exposed to the temperature [67]. The reduction in hardness with temperature and time of the materials commonly used for cylinder heads is given in Fig. 239. The values are determined after letting the engine run for 25 hours, for instance, at the required load and then dismantling the engine and cutting the parts under test (cylinder head, piston, crankcase etc.). By measuring the hardness on the faces formed by cutting, the reduction in hardness will be obtained and

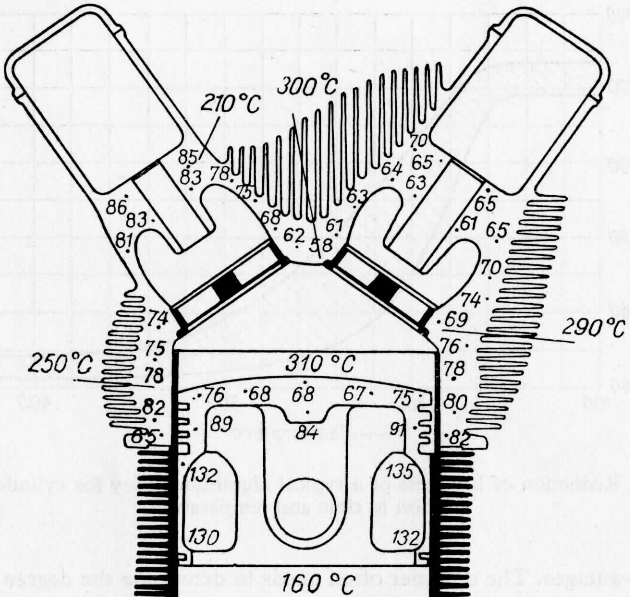


FIG. 240. Points of different Brinell hardness on the cylinder head of an aircraft engine and corresponding temperatures estimated from the drop in hardness.

the operating temperature of the points in question determined with a great degree of precision. Naturally the part must not have been subjected to the effects of heat before the beginning of the test. An example of such measuring conducted on an air-cooled aircraft engine cylinder is shown in Fig. 240.

The common means of measuring temperature of metals is by thermo-couples, which are to be preferred for their small size, precision and for the fact that they provide instantaneous temperature readings. An example of a thermo-couple suitable for measuring the temperatures of air-cooled engine cylinders and cylinder heads is shown in Fig. 241. An exact hole must be drilled at the required spot to the required depth of 1 to 1·5 mm under the surface of the cylinder or combustion chamber and the thermo-couple is



pressed into the cavity in such a way as to ensure good metal-to-metal contact with its surroundings. The exact temperature of the area can be found by measuring the current produced by the two heated metals. With closely spaced fins it has to be borne in mind that the flow of co oling air may be hampered by the leads from the thermo-couple, thus affecting the temperature of the measured area.

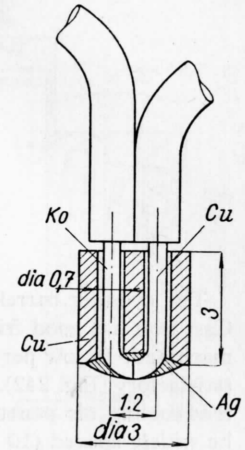


FIG. 241. Dimensions of a thermocouple normally used for measurements of cylinder temperatures.

The measuring of oil temperature is relatively simple and resistance or mercury thermometers are used. Greater problems are set by the need to measure the temperature of air, particularly of the warm outgoing stream from the engine, for the temperature is unevenly distributed over the whole section and air velocity varies. Usually one must be content with measuring the air temperature at several locations and obtaining mean temperature by a rough approximation. In order to measure the mean temperature of the whole section, a resistance wire net can be used, the value being calculated from readings of the resistance of the net. The temperature of air entering the fan and the carburettor is measured with mercury thermometers shielded from heat radiated by the warm engine parts.

Exhaust gas temperature is measured by thermo-couples, resistance thermometers or by direct observation through pyrometers.

# CHAPTER XII

# THE CYLINDER BARREL

## 1. Materials and design

The cylinder barrels of air-cooled engines are generally made of cast iron. Cast iron has good frictional properties, high resistance to wear and is easily machined. In low performance engines, fins cast integrally with the barrel are satisfactory (Fig. 242). On motor cycle engines care has to be taken to ensure that cooling air penetrates to the base of the fin and the fins must therefore be widely spaced (10 to 12 mm). The necessary cooling area is gained by a large fin diameter made possible by the fact that the cylinder stands unobstructed as a rule without the height of finning being limited by considerations of space.

On side-valve cylinders, the whole circumference of the exhaust valve seat must be well cooled. Sufficient clearance must be provided for air to pass between the valve port and the cylinder wall and the port must be extensively finned. An illustration of such a cylinder used on a motor cycle engine is given by Fig. 243. Note the shape of the countersunk valve seat and the holes in the lower part of the cylinder of this flat engine for additional lubrication. (See also Fig. 230)

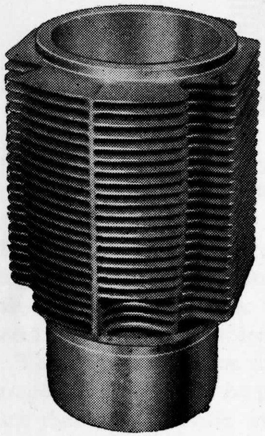

FIG. 242. Cylinder of an air-cooled compression-ignition engine with cast fins.

Automobile engines, working under higher stress, cannot make use of cast fins and therefore the fins are machined by turning from solid. In this instance sets of cutting tools combined in comb fashion turn all fins simultaneously (Fig. 244). In automobile engines the fins generally have to be intersected in order to provide room for retaining bolts and for push rod covers. Such niches are cast in the rough shape of the barrel so that no additional machining is needed after turning the fins. Fig. 245 shows (left) the casting of a Tatra compression-ignition engine cylinder barrel and (right) the same barrel with machined fins. The machining operation takes 20 minutes. Machined fins of cast cylinder barrels are usually spaced 5·5 to 3·5 mm apart with a height of 15 to



25 mm. Thickness is usually chosen as small as practicable, being about 1·5 to 1 mm at the extremity of the fins.

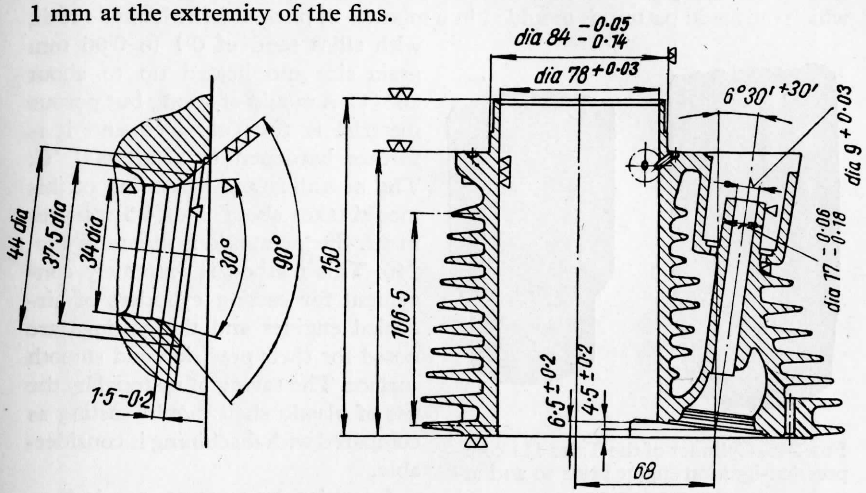


FIG. 243. Cylinder of the Soviet M-72 motor-cycle engine.

In the case of an in-line engine the choice of finning height is dictated by considerations of space. As this must be smaller, the fins are at reduced distances apart in order to achieve the same coefficient of heat transfer. Fig. 85 shows three forms of finning, all having the same base coefficient of heat transfer. If conditions permit the use of a height of fin amounting to 37·4 mm, the fins may be spaced at 12·7 mm apart, but with the height of fins of adjacent cylinders limited; proportionally reduced spacing must be used in conjunction with a reduced fin height. Cast fins are used in automobile engines up to spacings of about 6 mm.

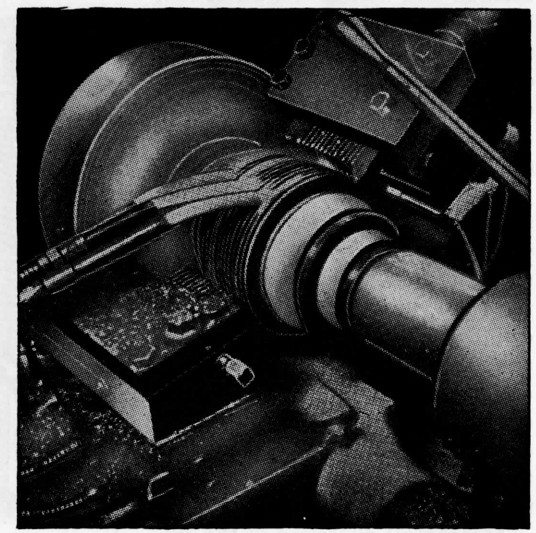

FIG. 244. Machining of fins of an air-cooled engine cylinder.

Densely spaced fins can be cast using the plastic shell moulding process. An accurate mould is produced by this method in which the metal pattern is moulded in a mixture of phenol-formaldehyde resin with silica sand of 0·1 to 0·06 mm grain size and heated up to about 200 °C. A mould of strong but porous material is thus obtained and it is further hardened at about 400 °C. The moulding and hardening of this mould takes about 3 to 4·5 minutes in all. Such a mould is shown in Fig. 246. This method is extremely convenient for casting cylinders of air-cooled engines and the castings are noted for their precision and smooth surface. The saving of material by the use of plastic shell mould casting as compared with machining is considerable.

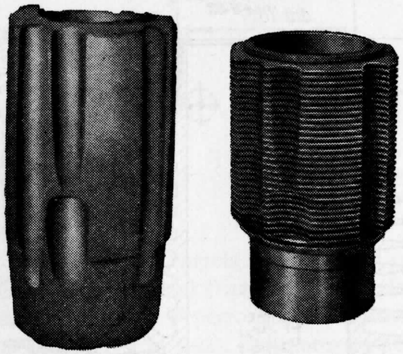

FIG. 245. Cylinder of the Tatra 111 compression-ignition engine prior to and after machining.

In order to prevent gas leakage between the piston and cylinder, the latter must be perfectly cylindrical at operating temperatures. The maximum tolerated ovality of large cylinders is 0·1 to 0·15 mm; with smaller bores this is reduced. Ovality may be caused either by imperfections of machining or by thermal and mechanical distortion.

The distribution of temperatures must be uniform over the cylinder circumference. Uneven heating can cause distortion and the cylinder in question will not provide a reliable gas seal when hot. Uniform temperature over the whole cylinder surface can be obtained by correctly designed cool air ducting. Air entering the cylinder can also reduce the temperature at that side of the cylinder wall, against which it is directed. With temperature differences on the periphery of the cylinder exceeding 40 to 50 °C, there is danger of considerable deformation through heat. The choice of suitable finning has already been discussed.

Mechanical distortion of the cylinder may be caused by uneven spacing of retaining bolts on either

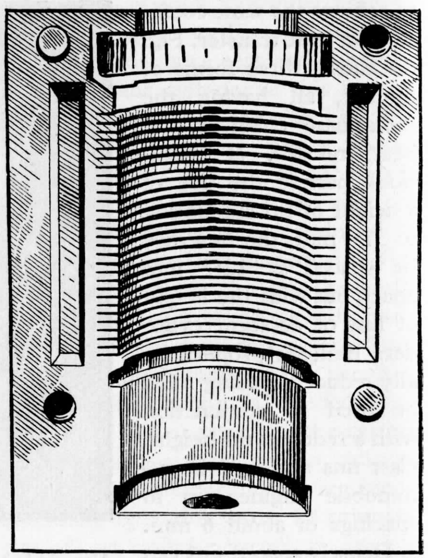

FIG. 246. Shell mould for casting cylinders.



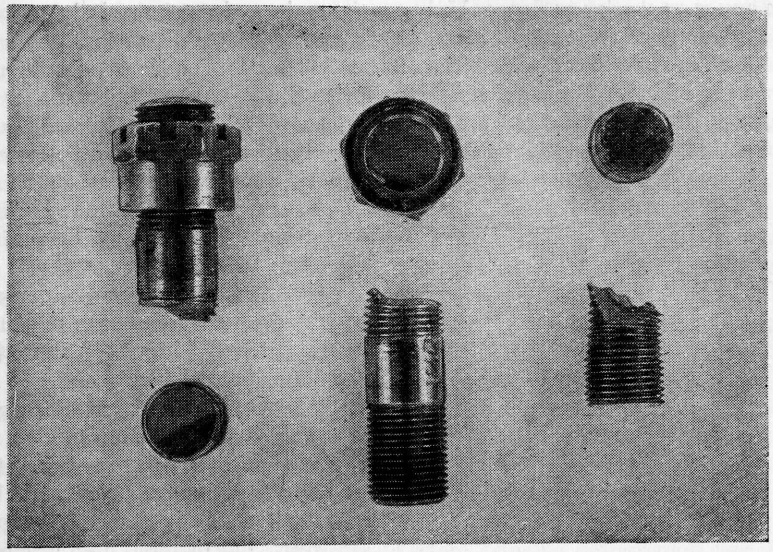

FIG. 247. An M 12/1 bolt fractured in operation. Left: fatigue fracture, right: static fracture.

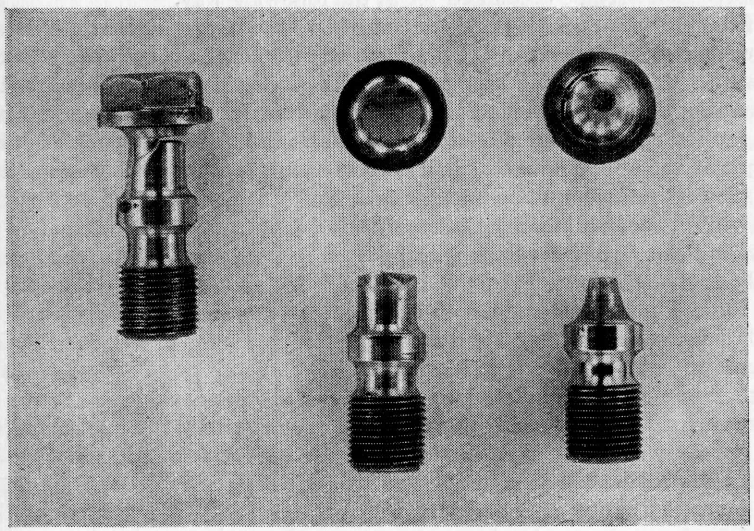

FIG. 248. Modified M 12/1 bolt satisfactory in operation. Left: fatigue fracture, right: static fracture.

the upper or the lower flange. Uniform tightening of the bolts is important and elastic bolts (of reduced diameter) reduce the risk of deformation by mechanical causes. Short and stiff bolts are unsuitable under all conditions. Breakage of bolts fastening either the lower flange to the crankcase or the upper to the cylinder head are generally caused by their rigidity, the rule being that the harder the washer, the more resilient must be the bolt used. Frequent breakages can therefore usually be cured either by fitting thinner bolts or by increasing their length.

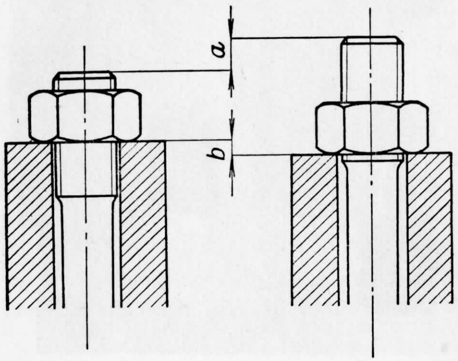


FIG. 249. By screwing up the nut the bolt is expanded by $a$, and the washer compressed by $b$.

An instance of such an increase in the tensile strength of studs is given by Figs. 247 and 248. The stud originally used had an M 12 × 1 thread and breakages were frequent. After altering its section as shown in Fig. 248, tensile strength increased by 21% as proved during fatigue tests. The material used was unchanged and weight was reduced by the modification. The studs proved reliable in service. The improvement may be accounted for in the following way.

If the nut (see Fig. 249) is tightened, the bolt increases in length by $a$ and its washer is compressed by $b$, the increase in bolt length and the reduction of washer thickness being proportional to the initial tensile load produced by tightening the nut. This stage can be plotted in the graph of Fig. 250 with the tension applied plotted on the vertical axis in kg and the increases in bolt length on the horizontal axis (right) and the compression of the washer (left). By subjecting the bolt to an initial tensile load $V$, the bolt increases in length by $a$ and the washer is compressed by $b$. By applying a force $P$ to the bolt, the force is not simply added to load $V$, but it causes a further increases in length by $c$, but the washer can expand by the same amount and its load will decrease to $Z$. The resulting force acting on the bolt is then $P + Z$.

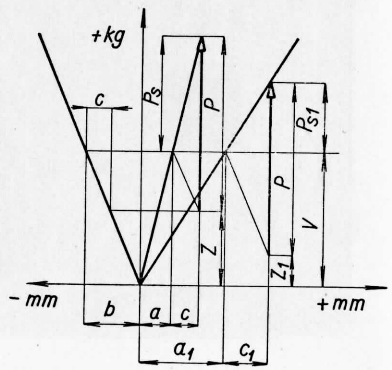


FIG. 250. The function of elastic bolts.

By reducing the bolt diameter, length will increase to $a$ for an equal load $V$. As there is no change in the washer, its compression will again equal $b$. By applying a force $P$ to the bolt as before,



the increase in length of the bolt will be $c_1$ and washer tension will be reduced to $Z_1$. The resultant force within the bolt will be $Z_1 + P$ — i.e. less than in the first instance.

The alternating load of the bolt will fluctuate within the range of $P_s$ in the first case and only of $P_{s1}$ in the second. The stress of the bolt will therefore be reduced at the expense of the washer. The initial load of the washer $Z$ must however always be a positive value, otherwise the flange would be lifted off the crankcase.

This example serves to prove that the use of short and stiff bolts is wrong in principle. The bolts should be long and reduced in diameter (resilient) and the washer should be stiff.

With a flange fit of cylinders to the crankcase (such as is the case with motor cycle engines), the flange must have sufficient rigidity in order to prevent distortion of the cylinder wall owing to the stress applied by the retaining bolts. Clear traces of deformation are shown by mirror polished areas of cylinder walls in the vicinity of the bolts. The base flange of aluminium cylinder barrels must be particularly thick and rigid.

Even in designs in which the cylinder barrel is compressed between the cylinder head and crankcase, its wall thickness near the upper and lower seatings must be increased in order to avoid possible deformation (see Fig. 260/II). A thin wall in the middle section makes for light weight and increases the cooling air flow area between the fins.

The spigot aligning the respective head and cylinder centres must not be too close a fit in order to prevent the transfer of distortion from the cylinder barrel to the head. A number of bolts or studs exceeding 4 is beneficial but it poses a problem in head design if the bolts are to avoid the spaces needed for ports, plug and sealing flanges.

From the point of view of cooling, light alloy cylinder barrels are highly desirable. The heat conductivity of aluminium is nearly three times that of cast iron. Aluminium is also lighter than cast iron and easy to cast and machine. The high coefficient of thermal expansion of aluminium is beneficial, for aluminium pistons may be fitted with a very small clearance which does not increase with the warming up of the engine. This advantage is put to good use in chronium plated bores. The thin layer of chrome on the inner aluminium surface impairs neither cylinder expansion nor heat transfer.

Other conditions being unchanged, the change from cast iron to aluminium as a constructional material for cylinder barrels, reduces cylinder temperature by about 20 °C. Owing to this improvement in cooling, the compression ratio may be raised and thermal efficiency increased [40] [37].

It is interesting to note that in the quantity of heat removed, there is hardly any difference between an aluminium and cast iron cylinder. Heat transfer, it will be remembered, is dependent on outer surface area, which is not affected by a change of material. But owing to improved heat conductivity, the temperature difference in the cylinder wall is reduced and the temperature of the cylinder inner surface is also reduced. The very favourable heat conductivity of aluminium aids tangential heat flow and the distribution of temperature over the cylinder circumference is more uniform. Chromium plated aluminium cylinders have brought about a great improvement in air-cooled engines.

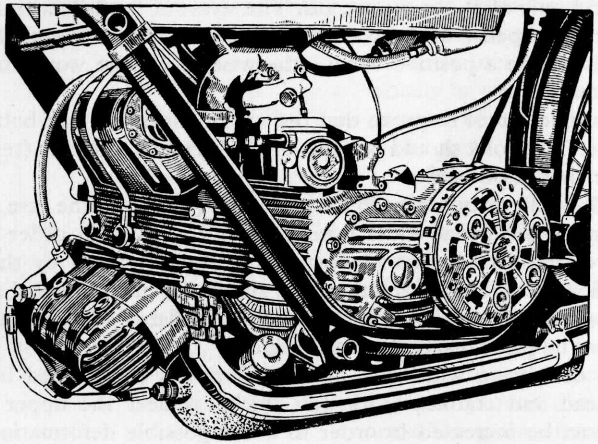

FIG. 251. The AJS motor-cycle engine with longitudinal finning of cylinders. Note the interrupted finning of the cylinder head in the region of the exhaust valve.

The Al-Fin process has the advantage of making use of the desirable properties of both aluminium and cast iron. The bonding of aluminium with a cast-in iron or steel liner is so complete as not to hinder the transfer of heat. The good frictional properties of cast iron are used in conjunction with the good heat conductivity of aluminium fins.

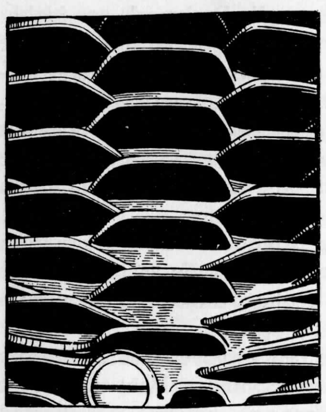

FIG. 252. Intermittent finning of the cylinder of the Triumph motor-cycle engine.

When pressed-in cylinder liners are used for aluminium cylinders, the interference for pressing in must be chosen correctly in order to prevent the liner from working loose in a heated cylinder. As soon as the insert is freed inside the cylinder when heated, the air space thus created forms an obstacle to heat transfer and local overheating of the liner may ensue. This problem is not as acute in small bore cylinders as it is with larger bores. Wall thickness of the liner is usually about 1·5 to 2 mm. Thicker liners must be used for two-stroke engines in order to prevent inward bulging of the liner at the



partition between the ports. A high nickel content alloy is sometimes used for its high coefficient of thermal expansion. The liner does not lose its initial load imparted to it by pressing in when the cylinder is heated and retains close contact. The higher coefficient of expansion of the liner has the further advantage of making possible a smaller piston clearance.

Cylinder finning must be such as to promote unhindered cooling air flow. On aircraft and automobile engines, only fins normal to the cylinder axis are used. The direction of the fins of motor cycle engines is sometimes modified to suit the direction of air flow. On very inclined cylinders longitudinal fins are therefore used, as shown in Fig. 251. The intermittent finning of this cylinder head should be noted in view of the already stated fact that such an arrangement improves the conditions of cooling. For the same reason intermittent finning is also used for cylinders, the two stroke TWN B 125 (Fig. 252) being an example on which the alternating intermittent fin layout is visible.

The striving for thinner fins has led designers to consider cast-in sheet metal fins. The production of such designs for automobile engines meets with difficulty in that the apertures for studs and push rod tunnels must be moulded in the fins before casting. The efficient bonding of sheet steel fins with the cast iron cylinder is of utmost importance if transfer of heat is not to be impaired. For production (moulding) the use of two semicircular fins is convenient, the amount of waste being reduced. Experiments so far conducted offer hope for possible future use of this technique.

## 2. Aircraft engine cylinders

The good cooling of cylinders is of prime importance in large aircraft engines and for this reason, only machined cylinders with dense finning are used. Fin thickness at the top is generally 0·75 to 0·5 mm. As the cylinder barrel transmits the load from the cylinder head to the crankcase, steel is used exclusively, making possible machining of thinner fins than would be the case if cast iron were used. An example of an aircraft engine cylinder is shown in Fig. 209. The studs are divided into four clusters for better accessibility. On cylinders screwed onto their heads the bolt holes are drilled and flanges relieved after screwing.

The amount of waste is naturally high when cylinders are turned from rough forgings, frequently as much as 90% of the material being removed by machining. For the production of the BMW 801 aircraft engine cylinder a new technique was

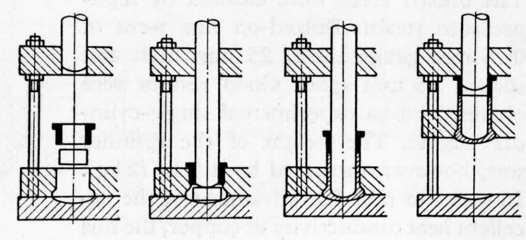

FIG. 253. Extrusion of a cylinder liner from a cylindrical blank.

evolved, resulting in a large saving in material. [10] Open hearth steel 1252 containing 1·4% $C_r$, 0·8% Mn, 0·45% C was used; satisfactory results were also obtained by the use of low alloy steels.

The liner was extruded from circular blanks of 172 mm dia by 62 mm. After uniform heating by induction the blanks were inserted into a special tool and extruded in a sequence of operations shown diagrammatically in Fig. 253. A disc of 50 mm dia was cut out of the heated pot bottom and the resulting flange was widened to a cylindrical shape. (Fig. 254.)

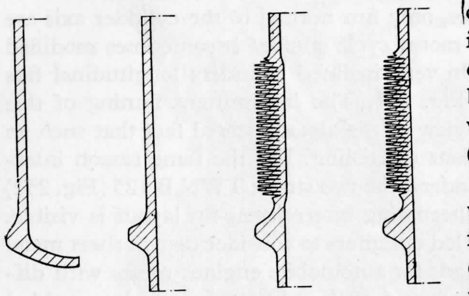

FIG. 254. Production operations of rolled fins on the cylinder of the BMW 801 aircraft engine.

Of great interest is the process whereby the fins were given their final shape by rolling. The sequence of production of the liner is shown in Fig. 254. The heated liner rotated on a core and 33 discs were pressed into it at a pressure of approximately 20 tons. The liner material was thus forced to "flow" to a height of 19 mm, forming fins of 0·5 mm thickness at the top and 0.9 mm at the base and spaced 3·6 mm apart. The lay of metal fibres in the flange and fins thus obtained is ideal. The only remaining machining operations consisted of cylinder boring, flange machining and of machining the threaded section of the cylinder by which it is attached to the cylinder head.

Experiments with sheet metal fins brazed to a steel cylinder barrel did not meet with such success as it proved impossible to maintain even spacing between the fins. Better results were obtained by turning a spiral on the cylinder circumference and by brazing a spiral of copper sheet to this. The brazed areas were cleaned by high-pressure steam. Brazed-on fins were of 0·75 mm gauge sheet, 25 mm high and spaced 2·5 mm apart. Good results were obtained on an experimental single-cylinder engine. The weight of the cylinder was, however, increased by 4·4 lb (2 kg). In order to take full advantage of the excellent heat conductivity of copper, the fins would have to be paper-thin — a requirement which cannot be met in production.

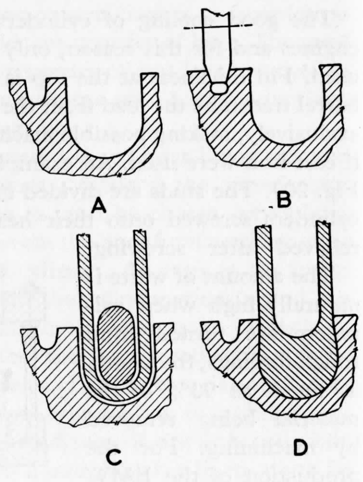


FIG. 255. Connecting U-shaped sheet metal fins to a steel cylinder.



For this reason the use of brazed-on aluminium fins which proved equally efficient for cooling was investigated, but so far no reliable method of brazing the aluminium fins has been developed.

Better results were obtained by mechanical means of attaching the fins to the cylinder barrel. [11]. The turning of grooves for separate thin sheet metal fins was, however, difficult and the tool used wore rapidly; to overcome this a wider groove, housing two fins, was then turned. A helical 3·9 mm wide groove was turned on the cylinder circumference as shown in Fig. 255. In between the grooves a slot was turned and by rolling out its edges as shown in Fig. 255 B, the fin groove walls were sloped. From aluminium 0·6 mm gauge strip a helical U shaped double fin was produced on a special machine, wound into the groove and fixed into position by aluminium wire (Fig. 255 C). The last operation consisted of rolling down this wire and thus ensuring a perfect joint between the aluminium and groove walls. With no weight increase, the cooling area of the fin was thus increased by 80%.

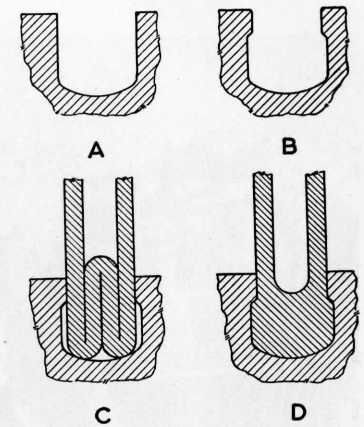


FIG. 256. Connecting W-shaped sheet metal fins to a steel cylinder.

An improved method illustrated in Fig. 256 was adopted after some experience with such fins. This makes use of circular grooves (as distinct from helical), which make for easier and quicker machining. By moving the forming tool to both sides, the base of the channel is widened (Fig. 256 B). Semi-circular fins of W section are then inserted into the channels (Fig. 256 C).

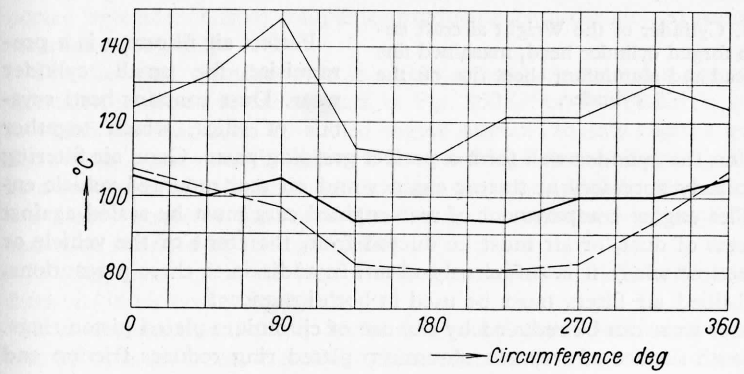


FIG. 257. Temperature of the cylinder surface circumference at the fin base.
Upper full line – steel fins, lower full line – aluminium fins, dashed line – copper fins.

The last operation consists of rolling down the aluminium and thoroughly filling the groove, the final stage being shown in Fig. 256 D. This process has the following advantages:

1. there is no need to use aluminium wire;
2. thin sheet fins must be reinforced in order to prevent damage during handling. The dividing slit between two adjacent semi-circular fins is bent at 90° with the ends deflected so as to contact the adjacent fin and act as a reinforcement of the finning;
3. machining of grooves is speedier;
4. individual damaged fins can be replaced.

The results of tests with such fins are given in Fig. 257. Temperature distribution over the cylinder circumference is very even and temperature is lower than with steel fins. The comparison was made at equal power outputs and an equal pressure head. Such finning proved most satisfactory in actual service. Fig. 258 shows a cylinder with forged and machined head and a cylinder with sheet metal fins.

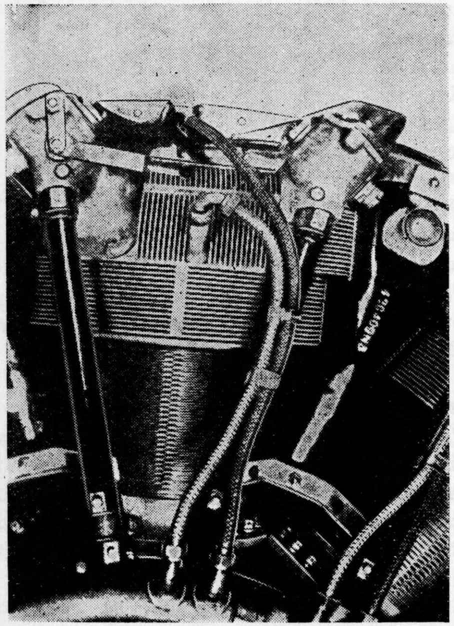

FIG. 258. Cylinder of the Wright aircraft engine with forged cylinder head, machined fins on the head and aluminium sheet fins on the cylinder.

### 3. Cylinder wear

Perfect air filtration is a prerequisite for small cylinder wear. Dust contains hard crystals of silica, which together with oil on the cylinder wall form a perfect grinding paste. Good air filtering is particularly necessary in tractor engines and on rear mounted vehicle engines. The engine compartment of rear-engined cars must be sealed against the ingress of dust, or air must be ducted from the front of the vehicle or from a source where it is sufficiently clean. In addition to these precautions, good oil-filled air filters must be used in both instances.

Cylinder wear can be reduced by the use of chromium plated piston rings. The smooth surface of a run-in chromium plated ring reduces friction and cylinder surface wear.

The first compression ring has the greatest effect on cylinder wear reduction and for this reason a chromium plated ring is generally fitted only in this position.



Cylinder wear is not only the result of mechanical abrasion but its major cause is the corrosive effect of the products of combustion. With a cylinder temperature below approx. 65 °C exhaust gases condense on the cylinder walls, corroding them and increasing wear. Most rapid wear occurs before the cylinder walls warm up after starting from cold. The influence of cylinder wall temperature on the rate of wear is shown in Fig. 259 [66]. At temperatures below 65 °C, the rate of wear increases rapidly and it is therefore important for the engine to operate below this temperature only for the shortest possible time.

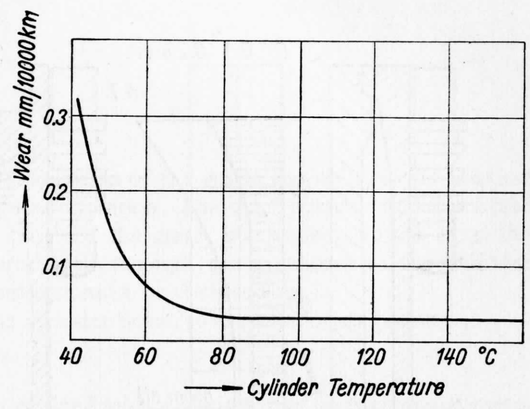


FIG. 259. Influence of cylinder wall temperature upon wear. Note the rapid increase of wear at temperatures below 65 °C.

A smaller mass is concentrated around the cylinder of an air-cooled engine than in a water-cooled engine. The air-cooled cylinder therefore reaches its operating temperature sooner. The warming-up period was discussed in the chapter on cooling control. The temperature of an air-cooled cylinder does not drop below the critical boundary of 65 °C even at idling speed. All these considerations result in a rate of wear which amounts to one third to one half of the wear shown by a water-cooled engine — an observation which is supported by evidence from companies producing both the air and water-cooled variations. [31], [52].

The fact that cylinder wear is chiefly caused by corrosion through condensation is shown in the diagram in Fig. 260 (after Dr. Seifert); according to which the wear in an air-cooled engine amounts to only about a quarter of the wear in water-cooled engines. The use of high duty (detergent) oils results in a reduction of cylinder wear in water-cooled engines by almost one half, the main reason of this reduction being the increased protection against corrosion afforded by detergent oils.

No improvement in the rate of cylinder wear resulted from the use of high duty oils in air-cooled engines.

It is obvious that the cylinder surface must be well lubricated in order to restrict cylinder wear. Plentiful cylinder lubrication is preferred today with surplus oil being removed by the oil-control ring. Good oil-control rings with high specific pressure and a narrow sealing surface in conjunction with large holes for the return of oil below the ring ensure low oil consumption together with efficient lubrication of the cylinder wall.

In horizontal engines a separate jet of oil must be directed against the upper cylinder region of the right-hand bank of cylinders. With oil cooling of the piston crown employed, the cylinder wall is generally well lubricated by oil dripping off the piston.

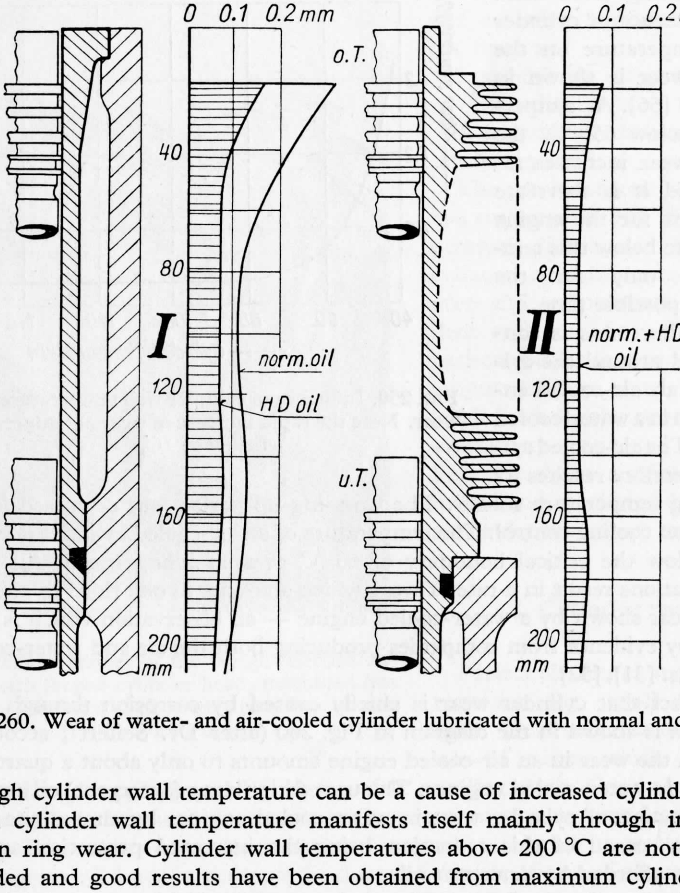


FIG. 260. Wear of water- and air-cooled cylinder lubricated with normal and HD oil.

High cylinder wall temperature can be a cause of increased cylinder wear. High cylinder wall temperature manifests itself mainly through increased piston ring wear. Cylinder wall temperatures above 200 °C are not recommended and good results have been obtained from maximum cylinder wall temperatures of 180 °C. Higher temperatures are, however, permissible with high grade oils and high quality materials used for the manufacture of cylinders.