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Internal combustion engines

Neal Ham

INTERNAL COMBUSTION ENGINES.

By

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A

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Principles of Operation

Article I

Every one is either directly or indirectly concerned with two types of power plants. The steam power plants of Kansas City furnish us with light, power, and transportation. In this day these are indispensable. The gas, or internal combustion engine power plant furnishes transportation, mainly and some power. Each of our big buses has an internal combustion engine power plant under the hood.

It will be our aim here to show how the internal combustion engines operates and discuss some of the types in use in automobiles and stationary power plants. When one contemplaes the immense amount of power developed by the internal combustion engine in this country and how important power is in our daily life, the subject becomes extremely interesting.

The internal combustion engine is used today in automobiles, tractors, airplanes, boats, and many kinds of industrial plants. Some of these plants include ice factories, pumping station,s flour mills, power stations and so on. Generally speaking all of these engines operate in the same way. Liquid or gaseous fuel of some kind is made to burn in the combustion space of the engine cylinder. Hence the name internal combustion as opposed to the steam engine where the burning of the fuel is external to the engine itself. There are a number of fuels used commercially in the internal combustion engine today, such as natural and artificial gas, gasoline, kerosene, wood alcohol, fuel oil, crude oil and tar. Before any of these fuels burn efficiently they must be in a completely gasified condition in the combustion space of the engine cylinder and thoroughly mixed with air or oxygen. Burning is then brought about in one of several ways as we shall later see. In as much as all fuels are gas just before burning, the internal combustion engine is often called a "gas" engine. We shall follow this custom here.

When a series of events takes place in the same sequence again and again we speak of the occurence as a cycle. Now, some gas engines complete cycle in two strokes of the piston and some in four. Engines operating on this principle are known as four stroke cycle engines, and two stroke cycle engines. The detail workings of these two types of engines shall be explained later in another article.

There is still another classification of gas engines as pertains to cycle of operation. In the case of most internal combustion engines, such as the natural gas gasoline, kerosene, and similar engines, the burning or ignition, or explostion of the fuel, is effected by an electric spark produced by some kind of ignition apparatus as a magneto or spark coil. In each of these engines, the burning occurs very near the end of the compression stroke. The pressure in the cylinder rises very rapidly and burning is completed in a short space of time. The time is short, in fact, that the piston remains practically stationary during burning and the cylinder volume does not change materially. This occurrence has led engineers to designate the engine as a constant volume engine. One of the first to develop this engine commercially was the German engineer Otto. Hence the cycle is known as the Otto cycle. It should be remembered that an Otto cycle gas engine can operate on the two stroke or four stroke cycle principle. At present the commercial automobile engine is an Otto cycle engine.

INTERNAL COMBUSTION ENGINES

Article II-Oil Engines--History--Types.

AKROYD ENGINE.

The origin of the internal combustion engine dates back to 1886, when development work was undertaken independently by Herbert Akroyd Stewart in England, and Rudolf Diesel in Germany.

The first Akroyd engine worked on the four stroke cycle principle; the fuel was sprayed into the cylinder or combustion chamber during the suction stroke and ignition was attained by the heat of compression in addition to heat absorbed from a hot cap or tube. As compared with these of today, this was, of course, a very crude engine, but nevertheless, it was the first commercially successful oil engine.

About 1890, the Bletchley Iron Works, Bletchley Bucks, England, introduced 2,4, and 6 HP engines under the Akroyd patent No. 7146. These engines differed from the original Akroyd, in that the fuel instead of being injected on the suction stroke, was timed to enter the cylinder near the end of the compression stroke, so that preignition, which had been a serious fault of the earlier engine, could not occur. It is interesting that in principle, this engine differed very little from the solid injection engines of today. It is strange that although the principle was clearly outlined in 1890, it took nearly thirty years tc develop the modern solid injection engine.

In October 1890, Herbert Akroyd secured British patents covering the combination of a combustion chamber connected to the cylinder through a neck. The inlet valve was located in the cylinder side of the neck and the fuel was injected into the combustion chamber during the suction stroke, as in the original engine in 1886.

In June 1891, Messrs Richard Hornsby & Co acquired the sole right to manufacture this Akroyd engine under license; while the other Alroyd engine, employing the injection on compression stroke was not developed.

In 1898 The De La Vergne Machine Company in New York, purchased the Akroyd American patents and began manufacture of the engine. This was the first oil engine in the United States. Many hundreds installations of this type are to be found throughout the country, and a great percentage of the engines which were built during the first years are still in daily operation; some installations having a record of over twenty years service.

Thus the decision of Akroyd and the Hornsby Brothers back in 1891, to develop and market the engine using the suction stroke injection principle, no doubt retarded the development of the solid injection engine.

The old HA type engine mentioned above used about 1 lb of fuel oil per Brake Horse Power. It became apparent that the fuel economy of this type engine had to be increased. It soon became clear to designers that to improve the efficiency of the Akroyd engine, the compression must be increased, and to do this, it was necessary to adopt the engine which used the method of injection on the compression stroke.

Between the years of 1906 and 1916, this type engine was developed and economies of 0.5 lb per BHP per hour was attained. This departure was so radical from the old engine that they were not built under Akroyd patents.

Based on ecomony these engines were still inferior to the Diesel. Another drawback was the use of blow torches to heat the hot bulb before starting.

DIESEL ENGINE

Almost parallel with the development of the Akroyd engine and the American solid injection engine, runs the invention of the Diesel engine, in Germany. Dr. Fudolf Diesel established the first patent in 1892 on an internal combustion engine, which was to use powdered coal as fuel. This first engine was a fialure, and it was not until oil was used as a fuel that some degree of success was attained. The Diesel engine was more efficient than the Akroyd engine, but there were so many difficulties that years passed before the Diesel was improved to such an extent that it could be used for commercial uses. In the United States, the Diesle rights wereaqquired by the American Diesel Engine Company, but when the patents ran out, several engine manufacturers began the manufacture of Diesel engines; refinements and improvements followed that had previously been retarded.

Compression pressure in a Diesel is from 450 to 500 lbs. To inject fuel, and to assist in effecting perfect atomization, air at about 1000 pounds is used.

The air compressor, necessary for air injection requires 8% to 13% of main engine power out-put and this percentage represents the greater mechanical efficiency of the Price Engine.

The air injection system provides more air for combustion of fuel, by the amount or volume of the jet, and increases the rated indicated MEP, which is a claimed advantage in the Diesel Engine. The advantage disappears when the increased MEP is shown to represent the power required to drive the compressor that furnishes the air.

PRICE ENGINE

A notable achievement was accomplished by the late Engineer and inventor W. T. Price, when in1916 he designed and built the Price opposed spray engine, to operate with a compression pressure of 240 pounds per square inch. When starting from cold, it was necessary to pass a current through a resistance coil in the combustion chamber to get sufficient heat to fire the mixture, but after the engine had run a few minutes, the heat of compression was sufficient for ignition without the use of the fuse wire. The Price engine was the first low compression engine with all surfaces surrounding the combustion chamber completely water cooled; it was also the first low compression solid injection engine that operated with a fuel consumtion as low as the Diesel Engine.

In the spring of 1919 Ingersoll Rand Company took an option on the Price patents, ard the first Ingersoll Rand "Price" Oil Engine was put in operation for a series of tests during the spring and summer of 1920. Further research work done by this company, led the adoption of 350 lbs compression instead of 240 lbs as used in the Original Price engine. This change eliminated the only two objectionable features of the engine, namely: the necessity of using electric current to generate heat to start and the very annoying fuel knock or detonation which is common to all low pressure engines, due to the sudden great pressure increase while the piston is in inner dead center position.

The Price engine, therefore, starts from cold as readily as a 500 lb compression, air injection engine,

MISCELLANEOUS TYPES

Oil engines made in the United States are of various types, such as

Diesel (high compression) with or without air injection;
Medium Compression, with mechanical or solid injection;
Low Compression, Hot bulb, Hot Plate, Hot Spot, etc
with mechanical injection.

Engines of very small horse power and of greatest horse power are generally two stroke cycle.

In the two stroke cycle design, the aim is to get more horse power per cylinder at lesser unit cost, or more power out of the same weight or material This can be accomplished only by restricting the time of scavenging to about 40 degrees on both sides of outer dead center, and making every out stroke, a firing or power stroke.

Maximum efficiency exacts complete combustion and scavenging and complete scavenging means four stroke cycle and a heavy engine. Although very encouraging results have been attained with large two cycle engines, they have never attained the efficiency possible in four cycle engines.

Engines of the hot surface type are manufactured pricnipally in sizes twenty five horse power and under. In engines of the Diesel and medium compression principle, cylinder compression is from 350 to 500 pounds, and combustion is effected by the heat of compression. In engines of the hot surface principle, cylinder compression is from one hundred fifty to two hundred and fifty pounds, and combustion is effected by impinging fuel against hot surfaces, and fuel not heavier than thirty degrees Beaume is usually necessary.

COMBUSTION

In the Diesel engine, the use of injection air is not primarily used for atomization of the oil. Finer atomization may be attained without the use of compressed air. The real function of air injection is to produce turbulence, and as good or better results may be obtained by introducing the compressed air and the oil into the cylinder through separate nozzles. When this system is used, the initial compression pressure must be somewhat higher than when solid injection is used, due to the fact that the injection air reduces the temperature of the compressed air.

In the Price engine, combustion takes place in a spherical chamber. Air injection is not used. The fuel is pump injected through two opposed nozzles. Turbulence is obtained by means of a contraction or neck through which the compressed air from the cylinder must pass in entering the combustion chamber proper. This arrangement produces sufficient turbulence to give the desired results, also the air is moving in such a direction as to help maintain the oil vapor in the center of the combustion chamber; i.e. the aim is to keep the burning oil away from any of the metallic surfaces and this is accomplished. It is evident that with this type of engine the surface of the combustion chamber and cylinder is much larger than with the air injection engine. Therotically the air injection engine is supposed to compress to about 500 pounds per square inch, and then inject oil at a rate th t will maintain the temperature of compression during only a portion of the working stroke. This is found to be very difficult to obtain, and the usual practice is to inject the oil in such a way as to obtain combustion at constant pressure.

In the Price engine, compression is carried to approximately 350 pounds per square inch; obtaining combustion at constant volume with an increase in pressure to 500 pounds per square inch and then combustion at constant pressure for a short portion of the stroke.

The advantages of this system are principally two: The high pressure air compressor, which has been the cause of considerable difficulty with the air injection engine, is eliminated, and the walls of combustion chamber and the head of the piston are not subjected to maximum temperature of combustion.

OIL ENGINE POWER RATING

Conservatively designed four stroke cycle solid injection oil engines are usually rated at about 70 lbs Brake MEP this being the average pressure exerted dur to allowable maximum temperature of combustion.

Brake MEP Formula

For 4 stroke cycle engines $BMEP = \frac{33000 \times BHP \times 2}{A \times S \times N \times C}$

For 2 stroke cycle engines $BMEP = \frac{33000 \times BHP}{A \times S \times N \times C}$

BHP --Brake Horse Power per cylinder
A --Area of piston in square inches
S --Stroke in feet
N --RPM
C --Number of cylinders

ENGINE EFFICIENCY

The Internal Combustion Engine converts heat into work at the highest efficiency of any prime mover.

Thermal Efficiency Brake

Steam Power 10%	(1000 HP and under)	
Overall Plant.......18%	(20000 HP and above)	
Diesel Oil Engine...35%	Mechanical efficiency 75%	
Price Oil Engine....35%	Mechanical efficiency 85%	

INTERNAL COMBUSTION ENGINES

Types and Construction

Article III.

In the first article we classified internal combustion engines according to the cycles of operation. We learned that all gas engines are either two or four stroke cycle and operate as either Otto cycle or Diesel cycle engines. It will now be profitable to study the construction of the various types under each head, as well as the characteristics desired of a particular type.

The most common type is the automobile engine, which, as we have said, is usually a four-stroke Otto cycle engine. In this type are found the L-head, T-head, and valve in head construction. The L-head engine has both inlet and exhaust valves on one side of the combustion chamber of piston; the T-head engine has one valve on each side of the piston, and the valve in head (also termed overhead of I*head engine) has the valves in the head above the piston. Some engines have one and some two cam shafts, and the cam shaft may be driven by either a chain or gear. Some engines are water cooled and others air cooled. Then there is the sleeve valve engine. These different construction features are found in all automobile engines, which include automobile, tractor, air plane, and motor cycle. Startionary and marine engines also have these different features.

The characteristics required of each of these engines are different, at least in degree. Some of the characteristics demanded are reliability, quick starting, and acceleration, smooth and quiet operation and fuel economy. Reliability appears to be the prerequisite of all types, but more especially in the case of the air-plane engines. Speed, quick starting and "getaway" mean more to the American public than economical gasoline consumption. These qualities are, however, not important in tractors and trucks, while fuel economy is. With these engines we find rugged construction very desirable and the engines are heavy. This applies to those engines designed especially for tractors and trucks. The air plane engine must be strong enough to be thoroly reliable, but it must also be as light as possible. Some airplane engines weigh only about two pounds per horsepower, while other automobile engines exceed this amount several times. It is strange that water cooled airplane engines are now made lighter then ones cooled by air.

Another factor effecting engine performance and economy is the ratio of gasoline to air, or mixture entering the cylinder. There is a definite amount of air required for each pound of gasoline. Some of the gasoline will remain unburned. Lubricating oil and dirt are the other sources of carbon in the combustion chamber..

The large gas engines found in steel mills, and the centers where artificial or natural gas is avilable, are usually horizontal. They have one, two, or four cylinders. In the latter case there are two sets of cylinders in tandem; that is, one cylinder ahead of the other. These engines develop as much as 5,000 horse power and drive generators whose current is used for power and light.

are vertical; some inject the fuel with air pressure, others with a pump, an so on.

At present the Diesel is used for heavy duty service, such as driving pumps, ice machines, and other machinery.

The Diesel engine will be discussed more fully in the next article.

INTERNAL COMBUSTION ENGINES

The Diesel Engine

Article IV.

There are three methods for the injection of fuel into the combustion chamber of a Diesel engine. The methods may be enumerated as follows: air Injection, pump injection and gas injection. Until recent years the air injection engine has been the most prevalent, but now the pump injection engine has been becoming more popular, especially in medium and small sizes. The gas injection engine has also come into preminence. On the firt type of engine an air compressor stores air in a bottle, or drum, at a pressure of 1000 pounds per square inch. This air is piped to the fuel valve on the engine. A pump is attached to the engine sends oil to the fuel valve. At the proper time in the cycle (just at the end of the compression stroke) the fuel vlave is opened by a cam and rocker arm. The high pressure air then forces the oil from the fuel valve to the combustion chamber. The fuel enters in a cloud or vapor, and immediately starts to gasify and burn. It must be kept in mind that air alone is compressed in a Diesel engine cylinder, as was mentioned before. The compression of this air to 450-500 pounds per square inch creates enough heat to burn the fuel when it enters the combustion space. The high pressure air from the air compressor serves ohly in inject the fuel into the combustion space.

The pump injection engines dispenses with the air compressor, and the fuel pump alone forces the oil through the fuel valve into the combustion chamber. The elimination of the air compressor has an advantage. It is claimed that the compressor requires form 15 to 20 percent of the gross engine power. Also a somewhat lower compression pressure can be used with the pump injection engine for the same fuel. Although some large engines have been built using the method of pump injection of the fuel, most of the present day large engines, of 1,000 horse power and up, inject the fuel with air.

The gas injection engines are at present made in small units, as low as 5 horse power per cylinder. Severaly schemes are used to obtain gas injection of the fuel, but they all operate in the same general way. A small auxiliary uncooled combustion chamber is attached to the main combustion chamber and a small opening connects them. During the suction stroke of the engine, the correct amount of oil, metered by the governor, is pumped into the auxiliary chamber. During compression this chamber becomes hot enough to gasify the lighter products of the oil. Thees products explode and the sudden high pressure injects the remainder of the fuel into the main chamber, where it burns in the usual manner. It is reported these engines are quite successful.

As has been said before, the bulk of Diesel engines are used for heavy duty service, such as in power station, ice plants, mills, and so on. This situation has prevailed since the Diesel was first bought out. Consequent- there has been littel demand for an engine of other than rugged characteristics. The engines have operated at low speeds, have occupied considerable space per horse power have weighed around 400 pounds per horse power, and were rather costly per unit of power. It would appear, after close study, that these qualities are not necessarily fixed, and that Diesel engines of entirely different characteristics can be made. The fact is that engines are now made in both Europe and America with such differend properties as to make one think they are not true Diesels. The speed has been increased to as high as 1400 RPM. This has brought the weight and space required per horse power down to that of the present day automobile truck engine. The compression pressure also has been materially lowered. The cost can be made favorable with that of the present automobile engine.

The Diesel engine is then applicable for use in the automotive field as well as for industrial work and ship propulsion. If the Diesel engine can be fully perfected for use in automobile work, several advantages would be realized. The carburetor and ignition apparatus as we now know them would be eliminated.

About ten percent of the energy in the fuel goes to driving the truck or automobile of the presenet day. The Diesle engine has a thermal efficiency of around 35%, and so, instead of ten percent of the fuel being available for driving purposes, we could expect to utilize from 15 to 25% of the fuel's energy. The fuel used would cost about one thir of tone half what gasoline now costs. It can be seen that the fuel cost for automobile transportation would be about one fourth of what it now is. If worth while thought and resources are given over to thematter of perfecting a Diesel engine for use in automotive work, there is no reason why it should not be a success.

Turning our attention to the power and industial field let us see what the situation is. For this purpose any engine must give reliability and low cost of operation. Here and there in the industrial world are found exampl s of very good and very poor reliability and operation cost of Diesel engines. However, average results must be looked to for reliable information. One engine manufavturer states that over 96% of their engine horse power sold within the last eighteen years is still in successful operation. Many engines have been operated for months without a shut down. A company in the middle west has some 60,000 horse power of Diesel engines in operation. The following statement comes from this company: "With proper attention and intelligent operation, it (the Diesel engine) has been found to be as dependable as the steam engine".

Some of the factors which determine the operating cost of a Diesel engine plant are: kind and amount of fuel oil; design of th engine and plant; character of labor employed; quality of lubricating oil; capital costs.

It is often said that the Diesel engine plant entails too great an investment and this outweights any savings. Facts do no bear out this contention. Very often operating costs such aw labor, fuel, upkeep and lubrication exceed capital charges. One company operating both steam and Diesel engine plants s ates that the cost of a steam plant and Diesel plant are the same. Plant design and engine design influence very greatly fuel costs, lubrication costs, and upkeep costs. It would be better to spend more for the plant and make a greater saving in operating costs. The kind of labor employed also determines, to a large degree, the upkeep cost of a plant. For this reason, it is better to emply competent operators and engineers, as a greater saving than the additional salaries would be made. Actual operating costs of many plants are available and these are invariably lower than costs of steam plants of equal size and condition. Central power stations of say 15,000 kilowatts capacity and up are usually steam equipped. Obviously there is some size station above which it would pay to install steam machinery. This is because very large size steam units are available. At present the largest size Diesel is about 15,000 horse power. As was intimated previously this size may be increased materially in the future.

The ultimate goal in internal combustion engine engineering is the gas turbine. There are gas turbines in operation now, although they have not been perfected. If the high thermal efficiency of the gas engine can be combined with the mechanical advantages of the steam turbine, a real step forward in power plant engineering will have been made. The boiler room, as we now know it, would be eliminated, and the present condensing equipment woul be unnecessary.

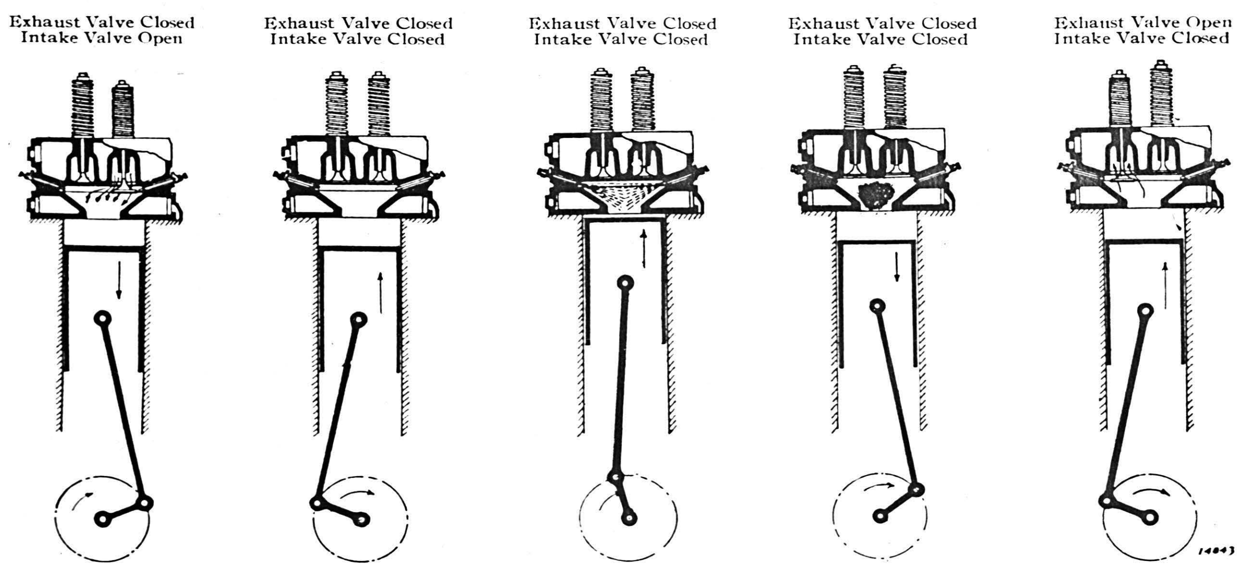
The question of fuel oil supply is often bought up. Various authorities have stated the situration relative to the world's petrolem supply. Looking at the matter as a whole, it would appear that there is no danger in petrolem for years to come. There are other sources of fuel supply for internal combustion engines in alcohol and coal tar. Coal tar has been used in Diesel engines in Europe for several years.

INTERANL COMUSTION ENGINES.

Comparison of Types.

Article VI.

It is my intention in this article to explain in detail the workings of a two and four stroke cycle engine, and give advantages of each. I shall also go into the commercial builders of engines today. In this article we shall deal with the oil engine only.



A—Suction Stroke | B—Compression Stroke | C—Injection | D—Combustion and Expansion Stroke | E—Exhaust Stroke

Referring to the above cut in figure 3, Suction stroke A.

The piston has just completed an exhaust stroke; it has passed the head end dead center and is moving away. The exhaust valve is closed and the intake valve is open to atmosphere. As the piston moves out, it draws air into the cylinder.

<u>COMPRESSION STROKE</u> "B"

When the piston has reached the crank end dead center, it starts to move forward. A few degrees past crank end dead center the intake valve is closed, and during the remainder of this stroke the piston compresses the air into the combustion chamber.

FUEL INJECTION "C"

Before the head end dead center is reached, the fuel pump ia actualted by its cam, and two sprays of fuel oil are injected into the combustion chamber. These sprays meet in the center of the combustion space and thoroughly mix with the air. Ignition takes place automatically as the fuel is injected. This is due to the heat generated in compressing the charge of air.

COMBUSTION OR EXPANSION STROKE "D"

The fuel injection is so timed that combus tion starts before the piston is on head end dead center and continues during the remainder of the injection period (about 10-15° after dead center.) Expansion begins 10-15° after head end dead center, driving the piston out. The exhaust valve opens shortly before crank end dead center is reached. This is the working stroke, or the one from which the engine develops it spower.

EXHAUST STROKE "E"

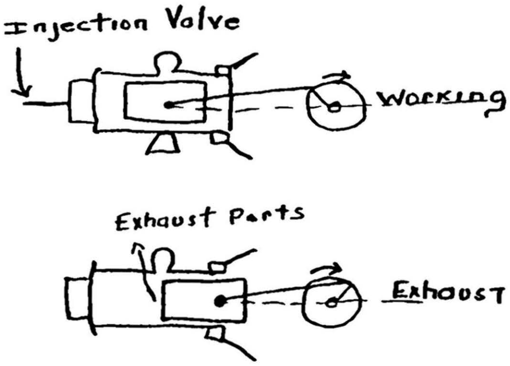
The piston passes crank end dead center, and during the following forward stroke forces the burned gases out through the exhaust port. This valve remains open until after the piston has slightly passed the head end dead center.

The engine is now ready for another cycle.

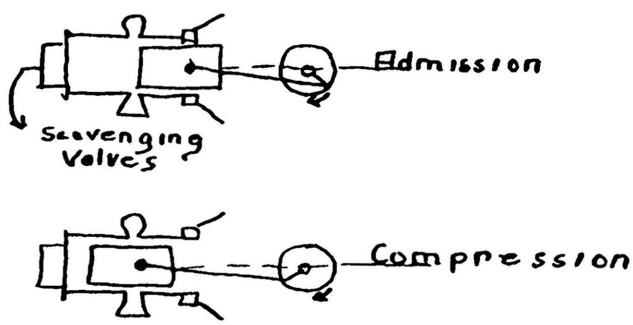
The above cycle is typical of Price engine of the four-stroke cycle design.

Events in a complete cycle of a two stroke cycle engine would be as follows:

Working & Exhaust Stroke

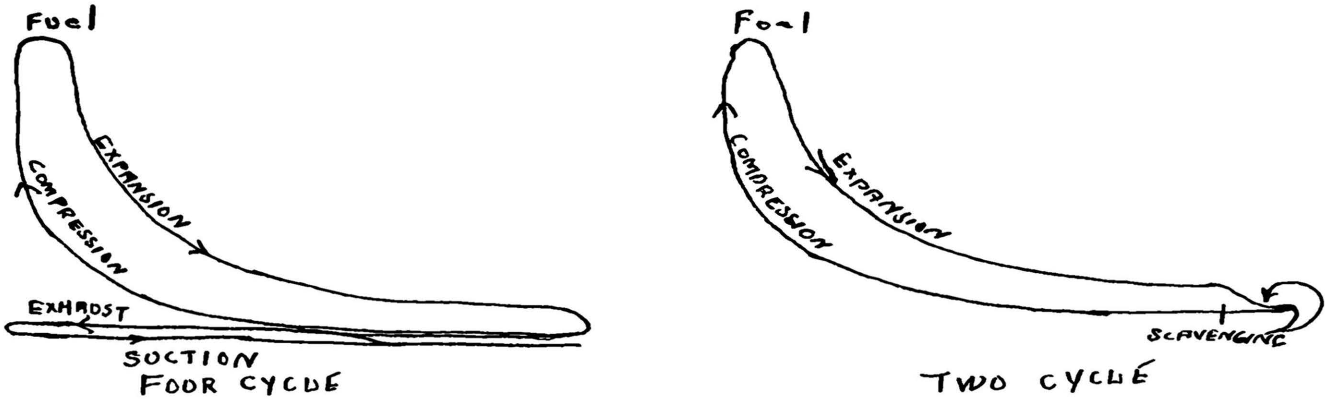


Admission & Compression stroke



<u>WORKING AND EXHAUST STROKE</u>

After the fuel has been charged into the combustion chamber, combustion takes place and the piston is forced inward by the expanding gases. Toward the end of the inward travel of the piston, the exhaust ports are uncovered, releasing the pressure in the cylinder. Immediately afterwards the scavenging ports are uncovered admitting fresh air under low pressure and scavenging the cylinder of burned gases. (Some engines have cam operated



Indicator cards from a four and two cycle oil engine.

The following is a general classification of the more important domestic builders supplying vertical oil engines for stationary power plant service which are competiive with the Price Engine, or Diesel Engine.

FOUR CYCLE

Solid Injection

1. Ingersoll Rand
2. Atlas Imperial (Engine Co-Oakland Cal.)
3. Bessemer (Gas Engine Co-Grove City, Penna.)
4. Chicago Pneumatic "Benz"
5. De La Vergne Machine Co
6. Falk (Gear Copr)
7. Foos (Gas Engine Co)
8. New London
9. Superior "Deutz" (Gas Engine Co)
10. Union (Gas Engine Co)
11. Wstern (Machinery Co)

Air Injection

1. Busch Sulzer
2. Fulton Iron Works
3. Lombard
4. McIntosh & Seymour
5. New Londeon
6. Pacific Diesel Engine Co
7. Worthington Pump & Machine Works
8. Winton Engine Co

TWO CYCLE

Solid Inject.

1. Anderson Engine Co
2. Bethelehem
3. Fairbanks Morse Co
4. Mianus Diesel Engine Co
5. Munci
6. Tips Engine Works
7. Venn-Severn
8. Worthington Blake

Air Injection

1. Bethlehem
2. Busch Sulzer
3. Hadfield
4. Nordberg
5. Worthington Double acting.

INGERNAL COMBUSTION ENGINES

Cost and Cost Comparisons

Article VII.

In dealing with cost comparison, the writer will deal only with oil engines, and that engine of the Price principle, with solide injection, and working on the four stroke cycle.

I have included some cnves showing cost operation of oil engine driven air compressors. Also a curve showing time it will take an oil engine compressor to pay out over a motor driven unit under certain conditions.

In this article we shall take three practical examples that have actually been analyzed very carefully from an operating standpoint. We shall take three examples; one comparing generated current with an oil engine to that of bought current; another an ice machine driven by an oil engine compared to a steam machine; another comparing bought current to motor drive an air compressor with several differenct combinations of oil engines.

An oil engine is fundamentally the most economical machine known, for producing power. This is becuase its thermal efficiency is from 30 to 35 percent; in other words, about one third of the heat units contained in the fuel is developed into actual power at the shaft. When one considers that the largest steam turbine plant in the country can obtain but 20% thermal efficiency, it is easy to see that the oil engine has a great economic advantage.

EFFICIENT USE OF FUEL

One horsepower is equivalent to 2545 B.T.U's. Therefore, if there are 18,500 B.T.U's in a pound of oil, a theoritically perfect oil engine would consume only 2545 divided by 18,500 or .14 pounds of oil per B.H.P. There are, however, the following losses:

1. Heat carried away by water jacketing. This loss is approximately 30%.

2. Heat in exhaust gases. As it is not practical to expand fuel oil gases down to atmosphere, the exhaust is at high pressure with a temperature of approximately 600 degrees F. This represents a loss of 30%.

3. The mechanical loss in the engine. The engine has a mechanical efficiency of approimately 85%.

Revising withe the total loss, the oil engine actually consumes .43 pounds of oil per B.H.P. or 7955 B.T.U.'s (.43 x 18500).

Taking into consideration the fuel and lubrication oil required to run a 55- h.p. engine, it costs only $2.00 for an 8 hour day--25 cents an hour.

The first curve shows a cost comparison between operation between oil, electric and steam power. In plotting this curve, I have assumed a year to be 300 working days of 8 hours each, or a total of 2400 working hours. Current at 2½ cents per Kw hour, coal at $5.00 per ton, and fuel oil at 7 cents per gallon are obtainable in many parts of the country, so the curve has been laid out with these figures falling on the same point of the horizontal line or abscissa.

ELECTRIC MOTOR

Current at 2½ cents per kw-hour.

Assume motor efficiency 85% (includes wiring losses) 1000 watts is 1 KW. 1 horsepower is 746 watts. With motor efficiency at 85%, it is necessary to draw 746 divided by .85 or 877.7 watts, from the power line. The total current, required to run a 100 hp motor a year, of 2400 hours will be 100 x 2 x 877.7 divided by 1000 or 210,648 kw hours. At 2½ cts per kw-hour, the cost of running a 100 hp electric motor for one year will be .025 x 210,648 or $5,266.20. This is equivalent to $17.55 per day, or $2.20 per hour.

STEAM ENGINE.

Coal at $5.00 per ton.

Assume steam consumption of 30 lbs. per h.p. per hour. 1 lb. of coal evaporates 5½ lbs. of water. The quantity of coal required to run a 100 -i.h.p. steam engine one year will be 100 x 2400 x 30 divided by 5½, or 1,309,000 lbs. of coal. This reduces to 654.5 tons per year at a total cost of 5 x 654.5 or $3,272.50. The b.h.p. of an engine is approximately 90% of the i.h.p. by card. Therefore, the cost of running a steam engine of 100 b.h.p. is $3,272.50 divided (.90) or $3,652.00. This is equivalent to $12.50 per day or $1.52 per hour.

OIL ENGINE.

Fuel oil at 7 cents per gallon.

Using a fuel consumption of .43 lbs per b.h.p. per hour a 100 b.h.p. engine will consume 100 x 2400 x .43, or 103,200 lbs. per year. This means 13,445 gals. per year (1 gallon) weighing 7-3/4 lbs. The fuel cost per year will be 13,445 x .07 or $941.15

Lubricating oil at 60 cents per gallon.

1 gallon is used for every 1300 b.h.p. hours on all this type oil engines, or gallon per 2000 b.h.p on horizontal engines. The total cost of lubricating oil per year will be 100 x 2400 x .60 divided by 1300 or $110.00 per year. The total cost of both fuel and lubricating oil will be $1051.15. This is equivalent to $3.50 per day or 44 cents per hour.

Note that the cost of lubricating oil at 60¢ per gallon is above the average.

DISCUSSION OF CURVE.

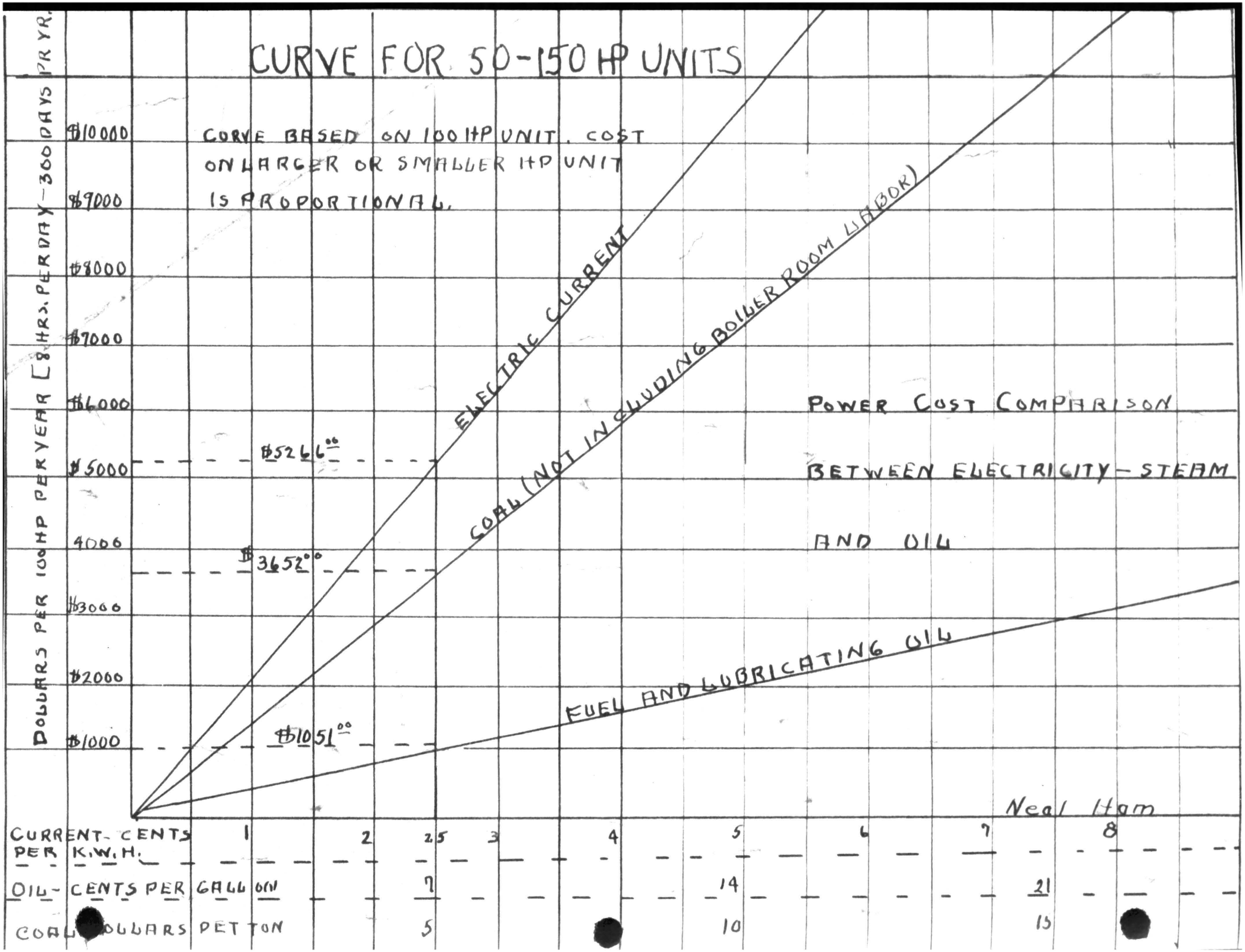
COST RATIO.

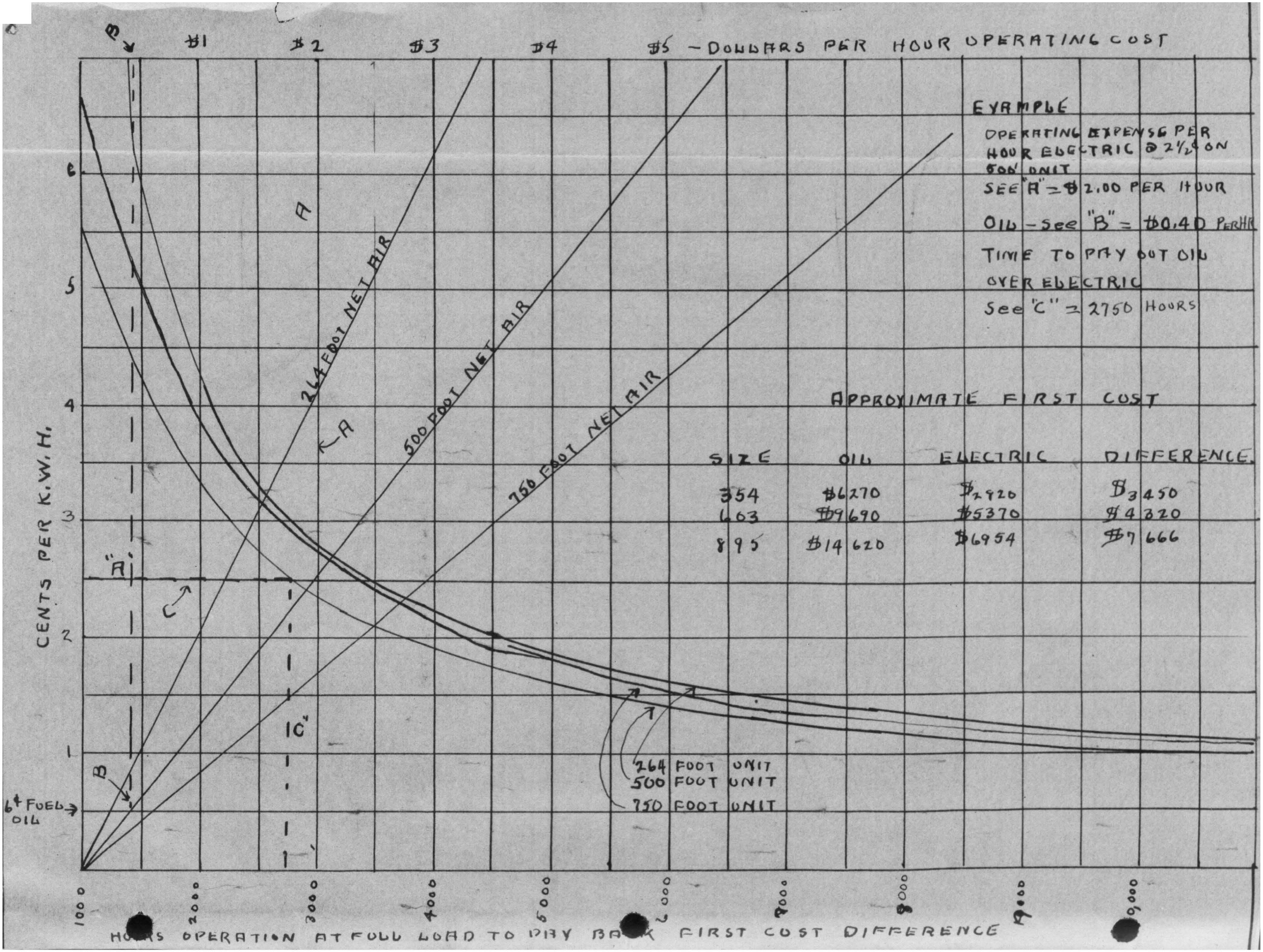
Current..............5

Steam................4

Oil..................1

The curve plotted from explanation given in preceeding sheets shows it costs more than 5 times as much to run a 100 hp electric motor than it does to run an oil engine of the same size. It also shows that it costs more than 3½ times as much to run a steam engine. The latter figure is very conservative, as the many variables in steam operation would probably raise it to four times.


CURVE FOR 50-150 HP UNITS
CURVE BASED ON 100 HP UNIT. COST ON LARGER OR SMALLER HP UNIT IS PROPORTIONAL.
DOLLARS PER 100 HP PER YEAR [8 HRS. PER DAY - 300 DAYS PR YR.
$10000
$9000
$8000
$7000
$6000
$5000
4000
$3000
$2000
$1000
$5266.00
$3652.00
$1051.00
ELECTRIC CURRENT
COAL (NOT INCLUDING BOILER ROOM LABOR)
FUEL AND LUBRICATING OIL
POWER COST COMPARISON BETWEEN ELECTRICITY - STEAM AND OIL
Neal Ham
CURRENT - CENTS PER K.W.H.
1
2
2.5
3
4
5
6
7
8
OIL - CENTS PER GALLON
7
14
21
COAL - DOLLARS PER TON
5
10
15



B
$1
$2
$3
$4
$5 - DOLLARS PER HOUR OPERATING COST
EXAMPLE
OPERATING EXPENSE PER HOUR ELECTRIC @ 2½¢ ON 500' UNIT
SEE "A" = $2.00 PER HOUR
OIL - See "B" = $0.40 PerHR
TIME TO PAY OUT OIL OVER ELECTRIC
See "C" = 2750 HOURS
A
264 FOOT NET AIR
A
500 FOOT NET AIR
750 FOOT NET AIR
APPROXIMATE FIRST COST
SIZE OIL ELECTRIC DIFFERENCE
354 $6270 $2920 $3450
603 $9690 $5370 $4320
895 $14620 $6954 $7666
CENTS PER K.W.H.
6
5
4
3
2
1
"A"
C
"C"
B
6¢ FUEL OIL
264 FOOT UNIT
500 FOOT UNIT
750 FOOT UNIT
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
HOURS OPERATION AT FULL LOAD TO PAY BACK FIRST COST DIFFERENCE

The next curve deals with a comparison between producing compressed with a motor driven air compressor or an oil engine driven air compressor. These figures only deal with operation costs only. On the blue print we have given the approximate cost of oil engine compressors and also the price of motor driven compressor.

From the curve you can read off direct the cost per hour of operationof oil engine compressors and motor driven compressors and the time in hours it will take to pay off the difference.

For example take the 500 cubic foot size oil engine compressor unit.The cost of this oil engine unit is approximately $9690.00 while the cost of a motor driven unit of the same size is $5370.00. There is a first cost difference in favor of the motor driven unit of $4320.00

However due to the low operation cost of the oil engine this difference will soon be wiped out in savings in operation cost.

If we start at 2½ cents per kw and go acorss the curve to the line of the 500 foot unit, then read up, we will see the cost of operation is about $2.00 per hour. Starting with the line of 6 cent fuel oil, we will see the oil engine costs about $0040 cents per hour. Now starting at 2½ cents per kw if we go across to the curve line of the 500 foot unit, we will see that it will take only 2750 hours of operation to pay back the first difference in cost. After that there will be a savings of $1660 per hour.

PRACTICAL PROBLEMS.

This problem is one which has been worked out for a large industrial plant in Kansas City. Their problem was whether to buy electric current from the power company or to buy oil engines and generate their own current. In all these comparisons we have taken interest, ann investment, and other fixed charges.

The engine offered in this comparison is the vertical three cylinder engine as shwon in the cuts in back of these comparisons. It is shown in figure 1, and is known as the Type PR Vertical Oil Engine.

PROJECT..................I

Bought current from the power company.

PROJECT..................II

Using fuel oil--oil engine with rated brake horse power of 170 giving a demand of 100 KW's.

PROJECT..................III

Using fuel oil--Oil engine with a rated brake horse power of 235 giving a demand of 158 KW's.

INSTALLATION COST.

ProjectI

No cost as current is bought.

PROUECT.......II

1-170 HP. Type PR Ingersoll Rand solid injection
oil engine and regular equipment...............$13,032.00
Extra for class A spares........................ 252.00
Extra for outboard bearing for direct connected exciter............................ 99.00
Extra for starting unit......................... 342.00
Extra for foundation bolts...................... 45.00

Engine total $ 13,770.00

1-General Electric or Westinghouse, AC
Generator, 240 volts, 3 phase, 60 cycles,
110 KW---132.5 KVQ.............................. 1,800.00
Extra for direct connected exciter.............. 585.00
Extra for foundation bolss...................... 15.30

TOTAL PROJECT II $16,170.30

PROJECT.......III

1-125 HP Type PR solid injection engine
and regular equipment...........................$17,887.00
Extra for class A spares........................ 25'.00
Extea for outboard bearing for direct connected exciter......................... 121.50
Extra for starting unit......................... 342.00
Extra for foundation bolts...................... 58.50

Engine total. $18,661.50

1-General Electric or Westinghouse AC Generator, 240 volts, 3 phase, 60 cycles
158 KW---197.5 KVA 2,340.00
Extra for DC Exciter............................ 891.00
Extra for foundation bolts...................... 18.90

Total cost Project III..$21,911.40

TOTAL INSTALLATION COST

	II	III
Engine and Generator	16,170.30	21,911.40
Freight to Kansas City	450.00	663.00
1-10,000 gallon tank (fuel Oil)	500.00	500.00
Pipings and fittings	200.00	200.00
Switchboard, wireing, day tank	1,000.00	1,000.00
Foundation costs	100.00	100.00
Rigging	315.00	510.00
	$18,735.00	$24,884.40
Round figures	$19,000.00	$25,000.000

OPERATION COSTS

Operatin cost is based under the worst operating condition for the oil engine. This figure is based on the engine operating all time from 7:300 to 5:30 (10 hours) for 26 days in month. This gives a total of 3,120 hours operated per year. Taking your total KWH from the power bill for year 1926 whihh was 289,180 and divide by total hours 3120 gives an average KW demand of 92.68 or 140 HP. This will give an average load of 82% on smaller engine and 60% on larger engine.

	I	II	III
Power cost as taken from yearly power bill	$6,248.55		
Fuel oil cost $\frac{140x.44x3120x.06}{7.5}$		1582.42	
Lubricating oil $\frac{140x3120x.60}{4000}$		66.00	
Fuel oil cost $\frac{140 x .45x3120x.06}{7.5}$			1617.50
Lubricating oil $\frac{140 x 3120x.60}{4000}$			66.00
	$6,248.50	$3,674.42	$4,349.50
Saving on total operating cost................................		$2,674.13	$1,899.00
		or	
Percent saving on total investment		14%	7½%

SUMMARY

In this comparison all factors, have been taken into consideration and the oil engine has been given the worst side. If a total of 110 KW would be large enough demand, this company could use the smaller engine and it would show a saving of 14% on the investment. If the large unit has to be used, it will show a saving of 7½% on the investment. However the figure would be better than this as the engine would run at above 60% load facotor a good deal of the time. Another factor to consider and which cannot be expressed in dollars and cents is that they will have a large reserve in KW capacity to take care of future expansion. I have considered using a 158 KW unit and are figuring in this estimate to consume 92.68 KW which would give them a reserve for future use or present use of 65 more KW8s. Should they increase the load up to the full capacity of 168 KW the cost of current would increase while the total operating cost of the oil engine plant would increase very little as the majority of the total operating cost is fixed charges which would remain the same whether operating at full load or partial load. The only increase in cost would be for fuel oil and lubricating oil which would be negligible. As you would increase your load, in comparison with electric cost, the percent saving would run up very rapidly and at full load would amount to approximately 18% on investment.

Practical Problem.

The units as considered in the following problem are illustrated at end of article.

The Ammonia machine knows as the XPVA is shown in figure 4. The POC-1A is shown in figure 3.

COST COMPARISON AMMONIA COMPRESSOR STEAM DRIVEN VERSUS OIL ENGINE DRIVEN COMPRESSOR.

STEAM DRIVEN---NINETY TONS CAPACITY REFREIGERATION.

Type...............XPV-A steam, Driven, duplex construction, compound air, compound steam, with piston steam valve, and automatic cut off oil governor which automatically changes the point of cut off for any change in the load.

Specifications.

- Size air cylinders   12 & 8½ x 14"
- I.H.P................ 130
- Weight.............. 23,770#
- Length............. 12' 6"
- Width............... 7' 8"
- Steam consumption per I.H.P......23.3 --duplex....27.5
- Cubic feet in foundation 535

STEAM DRIVEN--Fifty five tons.

Type................XPV-A steam driven, duplex construction compound air, compound steam, with Meyer steam valve gear.

Specifications.

- Size air cylinders.......9½ & 6-3/4 x 12"
- IHP.....................79.5
- Weight..................15,075
- Length..................10' 11"
- Width................... 6' 0"
- Steam consumption per IHP........23.9 compound
- Steam consumption duplex steam...38.5
- Cubic feet in foundation.........360

OIL ENGINE DRIVEN---Sixty Nine Tons.

Type...POC-1A

Specifications

- Engine sizes..................12 x 19"
- Compressor sizes..............9½ x 19"
- Weight........................37,450#
- Length........................21' 2¼"
- Fuel oil pounds of oil per ton refrigeration.....1413#
- Horse power...................103

OIL ENGINE DRIVEN--Ninety Nine Tons.

Type.....................POC-1A
Specifications
Engine sizes............21 x 24"
Compressor sizes........11¼ x 24"
Weight..................59,950#
Fuel oil per ton of refrigeration......14.9#

FIRST COST

XPVA--12 & 8½ x 12--Ninety tons........................$7,964.00

XPVA--9½ & 6-3/4 x 12--Fifty five tons................$5,104.00

POC-1A--17 x 19 & 9½ x19--Sixty nine tons.............$9,473.00

POC-1A--21 x 24 & 11½ x 24--Ninety nine tons........$14, 175.00

TOTAL INSTALLATION COST

	STEAM		OIL	
	90 Tons	99 Tons	55 Tons	69 Tons
Unit cost	$7964.00	14175.00	5104.00	9473.00
Freight	237.00	600.00	150.00	375.00
Fuel oil tank		200.00		
Piping and fittings	100.00	200.00	75.00	100.00
Foundation costs	300.00	555.00	210.00	545.00
Rigging	100.00	100.00	100.00	100.00
	$ 8,701.00	$15,830.00	$5,639.00	$10,593.00

FUEL COST

Ninety (90) tons --Steam driven
23.3 x 130 = 3,029#x$.0004 = $1.21 per hour
24x $1.21 = $29.078
Cost per ton refrigeration..........$0.32

Ninety nine (99) --Oil Engine Driven
$\frac{99 \times 14.4}{7.5}$ = 197 gallons per 24 hours
$0.06 x 197 = $11.82 per day fuel oil

$\frac{142 \times 24 \times .60}{2000}$ = $1.02 per day lubricating oil

$12.84 total cost per day.

Cost per ton refrigeration............$0.13

Fifty Five Tons (55)----Steam driven

25.9 x 79.5 = 2059#
2059 x .0004 = $.8236
24 x .8236 = $19.77 per day
Cost per ton refrigeration...........$0.36

Sixty Nine (69) ----Oil Engine Driven

$\frac{69 \times 14.3}{7.5}$ = 132 gallson per 24 hours

.06 x 132 = $7.92 fuel oil cost per day

$\frac{103 \times 24}{2000}$ x .60 = $ .74 lubricating oil cost per day

$8.66 total cost per day

Cost per ton refrigeration.........$0.12

TOTAL OPERATION COST BASED ON 60% LOAD FACTOR

	90 Tons	99 Tons	55 Tons	69 Tons
Fuel (60% load factor)	6367.00	2811.00	4329.00	1896.00
Interest on investment 6%	522.00	949100	338.00	636.00
Maintenance 2%	174.00	316.00	113.00	211.00
Insurance and Taxes 2%	174.00	316.00	113.00	211.00
Depreciation (15 yrs)	580.00	1055.00	376.00	706.00
	$7817.00	$5447.00	$5269.00	3660.00
Cost per ton per year	$89.00	$55.00	$96.00	$53.00

SUMMARY

All comparisons based on the 103 HP 69 ton oil engine compressor.

	90 Tons Steam	55 Tons Steam
Difference in first total installation cost favoring steam units	$1,892.00	$4,954.00
Savings effected per ton by oil engine installation	$89.00 53.00	$96.00 53.00
Savin s per ton	$36.00	$43.00
Based on 69 ton unit we will have the following saving each year	$2484.00	$2967.00

The above savings are in additon to the 6% already allowed on the investment.

Practical problem

The problem as given on the attached blue print gives very thoroughly the comparison between operation cost on motor driven air compressors and oil engine air compressors.

The problem here is to ascertain whether it would be more economical to buy current and install a direct connected synchronous motor driven air compressor together with a motor generator set for supplying DC current to other motors in plant. The air compressor installed would be similar to one shown in figure 5.

We have figured three combinations of oil enignes. In combination "A" we would consider using two units type POC-2 as shown in figure 2, and another Type PO engine to drive a generator only as shown in figure 7. In combination "B" we would consider using two POC-2 engines as shown in figure 2 to drive the air-compressors and consider a vertical oil engine as shown in figure 1 to drive the generator.

In combination "C" we have figured using a vertical engine as shown in figure 1 to drive the generator and also a similar to belt drive an air compressor as shown in figure 6.

In this comparison we did not know what the load factor was nor the price of current. I have therefore figured the cost at different load facotrs 40,50 and 60% with current at variable rates from 1-1/4 cents to 2¼ cents.

SUMMARY

By referring to this sheet we have noted the total operation cost per year of the various combinations. We have also brought the cost down to the cost per 1000 cubic feet actuall delivered which in reality is the basis for comparison.

We have also brougt the cost per KWH down to cents per KW to include energy and fixed, operation and other charges.

It develops that in this particular case, the load factor was 60% and the cost of current was 2cents per KW. Looking at the print we will note the total cost of current at this rate is $8183.00 per year. This includes operation on both air compressor and motor generator set. The total cost of the oil engine compressor as shown in combination "A" (which is the best combination, and the one we would try to sell) is $5658.00. This shows a savings of $2525.00 per year in addition to the 6% interest on the investment. This is a total of 14.5% on the investment.

Looking at the cost per 1000 cu ft we note on the compressor unit only on the oil engine that the cost is $0.0515. On the motor driven units it is $0.076. Going on down the line we will note that to equial air per 1000 cu ft at $0.0515, we would have to buy current at less than 1-1/4 cents per Kw. On our calculations the cost at 1-1/4 is $0.0564 so it would have to be a figure below this.

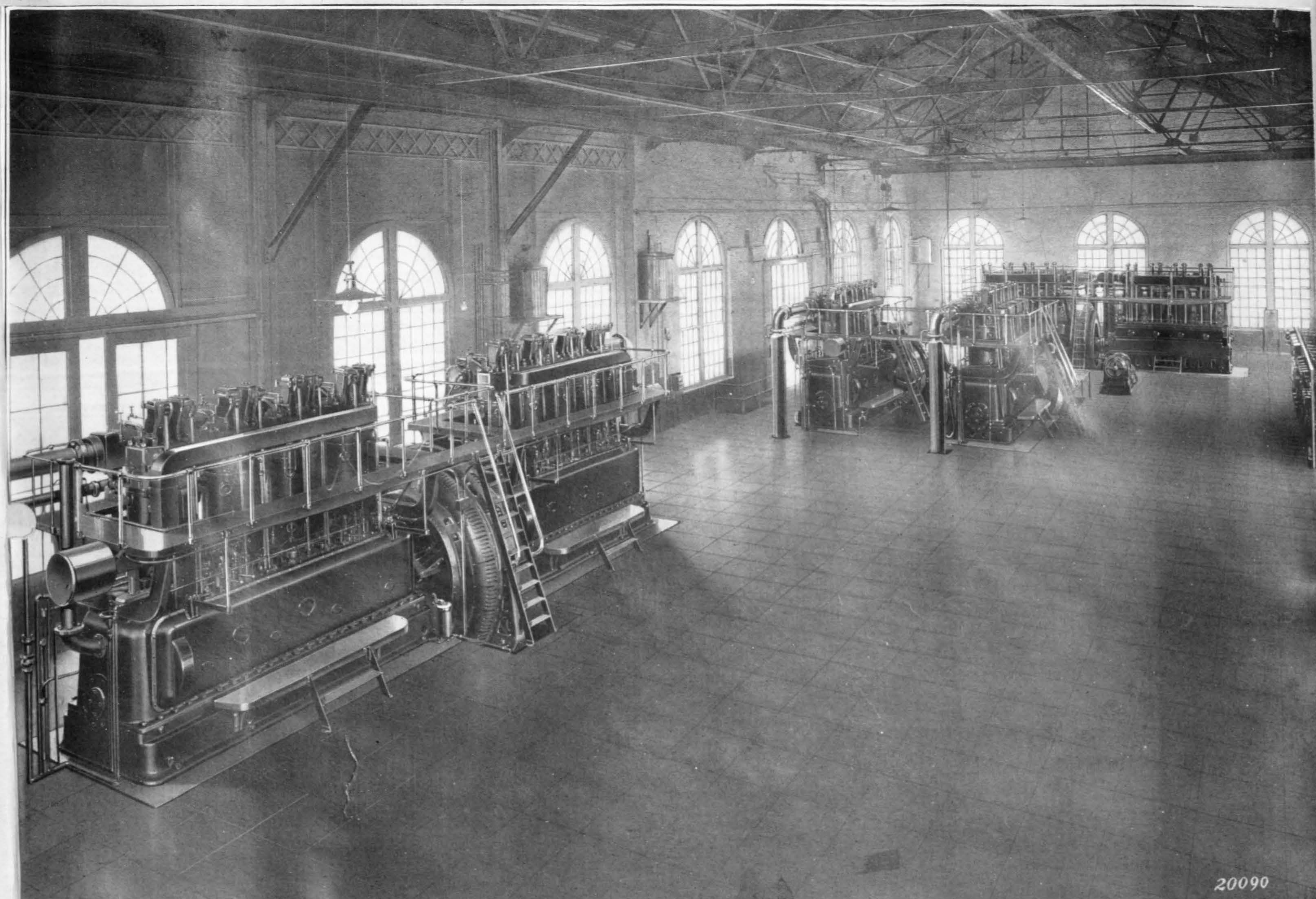


Figure 1

Type PR Engines.

Two 1000 BHP and two 500 HP Engines directed to Generators in a large industrial plant.

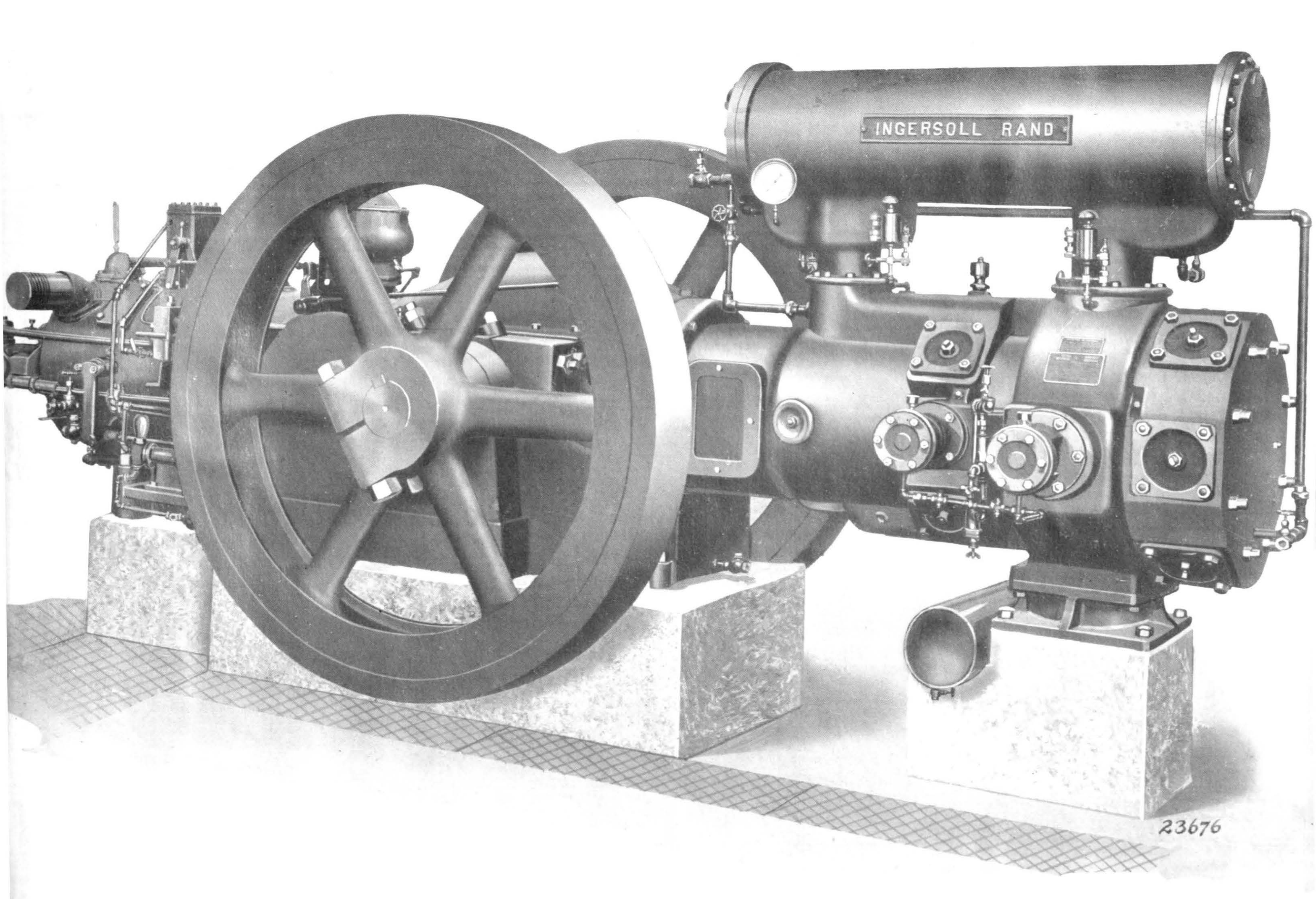


Figure 2

Type POC-2 Oil Engine Compressor.

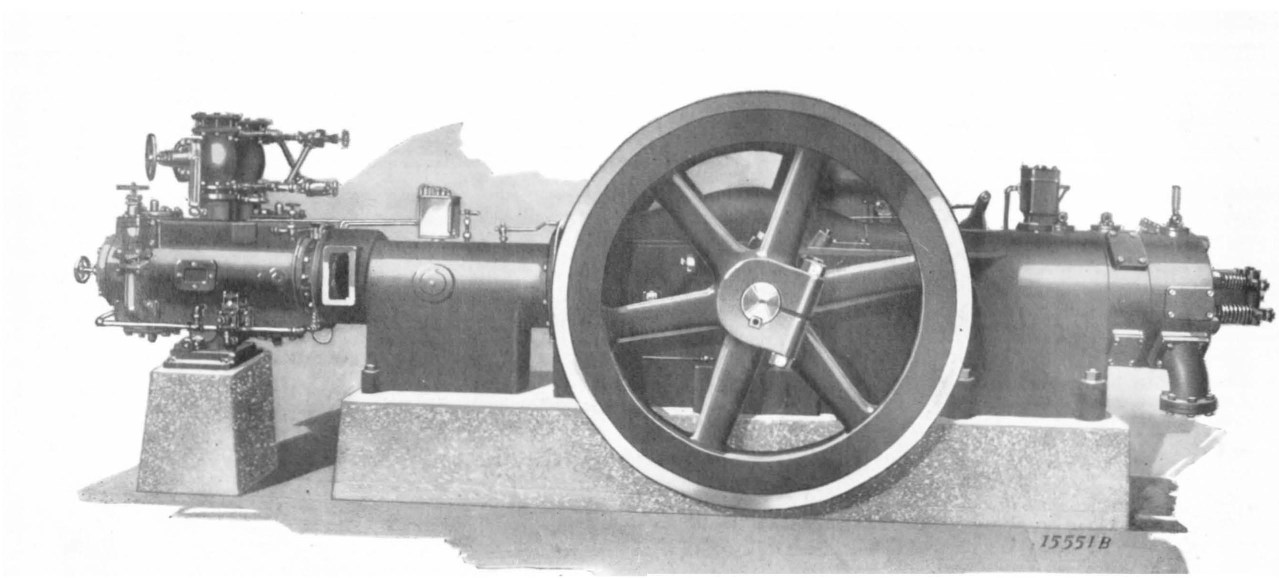


Figure 3

Type POC-1A Oil Engine direct Connected to Ammonia Compressor.

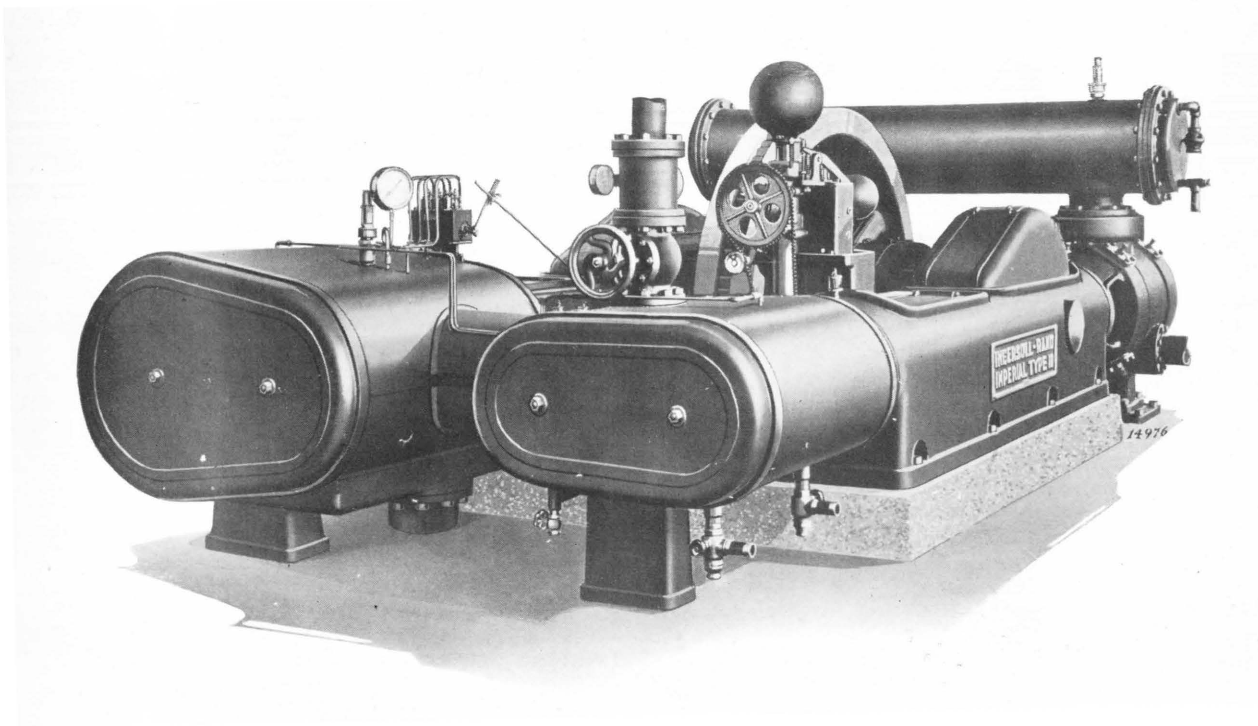


Figure 4

Type XPV-A Steam Driven Ammonia Compressor--Compound Steam and Compound Air with Automatic Cut Off Governor.

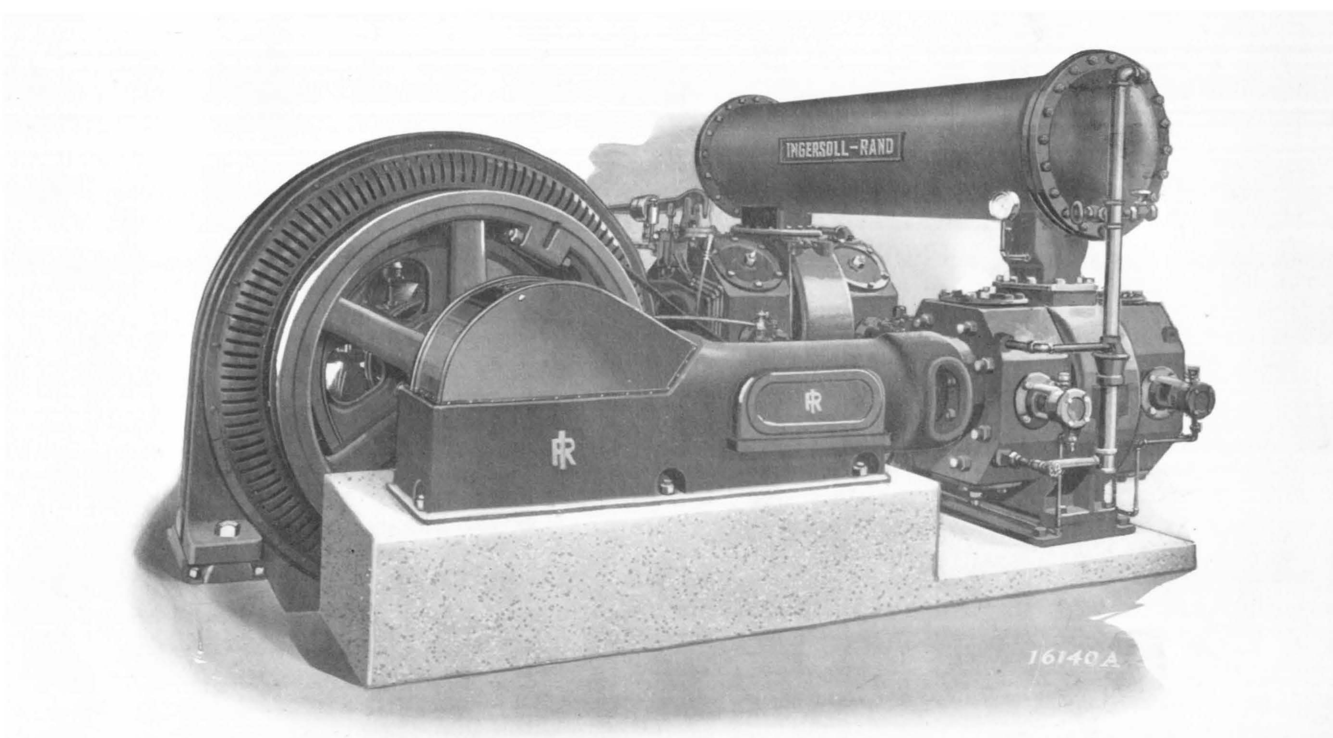


Figure 5

Direct Connected Synchronous Motor Driven Air Compressor.

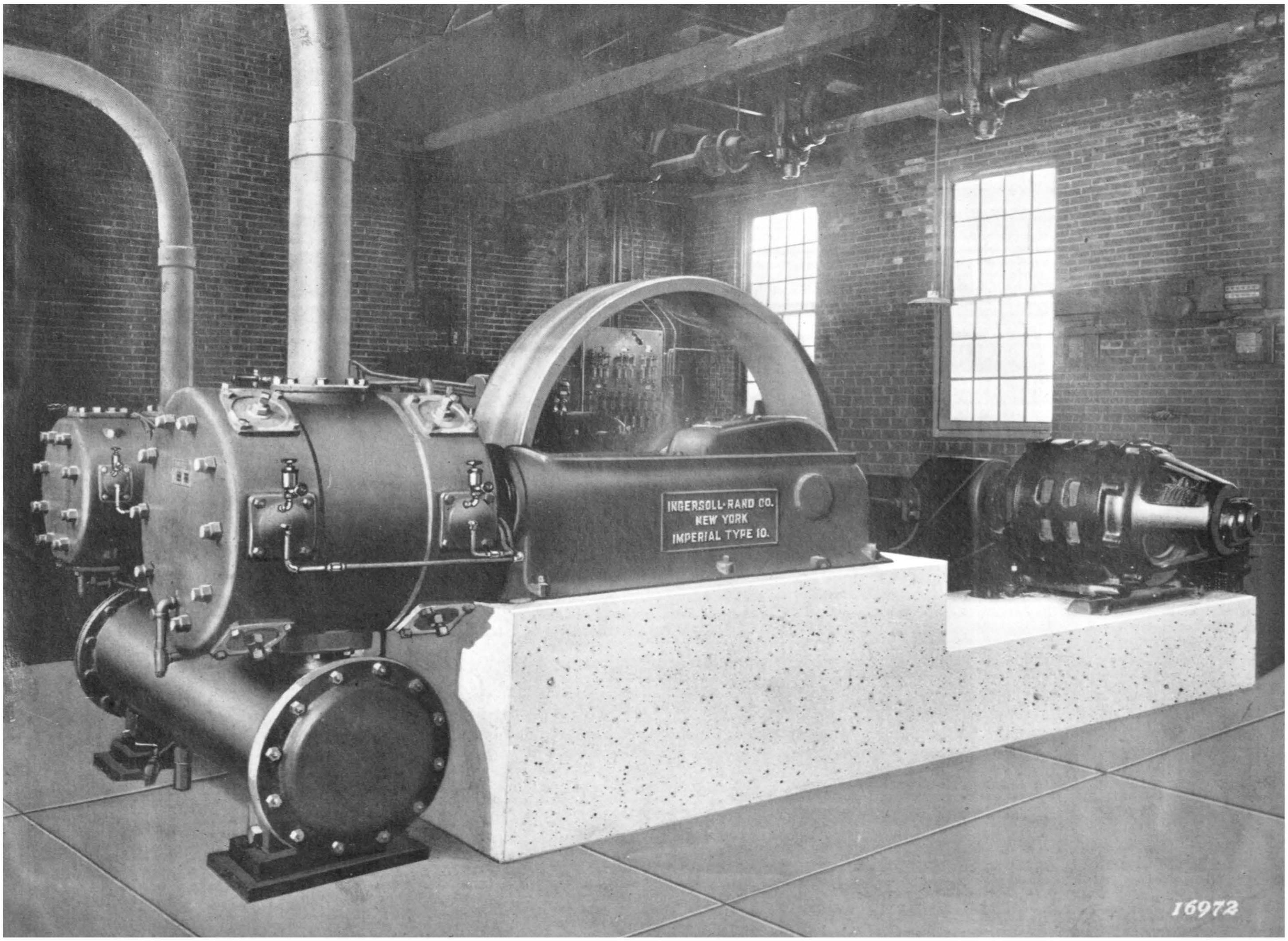


Figure 6

Type XCB-2 Air Compressor with Automatic Five Step Clearance Control.

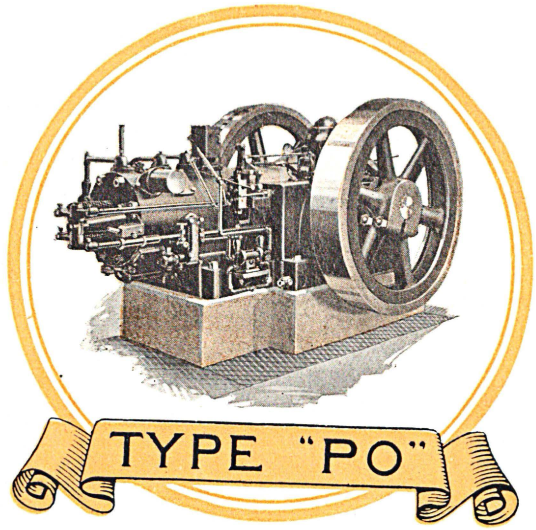


Figure 7

Type PO Horizontal Oil Engine.