Tests of a Simple Engine*

Taking Steam at Less Than Atmospheric Pressure

By R. C. Carpenter[1]

[The problem of the direct utilization of the radiant energy received from the sun is one whose importance can hardly be overestimated. Our readers will remember an account of Mr. Frank Shuman's experimental solar engine plant recently published in the SCIENTIFIC AMERICAN.[2] *We now bring an interesting account of some tests performed on a low-pressure engine of the type used by Mr. Shuman. The results will perhaps appear somewhat surprising to many engineers, for it is found that such an engine may be operated with remarkable economy.*—ED.]

So far as the writer can ascertain, there are very few data available as to the economy of reciprocating engines when operating with less than atmospheric pressure, although numerous tests have been made of nearly all types of engines under the usual conditions of steam pressure and vacuum. A considerable amount of data is to be found as to the results of steam-turbine tests, especially when of large size, operating with steam of low pressure. The impression generally prevails that the steam turbine produces much higher economy than the steam engine when operating with steam of less then atmospheric pressure.

The investigation, the results of which are given here, cannot be said to prove that the general opinion as stated above is erroneous, but it does tend to indicate that the reciprocating piston engine of small clearances can be operated with low steam pressures and high vacuum with remarkable economy.

The particular engine which was investigated was of the four-valve type and with cam-operated valve mechanism arranged to open and close with great rapidity. The total clearance space was about 1 per cent of the piston displacement. The valves were located so as to make the losses due to clearance a minimum. The results obtained in the investigations could not, in my opinion, have been produced by any engine built ten years ago.

The engine in question was 24 inches in diameter with 24-inch stroke. It was double acting with admission-valve seats on the barrel of the cylinder near the end, and exhaust-valve seats in the heads. This engine was developed to furnish power from steam generated by the heat of the sun in plate boilers which presented a large absorption surface and were designed by F. Shuman.[3] Its general features were conceived by Mr. Shuman. The engineering features were designed and developed by E. P. Haines.

The engine was developed to meet a special demand for a steam motor of small power that would give the highest possible economy with low steam pressure and a high vacuum. Its design and construction were undertaken by Mr. Shuman after he had thoroughly investigated the possibilities of obtaining a commercial engine or turbine which would meet his requirements. The best guaranteed performance for a 25-horse-power steam turbine which he could obtain from any builder was about 60 pounds per brake horse-power per hour with steam of atmospheric pressure and a vacuum of about 28 inches. No such turbine has been built and in the proposals the cost of development would have fallen principally on Mr. Shuman had one been built. As the motor was to be employed for driving a pump, the reciprocating engine at moderate speed possessed many advantages over the turbine. Mr. Haines was quite certain from his preliminary studies that he could construct an engine of about 20 horse-power capacity which would produce a brake horse-power with less than 40 pounds of steam per hour. Several attempts were made before final success was attained; in one of which attempts the entire cylinder and head were lined with soapstone in order to reduce the heat losses. Although this experiment was very expensive, it did not accomplish the desired result. Mr. Shuman only proved by that experiment what was already well known to scientific men, namely, that the principal loss of heat in the steam engine is due to the deposit and re-evaporation of a film of water on the interior walls and not to the loss of heat through a good conducting material.

The Engine.—In general appearance the engine was not greatly different from other engines of similar size, except that its working parts were light and it was provided with a rather long connecting rod. It had an overhung crank and an outboard bearing. Its general appearance is shown in Fig. 1. It could be turned readily by hand, showing that the friction loss was small.

The general arrangement of the valve-driving system and the valves can be seen from Figs. 2, 3 and 4. *A* followed by numerals indicates parts of the admission-valve system, and *E* followed by numerals represents parts of the exhaust-valve system. Two eccentrics were used which drove rocker arms, one of which *A*, Fig. 4, operated the steam valves, and the other *E* the exhaust valves. A cross-section of the admission valve and its driving linkage is shown in Fig. 2. Generally speaking, the valves were constructed so as to reduce the clearance space to the lowest possible limit.

The steam-admission valves, two in number, were of the slide-valve type, arranged to move parallel to the axis of the cylinder on a curved seat concentric with the cylinder. The steam-valve stems were driven by cams A_5, lifting A_6, Fig. 3, against the action of a spring. The oscillation vibrated the bell-crank lever of Fig. 2, which motion was communicated by links to the valve A_{10}, Fig. 2, and gave it a sliding motion on its seat. This design afforded steam ports with an opening 20 per cent of the piston area. These are on the top part of the barrel of the cylinder near each end and are provided by this construction with extremely short passages into the cylinder, thus making a small clearance loss.

The exhaust valves in this construction are especially novel; they consist of thin steel plates situated inside the cylinder heads and are vibrated in a plane perpendicular to the axis of the cylinder. Such valves are extremely unusual in the construction of steam engines and their operation was studied with a great deal of interest. In structure the valve was a flat thin disk provided with slots which were made to register with corresponding openings in the seat by the action of the valve-moving mechanism. It worked smoothly during the test; it was tight and its continued use apparently increased its tightness. The fact that it was very thin and that it was held in position by the pressure inside the cylinder, doubtless explains why the results were so good.

The exhaust valve is shown at E_1, Fig. 2, from which it will be noted that the area of the exhaust ports when open is very large. It amounts to 35 per cent of the piston area. The exhaust valves are vibrated by connecting to the eccentric *E*, Fig. 4, through the medium of rocker arms, links and cams shown in Figs. 4, 3 and 2.

The steam pipe is shown in the upper left-hand corner of Fig. 2, where it joins on to the steam chest. The exhaust-steam pipe is shown beneath the cylinders in Figs. 2 and 3.

The Test.—The test of this plant was conducted at Tacony, Pa., by Prof. W. M. Sawdon and myself. Because of the fact that the steam pressure was very low and that the work was done almost exclusively with less than atmospheric pressure, the method of testing which had to be adopted was quite unusual.

The engine was arranged to exhaust into a surface condenser connected to a vertical air pump. The water of condensation was delivered by a special hotwell pump into one of two tanks, which were placed on weighing scales and provided with suitable pipe connections and valves so that one could be filling while the other was emptying. The hotwell pump was provided with a governor for maintaining a constant level in the hotwell. Observations of the water level were also taken by means of a glass gage, and a correction applied for differences of level whenever necessary.

The engine took its immediate steam supply from a receiver 24x42 inches. The receiver was supplied with live steam from a low-pressure solar boiler situated in another building and some distance away, and it also received the exhaust steam from the air pump which produced the vacuum on the system. The live-steam connection from the boiler was provided with a valve by means of which the pressure was maintained constant by hand regulation. The main supply pipe was exposed to the weather, which was quite cold at the time of the test; as a result a considerable amount of water discharged into the receiver from both sources of steam supply, the height of which was determined by a glass gage and was regulated by a valve on a drain pipe. During some tests it was sometimes desirable to drain the receiver when the pressure was less than atmospheric; this was accomplished by connecting the drain pipe to an auxiliary receiver, which was connected to the suction side of the air pump and thereby kept under vacuum.

The steam pressure was measured by a U-tube mercury manometer attached to the steam pipe near the steam chest. This was kept as nearly constant as possible by hand regulation of the live-steam valve controlling the admission of steam into the large receiver. The vacuum was measured by a cistern mercury manometer connected to the condenser.

The temperature of the steam was taken by a thermometer placed in the steam pipe near the cylinder. The temperature of the exhaust was taken by a thermometer well in the exhaust near the cylinder. In general, all thermometers and pressure gages were very carefully compared with standards before and after the test, and the results corrected as necessary.

In order to guard against any water vapor in the discharge from the air pump which should have been charged against the engine, it was condensed, by discharging through a long pipe extending some distance outside the building. It then passed through a trap, was weighed and considered as steam consumed by the engine.

A gasometer was also placed in the air-pump discharge and so arranged that the volume of air pumped in a given length of time could be measured.

Quality determinations of the steam entering the cylinder were necessary in order to obtain accurate results, for the reason that the steam supplied to the main receiver, as already noted, contained a considerable amount of moisture. This problem was a very unusual one, as it required the determination of the moisture in the steam supplied at atmospheric, or less than atmospheric, pressure. In the tests made, the steam pressure varied from slightly above atmospheric pressure to about 7 pounds below.

The scheme of arranging a calorimeter for working under such conditions was quite original and was worked out in detail by Prof. Sawdon. The results which were

Fig. 1.—The 20 Horse-power Shuman-Haines Low-Pressure Steam Turbine.

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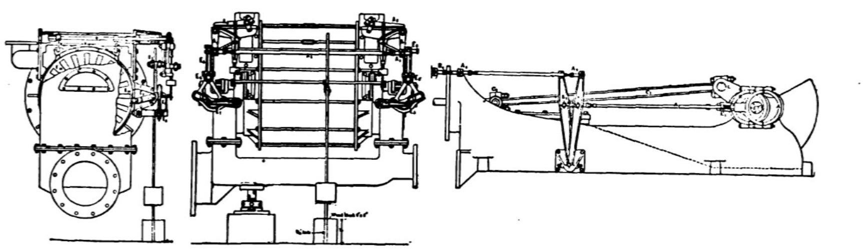
[2] September 30th, 1911, p. 291.

[3] See SCIENTIFIC AMERICAN, September 30th, 1911, p. 290.



Figs. 2, 3 and 4.—Elevations of the Shuman-Haines Engine.

(End view with section through exhaust; side elevation of cylinder; elevation of frame and eccentrics.)

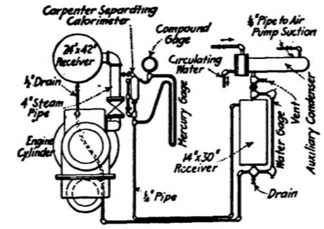


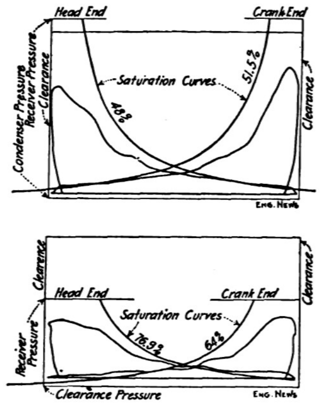
Fig. 5.—Diagram of Connections; Separating Calorimeter for Steam at Less Than Atmospheric Pressure.

obtained were proved, by subsequent tests, to be quite accurate. A separating calorimeter was connected in an auxiliary steam line extending from the main steam pipe to an auxiliary receiver, on which the same vacuum was maintained as on the engine, and through which a fair sample of steam could be drawn by suction. The scheme adopted is shown diagrammatically in Fig. 5. The quality of the steam in most of the tests which I conducted, did not differ greatly from 96 per cent. In a few of the tests conducted with very low pressures the quality approximated 90 per cent.

Indicator diagrams were taken during the test, special springs being carefully calibrated for the pressure conditions under which they were operated. Fig 6 represents the type of indicator diagram which was obtained when the entering steam, as measured in the receiver, was about ½ pound above that of the atmosphere. Fig. 7 represents the form of diagram when the initial steam in the receiver was about 7 pounds less than that of the atmosphere. On both the diagrams submitted, a saturation curve is drawn as a reference line. It will be noted that the expansion line is a long distance from the saturation curve at the point of cutoff, especially for the case of the higher steam pressure. However, it will be noted that these lines intersect before release, indicating that the moisture during expansion had re-evaporated.

With steam about 1 pound above atmospheric pressure and with a vacuum of 28 inches, the engine required 31.6 pounds of steam per brake horse-power-hour. With the same steam pressure, but with a vacuum of 28.8 inches, steam consumption was 28.8 pounds per brake horse-power-hour. These two tests indicate the very material effect of a high vacuum under such conditions of pressure.

With a steam pressure of about 8 pounds absolute (6.75 below atmosphere) and 27 inches vacuum, 37.8 pounds of steam were required per brake horse-power-hour. With the same steam pressure but with a vacuum of 28.66 inches, 35.7 pounds of steam were required per brake horse-power-hour.



Figs. 6 and 7.—Typical Cards from the Shuman-Haines Low-pressure Engine.

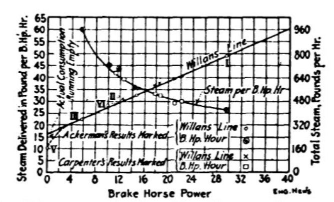


Fig. 8.—Diagram of Test Results on Low-pressure Engine.

As compared with the Rankine cycle, the efficiencies vary from 43.8 to 52.4 per cent, depending on the load and steam pressures. On the whole, the results will certainly compare favorably with any published results of any small steam turbines which I have seen.

An independent test of the same engine was made by E. P. Haines a few weeks previous to the tests made under my supervision, and these tests showed substantially the same results.

A. S. E. Ackermann, a noted mechanical engineer of London, England, made a series of independent tests on this engine a few months later than those which I have reported. Mr. Ackermann sent me the general results of his tests and also a diagram on which he had plotted his results and those which I obtained. His diagram is appended (Fig. 8). This diagram was constructed by using the total brake horse-power as abscissas and the total water consumption as ordinates. The plotted results all fall remarkably near a straight line. The fact that the results of the tests of many kinds of prime movers when plotted in a similar way, fall in a straight line, has been proved by numerous experiments, and this empirical law is for this reason a great aid in determining the accuracy of independent tests made on the same prime mover. The fact that my tests and Mr. Ackermann's fall on the same straight line indicate the substantial accuracy of both series of tests. The straight line which characterizes results plotted as explained is frequently referred to as Willan's line, Mr. Willan being a noted English engineer who first pointed out the existence of such a relation. The diagram also shows the steam per brake horse-power per hour for different load conditions.

Wires as a Remedy for Defective Acoustics*

By F. R. Watson

In the popular mind, one of the first aids for a hall with poor acoustics is to install a system of wires or strings with the expectation that in some way the defect will be cured. This prevalent idea is doubtless due to the fact that there are many halls where wires have been strung, and people naturally conclude that there must be some merit in the method. As a matter of fact, this popular impression does not seem to be well founded, for the author has inspected a number of halls thus treated, and has found no marked improvement in the acoustics.

Thus, in Dr. Parkhurst's church in New York city where a thin network of silk fibers of large mesh was stretched horizontally about half way between the floor and the dome, there still persisted a reverberation and an echo. In the Royal Cathedral in Berlin, a number of silk cords are installed in a horizontal network, yet the acoustics remain very defective. A fishnet is stretched near the ceiling in one of the court rooms of the Berlin Rathhaus with no benefit to the acoustical properties. The Royal Albert Hall in London has a series of wires installed, and, while the acoustics there are improved, other features than wires have unquestionably produced the effect. The warden of a church in Nottingham, England, writes:

"Several dodges were tried to overcome the (acoustical) defect, such as stretching wires across the nave." And so on for other cases that might be cited.

The conclusions of the author in regard to the inefficiency of wires have not always been in accord with the opinions of the auditors in the various halls mentioned. The janitor of Dr. Parkhurst's church, in answer to the question, "Does the net help the acoustics?" replied, "Some says it does, and some says it don't." In the Royal Cathedral in Berlin, according to the attendant's account, the Kaiser thought the wires produced no improvement while the Kaiserin thought they did. The direct question to the attendant as to his own opinion proved very embarrassing and brought only a shrug of the shoulders. Later conversation, however, revealed his conviction that no help had been rendered. In the majority of cases where opinions were asked for, there was a decided expression against the use of wires—"the acoustics are as bad as before," "The wires have not helped," etc.

Some people, however, claim that the method is advantageous, and that the acoustics are really benefitted. The author believes these claims are sincere, but attributes the better hearing to other features than the wires. For instance, the acoustics are usually improved when a large audience is present. Also, the opening of windows produces a good effect. Furthermore, regular attendants in a hall with poor acoustics gets used to the defect, and, by an adjustment of the attention, are able in some cases to subordinate the disturbing factors and hear better than before. Thus, on one occasion the author fixed his attention on a particularly strong echo and was able to hear more distinctly than by listening to the words as they came directly from the speaker. On another occasion in this same hall the leader of the band had great trouble in conducting a certain selection. The piece being played was a xylophone solo with orchestra accompaniment. After some time the leader discovered that he was beating time to the *echo* of the xylophone. The players near the soloist kept proper time, the others near the leader played in unison with the echo. The result may be imagined.

While both observation and opinion indicate that acoustical defects are not helped by wires, it is interesting to look for further confirmation from the standpoint of theory. It is well known that if a loud tone is sung near a piano, certain wires of the latter will resound. Perhaps this phenomenon suggested the use of wires in auditoriums, with the hope that the objectionable sound would be absorbed or broken up in some way. But the conditions for the response of the piano strings are very favorable. There are many wires tuned to different pitches, so that certain ones are in tune, or nearly so, with any tone sung, and these are the wires that resound. The wire in the auditorium would respond therefore to only one of the many tones present. To be effective on this score, there would have to be many wires tuned so as to cover a wide range of pitch. Secondly, the piano wire is backed by a sounding board, which absorbs considerable energy and communicates it to the wire. The response is thus very much greater than it would be without the sounding board. The wire in the auditorium has no such sounding board, therefore it absorbs less energy and has less effect on the sound. Finally, the piano occupies a considerable portion of the space of the room and gets energy not only directly, but also by reflection from the near-by walls and ceiling. On the other hand, the wire in the auditorium is small, and is struck by only a small part of the sound waves, direct or reflected, hence has a small chance to help matters. All of these considerations indicate the smallness of the effect to be expected.

One other way in which wires might be beneficial lies in the possible scattering of the sound waves. Here again, however, the small bulk of the wires allows but little effect. The sound waves pass around the wires in much the same way that large water waves on a pond pass by a stake projecting through the surface. It is only when the obstacle has some size compared with the waves that a disturbance is set up. If there were a large number of wires close together, the sound waves would be influenced. In halls, we find usually only a few wires installed, probably with the idea of having them inconspicuous.

From the various considerations mentioned, it is seen that the installation of wires in halls having poor acoustics is without marked effect. While much remains to be done on the problem of architectural acoustics, and though the means of cure can not be specified readily for each case, it is nevertheless of value to know that the installation of wires, as now used, will *not* serve to cure the trouble.

* Reproduced from *Science*.

A Floating Moving-Picture Theater.—A floating moving-picture theater may be seen in the harbors of the Netherlands. The boat is 164 feet in length, has its own electric light plant and is otherwise equipped with the greatest comfort. The venture proved to be a success, as the theater is always well patronized by sailors and residents of the seaport.