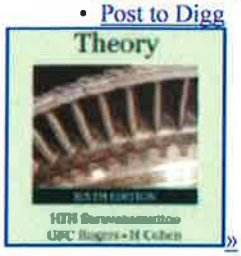

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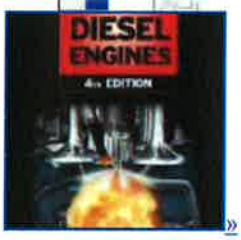

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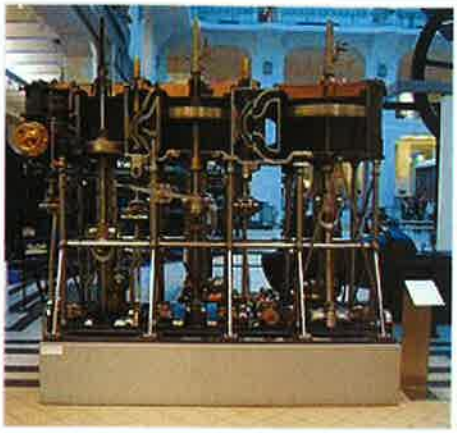
Compound steam engine

From Wikipedia, the free encyclopedia

A **compound steam engine** unit is a type of steam engine where steam is expanded in two or more stages.[1][2] A typical arrangement for a compound engine is that the steam is first expanded in a high-pressure *(HP)* cylinder, then having given up heat and losing pressure, it exhausts directly into one or more larger volume low-pressure *(LP)* cylinders. Multiple-expansion engines employ additional cylinders, of progressively lower pressure, to extract further energy from the steam.[3]

Invented in 1781, this technique was first employed on a Cornish beam engine in 1804. Around 1850, compound engines were first introduced into Lancashire textile mills.



Cutaway of triple expansion compound steam engine, 1888

A Robey horizontal 'cross-compound' steam engine: the smaller, high-pressure cylinder is on the left; the larger, low-pressure cylinder on the right

Contents

Compound systems

There are many compound systems and configurations, but there are two basic types, according to how HP and LP piston strokes are phased and hence whether the HP exhaust is able to pass directly from HP to LP (Woolf compounds) or whether pressure fluctuation necessitates an intermediate "buffer" space in the form of a steam chest or pipe known as a *receiver* (receiver compounds).[4]

In a single-expansion (or 'simple') steam engine, the high-pressure steam enters the cylinder through a cut-off valve (archaically known as a regulator). The piston moves down the cylinder, and when it is at about 25%–33% of its stroke, the cut-off valve shuts and the steam expands, pushing the piston

to the end of its stroke, the exhaust valve opens and expels the depleted steam to the atmosphere, or to a condenser. As steam expands in a high-pressure engine, its temperature drops; because no heat is released from the system, this is known as adiabatic expansion and results in steam entering the cylinder at high temperature and leaving at low temperature. This causes a cycle of heating and cooling of the cylinder with every stroke which is a source of inefficiency. The steam cut-off point when using a slide valve is less than 30% of the stroke. Early cut-off causes the turning moment on the shaft to be more uneven, requiring a larger flywheel to smooth this out.[4]

Compounding engines

A method to lessen the magnitude of this heating and cooling was invented in 1804 by British engineer Arthur Woolf, who patented his *Woolf high pressure compound engine* in 1805. In the compound engine, high-pressure steam from the boiler first expands in a high-pressure (HP) cylinder and then enters one or more subsequent lower pressure (LP) cylinders. The complete expansion of the steam occurs across multiple cylinders and, as there is less expansion in each cylinder, less heat is lost by the steam in each. This reduces the magnitude of cylinder heating and cooling, increasing the efficiency of the engine.

There are other advantages: as the temperature range is smaller, cylinder condensation is reduced. Loss due to condensation is restricted to the LP cylinder. Pressure difference is less in each cylinder so there is less steam leakage at the piston and valves. The turning moment is more uniform, so balancing is easier and a smaller flywheel may be used. Only the smaller HP cylinder needs to be built to withstand the highest pressure, so reducing the overall weight. Similarly, components are subject to less strain so can be lighter. The reciprocating parts of the engine are lighter reducing the engine vibrations. The compound could be started at any point in the cycle, and in the event of mechanical failure the compound could be reset to act as a simple, and thus keep running.[4]

To derive equal work from lower pressure steam requires a larger cylinder volume as this steam occupies a greater volume. Therefore the bore, and often the stroke, are increased in low-pressure cylinders resulting in larger cylinders.

Double-expansion (usually just known as 'compound') engines expand the steam in two stages. The pairs may be duplicated or the work of the large LP cylinder can be split across two smaller cylinders, with one HP cylinder exhausting into either LP cylinder, giving a 3-cylinder layout where the cylinder and piston diameter of all three are about the same making the reciprocating masses easier to balance.

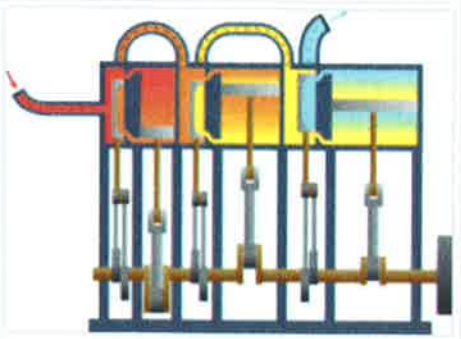
Two-cylinder compounds can be arranged as:

- **Cross-compound** – the cylinders are side-by-side.
- **Tandem compound** – the cylinders are end-to-end, driving a common connecting rod
- **Angle-compound** – the cylinders are arranged in a vee (usually at a 90° angle) and drive a common crank.[Cylinder phasing[›]]

The adoption of compounding was widespread for stationary industrial units where the need was for increased power at decreasing cost, and almost universal for marine engines after 1880. It was not widely used in railway locomotives where it was often perceived as complicated and unsuitable for the harsh railway operating environment and limited space afforded by the loading gauge (particularly in Britain). Compounding was never common on British railways and not employed at all after 1930, but was used in a limited way in many other countries.[5]

Multiple expansion engines

It is a logical extension of the compound engine (described above) to split the expansion into yet more stages to increase efficiency. The result is the **multiple-expansion engine**. Such engines use either three or four expansion stages and are known as *triple-* and *quadruple-expansion engines* respectively. These engines use a series of double-acting cylinders of progressively increasing diameter and/or stroke and hence volume. These cylinders are designed to divide the work into three or four equal portions, one for each expansion stage. The image to the right shows an animation of a triple-expansion engine. The steam travels through the engine from left to right. The valve chest for each of the cylinders is to the left of the corresponding cylinder.



An animation of a double-acting inverted triple-expansion marine engine.
High-pressure steam (red) enters from the boiler and passes through the engine, exhausting as low-pressure steam (blue) to the condenser.

History

Early work

- 1781 – Jonathan Hornblower, the grandson of one of Newcomen's engine erectors in Cornwall, patented a double-cylinder compound reciprocating beam engine in 1781. He was prevented from developing it further by James Watt, who claimed his own patents were infringed.[6]
- 1804 – A method to lessen the magnitude of the continual heating and cooling of a single-expansion steam engine that leads to inefficiency was invented by British engineer Arthur Woolf. Woolf patented his stationary *Woolf high-pressure compound engine* in 1805.

Double-expansion

- 1845 – William McNaught (Glasgow) devised a method of fixing an additional high-pressure cylinder within an existing beam engine. To do so involved using a long pipe to connect the cylinders, and an extra set of valves to balance them. In effect this acted as a receiving chest, and a new type of compound had been invented. This system allowed greater control of the steam intake and cut-offs. An engine could be slowed by either a throttle which reduced the pressure of the steam, or by adjusting the cut-off on either cylinder. The latter was more efficient as no power was lost. The cycle was smoother as the two cylinders were not in phase.[7]
- Understanding thermodynamics rather than believing in calorics
- Corliss valves

Multiple-expansion

- 1861 – Daniel Adamson took out a patent for a multiple-expansion engine, with three or more cylinders connected to one beam or crankshaft. He built a triple-expansion engine for Victoria Mills, Dukinfield which opened in 1867.[8]