The hot air engine – yesterday and today

After the steam engine the hot air engine is the second oldest thermo power engine according to one of its inventors, the Scottish clerical **Robert Stirling**, also worldwide called **STIRLING-motor**.

About 1800 the steam engine was the mostly installed power engine, however by operating of the necessary steam boilers involved great dangers at that time by exploding steam boilers.

The history of the hot air motor in the former construction of bigger machines reaches back to the year 1807, when Sir George Cayley (1773 – 1857) published in England the construction drawing and – description of a machine he called “caloric machine”. This machine stayed on the drawing board and wasn’t realized later. But this idea stimulated a lot of engineers to follow up the idea and to improve it.

In the year **1816** reverent Robert Stirling, at that time 26 years old, applies for a patent for the first “STIRLING-machine” and the “economizers”. The effect of the economizers has its signification in the industry until today.

1827 the improved hot air engine is applied for a patent in cooperation with his brother **engineer James Stirling**. This hot air engine was the first running with a totally closed circulation and represented in its construction a design (Beta-Type) welcomed up to the present.

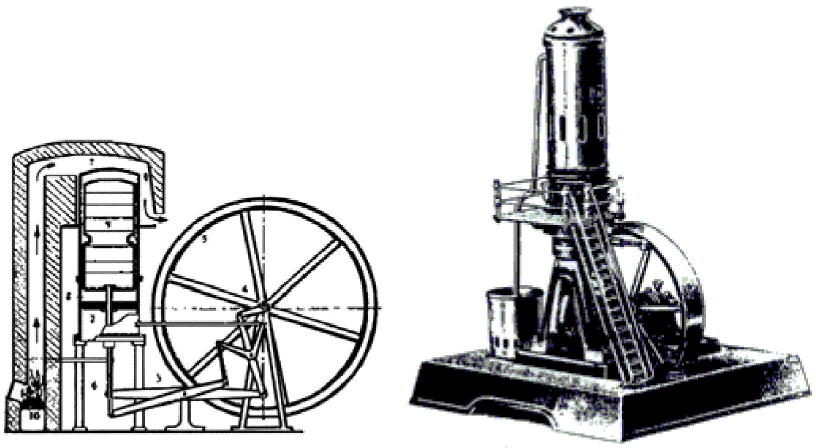


Illustration: on the left: reproduction of Stirling’s patent drawing 1816, so it was brought into action about 1818 (according to Finkelstein 1959) in an English quarry. On the right: Stirling’s first own construction exhibited in the Royal Scottish Museum Edinburgh.

Today the „STIRLING-motor“ is around the globe a collective name for thermopower engines working on this principle.
Several names of the past century are connected with the continued development of the machine: The Swede **J. Ericsson** the most famous pioneer on this sector, **A.K. Rider** (USA), **W. Lehmann** (Deutschland).
To list their machines and inventions would break through the here assigned information scope.

Construction and machine types
In spite of the overwhelming power of water and steam the study group air could maintain in some special application areas as an efficient alternative.

Especially in the retail trade in the second half of the 19th century there was a demand for special simply to be served small drives. The human spirit of invention was the result of many machines of this type. According to *J.O. Knoke* it‘s owing to the conrector *G. Delabar* to have established order in the different hot air machine types and to classify them according to their function and mode of operation into groups. For a long time *Delabar* accomponied as a very remarkable skilled author the development of the hot air engines in the former technical literature and reported about progresses in this area, mainly in Dingler‘s polytechnic journal. He judged the construction types by their function principle and distinguished three main groups:

1. Open hot air engines
Here the fire gas doesn‘t come into touch with the operating piston and sucks in normal atmospheric air, becomes heated,
works efficient and then leaves again the machine into the atmosphere. The most well-known machine of this construction
has been built in 1861 by *Messrs. Wilcox.*

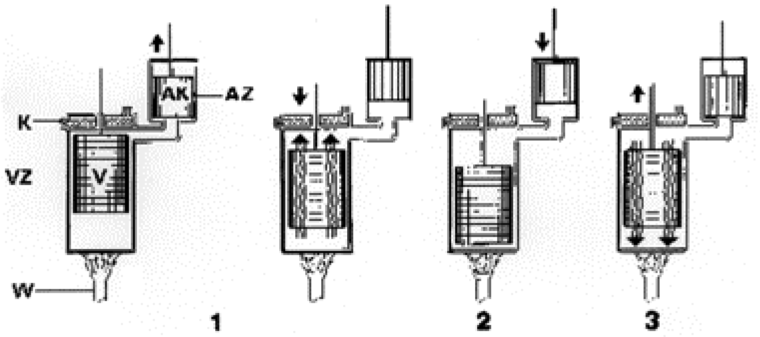
2. Fire air engines
Here the fire gas works directly efficient on the operating piston and partly for the reduction of the temperature and by this way sucks in fresh air.
Here we want to refer to Messrs. Windhausen
and *Huch* in Braunschweig. In 1864 they had constructed a fire air engine, protected by patent, and had accordingly to Knoke built them in a small number of pieces. The former

technical possibilities pointed out the limits of this type of construction, sothat they were only less successful.

3. Closed machines
A constant air quantity passes in a closed system a circulating process (**System Stirling**).

Closed hot air machines

The principle of closed hot air engines is based on the consideration, to let a constant quantity of air run through in a closed variable space of a circulating process and so works efficient to transform the heating energy into mechanic energy. The machines of this group dispose of an operating- and displacement piston, that can be positioned alternatively in one or two cylinders. Both pistons are connected by piston stems with the crankshaft, whereby the displacement piston **DP** runs approximately a quarter r.p.m. (between 65° up to 99°) forward to the operating piston **OP.**

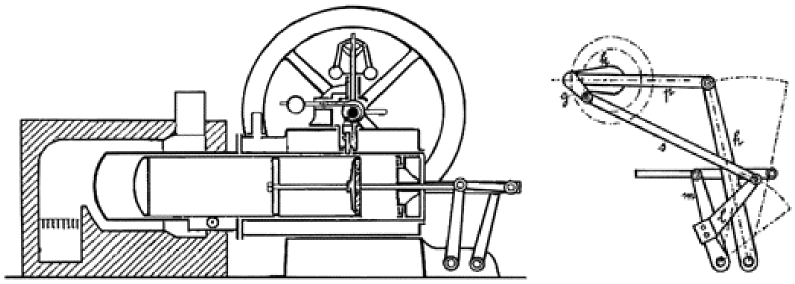


The working principle of a closed caloric machine is relatively simple. If you think of a certain constant air quantity to be enclosed in a cylindrical space in that way, that it is possible to displace a piston within the cylinder airtight, so as soon as the involved air is somehow heated, the air will extend and tries to extend within the space. The rising pressure increase of the hot air then moves the displaceable piston in advance. If you suddenly cool down the air in the cylinder, so it draws together; the pressure from inside to outside stops and the return of the piston is then produced by the centrifugal force of a heavy flying wheel fastened on the input-shaft of the motor. That is the reason why the machine is a one-sided operating machine, as the moving power is only causing the input of the operating piston, while the output is effected by the centrifugal mass.
According to this operating method the hot air engines have two cylinders as a rule, the displacement cylinder **DP** with a bigger diameter and the operating cylinder **OP**. In the displacement cylinder

DP is moving a hollow piston made of thin walled iron, copper- or yellow brass plate; but in any case the displacer **D** that is not fitted close to the cylinder, so that the air can pass by. On the other hand the operating piston **OP** is placed in the operation cylinder **OC** well greased and gas tight, it locks up the cylinder open at the top that is connected by a pipe (overflowing channel) with the displacement cylinder **DP**. **H** is the heating source in the „hot part“ and **C** is the cooling device, that is shown in this example as water cooling. A regenerator is not assigned in this scheme, but should be installed in the space of the piston/displacement most efficiently.
As a rule the displacement piston **DP** runs ahead the operating piston **OP** by 90° and hereby determines the rotation direction of the flying wheel.

In the operating procedure (1) the heated air **H** is extending in the displacement cylinder **DC**, is passing the displacer **D** and drives the operating cylinder **OP** upwards. Due to the occurring rotation of the crankshaft the displacer **D** is moving downwards and displaces the heated air quantity in the heating space. It streams ahead the displacer into the cooled space above and delivers its heating energy to the cooling device. This operating procedure you can consider as stress-leaving part (2). The pressure in the operating cylinder **OP** hereby sank down. The inertness of the oscillating mass drives the operating piston **OP** downwards. At the same time the displacer **D** moves upwards and displaces the cooled down air again into the warm part of the displacement cylinder **DC**. Relating to the movement of the operating piston **OP** you can call this operating part recoil step (3). If the displacer **D** has reached the upper dead centre, the circulating process starts again, the next operating process will be started.
All in history successful heat air engines operate according to this principle (*Rider, Ericsson, Lehmann etc.)* The reasons are clear, because contrary to the heating machine, where the water level in the boiler is constantly tested and must be refilled in doses by a dosing pump, to replace the consumed water. The continuous operating of an air heated motor is only determined by the fuel supply. If there had been provided a continuous supply, i.e. a liquid or gaseous fuel, the time of operating was practically unlimited, in spite of sporadic „lubrication intervals“. During this time the motor ran maintenance-free. These specific qualities were only surpassed by the electric motor.
A further important construction type of the closed machines is the placement of the two pistons in only one cylinder. The advantage is a more compact construction type and only one cylinder, where everything is taking place; the disadvantage is an extremely higher

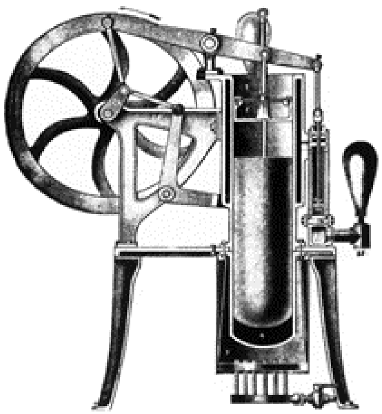
mechanical expense by driving the both pistons. The functioning is corresponding to the above explained mode of operation of the two cylinder machine. These machines have been successfully built in bigger numbers by *Messrs. Lehmann* in Germany and *Ericsson* in the USA.



Illustrations: Lehmann machine in secitonal drawing.
On the right: Illustration of a linkage to drive the both pistons. Problematical is the drive of the displacment piston, that must be connected through the operating piston with the crank drive.

In the year 1868 a closed machine of *Lehmann* was made known, which represents a development of the last open machine of *Ericsson. Lehmann* took over some important construction features, but he changed the function principle. He also closed a lying arrangement with a crankshaft installed above the machine. He guided the displacer by means of a roll in the inside of the cylinder and by the guidance in the operating piston. The heating was effected by coal in a stone built oven. The cooling system was installed around the cylinder. The first constructions didn‘t dispose of a regenerator.

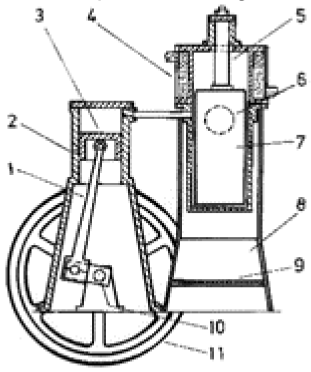
The result of Ericsson's development is the here illustrated arrangement. He changed the function principle he also had



by the recognized advantage of the closed kind of construction. Contrary to Lehmann he built his machines in a standing-up execution, what simplified the bearing and the guidance of the displacer. He couldn't avoid an extended mechanic. The steering of the two pistons was executed by means of a crank. The operating piston and the flanged water pump were connected by means of a balance with the crank. Ericsson found out in the fuel provision that for a nearly symmetrical run a continuous burning energy resource would be the basic consumption.

From all fuels which come into question even today gas is the most profitable and so Ericsson equipped this machine with a gas burner, that has the advantage of control and a simpler handling.

With the invention of *O.Ringbom* the classical development of hot air engines came to an end. *Ringbom* applied on behalf of him this machine type in 1907 for patent, long time after the introduction of gas-, petrol and electric motors, but too late still to have a chance in the market. Hereby is concerned a remarkable closed machine representing a further under



group of this type It is equipped with an elastic hung up displacer, which doesn't have a mechanic connection with the crankshaft. Only the operating piston is in connection with the crankshaft. The narrow, but not airtight suitable displacement piston is only moved by the air movement from the warm to the cold part and the back streaming air. The machine is indeed self running, that means the turning direction in which the machine starts to operate cannot be determined in advance.

At the end of the 19th century new inventions were put in the market, that represented a new epoch of industrialization (Otto-, Diesel-, electric motor) the hot air drive was very quickly displaced by these aggregates.

The hot air engine was due to its dimensions and capacity only suitable for the retail trade. That means it operated as a drive for pumps, stirrers, valves, grindstones, sewing machines, gramophones. For this purpose they had been built up to approx. 1920. Then it was uneventful in this type of drive.
As since the glorious days of the hot air engine nearly one century with two world wars had passed, it is explicable that only very few of these interesting machines have been preserved over the time and so are very rare. Only few museums and collectors dispose of old originals.

1938 Messrs. Philips took the idea up again. The idea was to develop a generator with STIRLING drive, to operate the former valve radios independently from the mains of supply. When the aggregate was ready for production on the other level the transistor and powerful batteries contrasted with the STIRLING aggregate and started their triumphal procession. Philips, however, went on developing the STIRLING motor up to the seventeenth and obtained a lot. Many technical inventions and patents had been acquired. So developed energy aggregates, yacht motors,
U-boat motors, compressors. This technical development let the enterprises in the world listen attentively. Patents and licences had been conferred, i.e. to General Motors, MAN, Ford Motor company. Not only few firms dispose today about drives between 45 – 800 PS. Nearly all motor car groups have their own prototype, especially in Japan. In Swede the STIRLING motor is operated in U-boats as a Hybride system. For small
U-boats a 100 kW STIRLING motor is offered with a duration of life of 30 years.

Totally worldwide about 100 enterprises are employing with the STIRLING technology. The fact that the STIRLING motor meanwhile is in nearly all people‘s mouth is obviously owing to the increase of the energy price. The importance of the STIRLING motor has been continuously growing up.
Though a bigger number of enterprises is employed with the development, even technical interested circles are unaware of the possibilities of installation. Unfortunately this circumstance affects negatively the production costs and by these means the end price and stops a desirable distribution.

We may be anxious to know, in spite of the one or other difficulty, in which areas even in the next years machines and aggregates will be working on the STIRLING procedure. Further extensive information please take from our offer in literature and books.

Hot air in toys

After *Ernst Plank* in the year 1866 was the first who employed with the production of toy steam machines it still lasted until 1895, when the first toy air heating motors appeared in the shops. You can possibly not find out who was the first supplier, but in contemporary catalogues at the same time appear machines of *Messrs. Plank, Schoenner* and *Krauss Mohr & Co.* They were all working with the closed system according to STIRLING, that means with side by side placed operating and displacement cylinder, whereby *K.M. & Co.* preferred the water cooling and the others the air cooling. Direct prototypes were not existing in the construction of big machines. These machines can be understood as educational aids to demonstrate physical effects. Two years later *Plank* brought the first boat with a hot air motor on the market, some time later even a locomotive and a tram. Real prototypes are only known from the ship building (*see Ericsson, 1852).*1903 *Carette* first appeared with a machine, where both pistons were placed in one cylinder. The competitors, i.e. *Märklin,* were soon following.
Finally is must be noticed, that also in the toy area the two cylindrical construction was applied due to its simpler construction.

Only *Märklin* kept to the hot air principle approx 1931, up to end (see Märklin catalogue DD8, 1931) in the one-cylindrical construction.

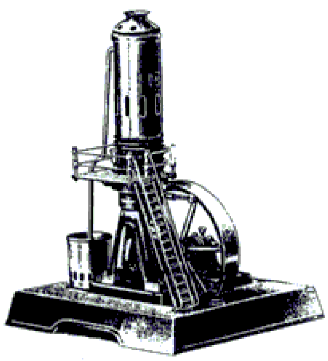


Illustration: on the left: One of the first-known illustrations in the catalogue of the firm Ernst Plank of the year 1895.
On the right: hot air motor, Märklin No. 4171, 1921-1931.

Hot air in the model engineering

No motor and machine engineer will be able to withdraw sooner or later of the fascination of this interesting technique.

If in model engineering you decide for the copy of historical prototypes or if you prefer to realize own constructions and ideas; in both cases you will apply the function principle of the closed construction according to STIRLING.

In the STIRLING model engineering is required a proper and careful treatment, as the model is only moved by the temperature difference between the cold and hot zone. A STIRLING model has considerable less power than a same dimensioned steam model. In the STIRLING model engineering the most important thing is to construct handsome fully functioning machines and not power machines. Finished kits are scarcely offered, because inexperienced engineers will possibly make mistakes and the success stays away.

An important help for the model engineers is the acquisition of good drawings and possibly material kits with the corresponding single parts by the corresponding possibility of (lathing, milling, drilling, soldering). The actual advantage hereby is to avoid time consuming search for suitable materials and special engineering parts, correctly existing in the material kit in dimension and the right material components.

All WIGGERS-models, if classic or own design work with the closed system like in the beginnings of this fascinating technique about 180 years ago.

Kind regards
WIGGERS STIRLING Model Engineering