THE HISTORY OF COMPONENTS

This section of the journal deals with one of the metal components used in the automotive industry, recording the changes in its design. At the same time, the many ways in which the techniques and materials employed in its manufacture have developed will be described.
This approach helps to emphasize the vital role played by metal component manufacturers in developing the basic materials and working out production processes.
The article in this issue deals with the piston.

The Piston

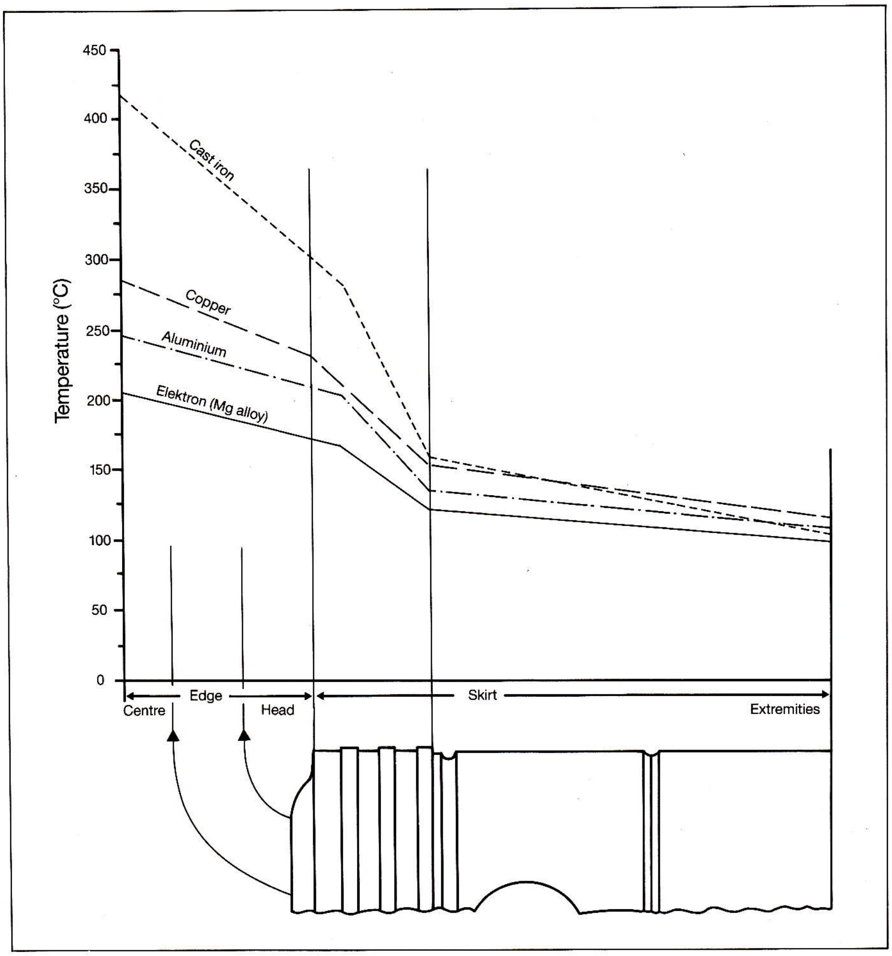
Giovanni Riccio

Abstract
*The piston, due to its functions of primary importance, is one of the most refined components of the internal combustion engine.
This article, following the evolution of the piston up to the present day, focuses principally on the new materials currently used and innovations in processing techniques.*

Riassunto
Il pistone
Il pistone, per le sue funzioni di primaria importanza, è uno degli organi più delicati del motore a combustione interna.
L'articolo, ripercorrendo l'evoluzione del pistone nel corso degli anni, prende in esame i nuovi materiali utilizzati e le principali innovazioni intervenute nelle tecnologie di fabbricazione.

The piston is the component that, more than any other, can be considered the heart of the internal combustion engine. Certainly it is the most refined component, which receives special consideration, both at the design stage and in the stages of manufacture and testing.
Leaving aside the cases of slow engines and diesel engines of medium revs, we will concern ourselves predominantly with pistons for high-speed engines (over 1000 rpm), both petrol and diesel.
The duties of the piston are essentially three:
- the first duty is that of transmitting to the crankshaft, via the connecting rod, the thrust received from the combustion gases; this is connected with the mechanical strength of the part and is one of the major obligations on the designer in choosing the thickness and the material.
- the second duty is that of ensuring gas-tightness, to allow maximum utilisation of the energy generated in the action of combustion, and avoiding oil being drawn through from the crankcase and burnt, with well-known consequences.
- the third duty is that of transmitting to the cylinder the heat of the combustion gases, promoting retention of the

Fig. 1 - Course of temperature in pistons for different materials (measured in a study of water-cooled engines).



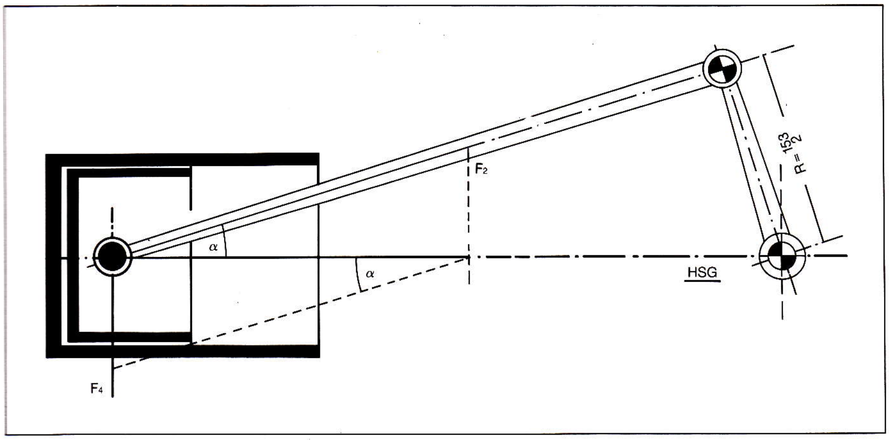


Fig. 2 - The inclination of the connecting rod gives rise to a component of the motive power directed normally against the cylinder wall.

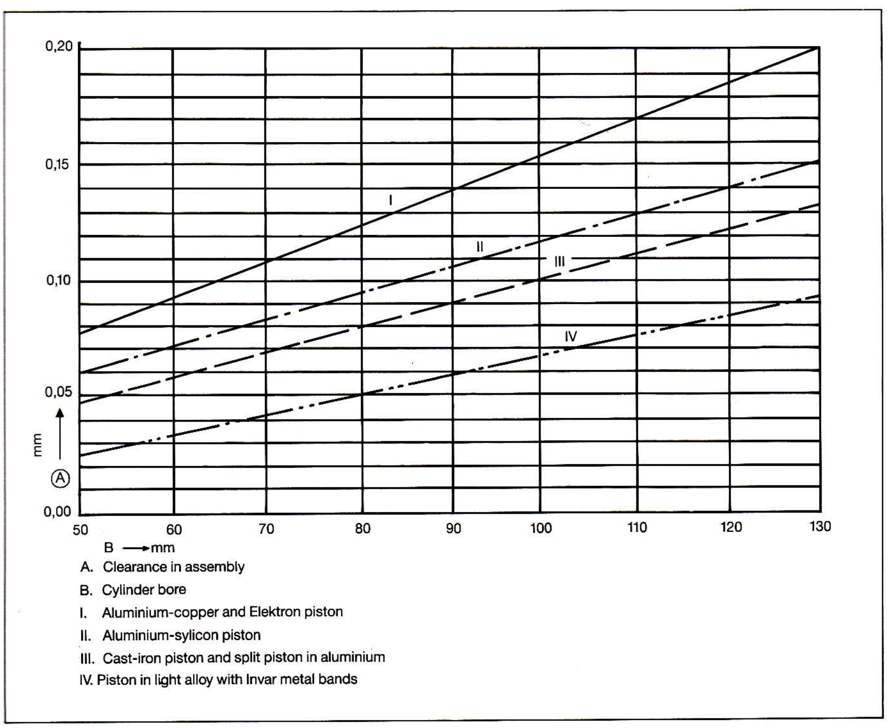


Fig. 3 - Piston-assembly clearance for different materials and cylinder bores.

mechanical characteristics of the materials and reducing the danger of seizure of the piston rings, and groove wear (Fig. 1).
The piston comprises a head, which directly withstands the thrust of the gases, and skirt, which serves as a sliding guide for the small end of the con-rod and contains the lateral thrust of it (Fig. 2).

Articulation between piston and con-rod is provided by a pivot or gudgeon pin, located by two opposite studs. The piston rings used in the grooves machined in the outer wall of the piston, have the duty of ensuring better gas-tightness and impeding the passage of oil from the crankcase to the combustion chamber.

The study of rational heat dissipation has made it clear that some of the snags encountered in practice were not due chiefly to the quality of the materials employed, but to incorrect proportioning, especially in the piston-ring zone, which is one of the most severely stressed from both the mechanical and the thermal points of view.
The piston head can be flat, spherical or conical, or concave, depending both on the compression ratio of the engine and on the most expedient shape assigned to the combustion chamber. This applies in particular to diesel engines, in which pistons often show recesses and grooves to facilitate, by means of swirling motions, the mixing of the fuel with the combustion air.
The thickness of the piston generally increases towards the head, to facilitate assimilation of the heat, and to have a temperature gradient as constant as possible. It is not easy to stabilise in a precise way the clearance existing between the piston and the cylinder in a balance between the head and the skirt (Fig. 3). For this it is necessary to design pistons with the head and skirt cylindrical or conical. In every case we must avoid the result of a piston too tapered in the cylinder, while it must have a certain adaptability to heat, so as to maintain its clearance. To ensure that in operation the piston has a shape as circular as possible, it is machined to have a certain degree of ovality when cold, the extent of which depends on the material used and on the effective heat conditions in the cylinder (type of cooling).
To limit the expansion of the skirt, pistons are made with inserts of material having a low coefficient of thermal expansion, with an expedient shape or with other design tricks.
When motoring first began, the material of which pistons were usually made, for a long time remained cast iron (Fig. 4). In 1911 Hispano-Suiza introduced pistons in aluminium, gaining a noteworthy

Fig. 4 - Cast-iron piston of the '20s.

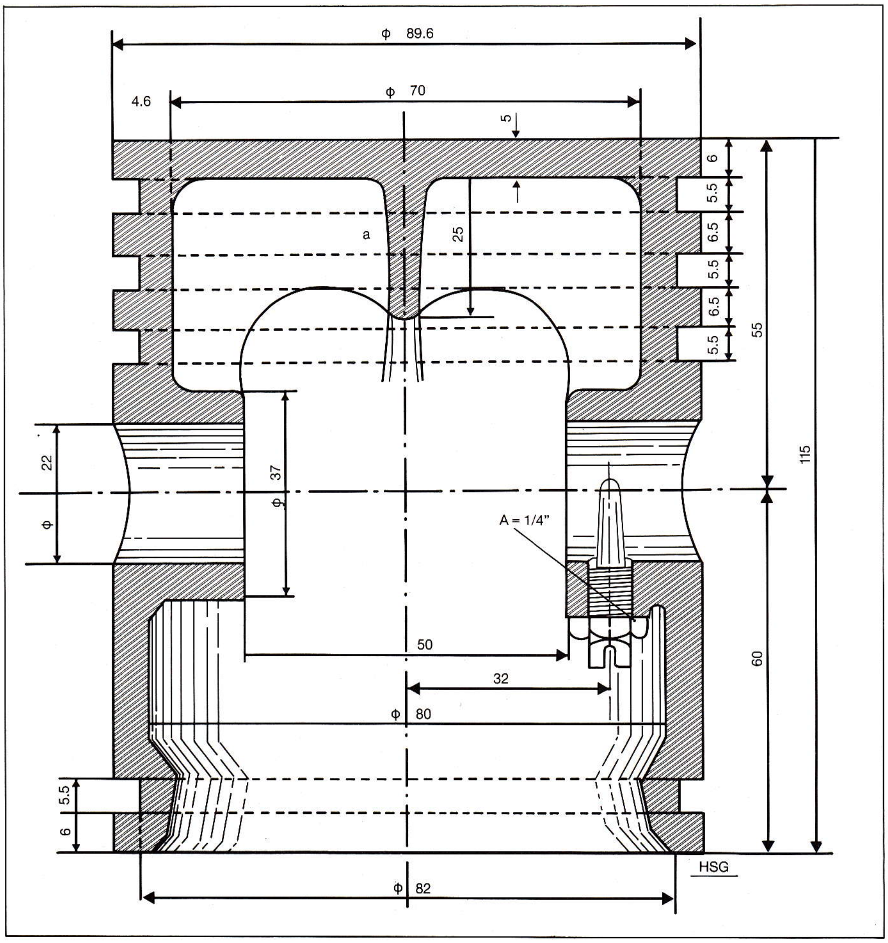
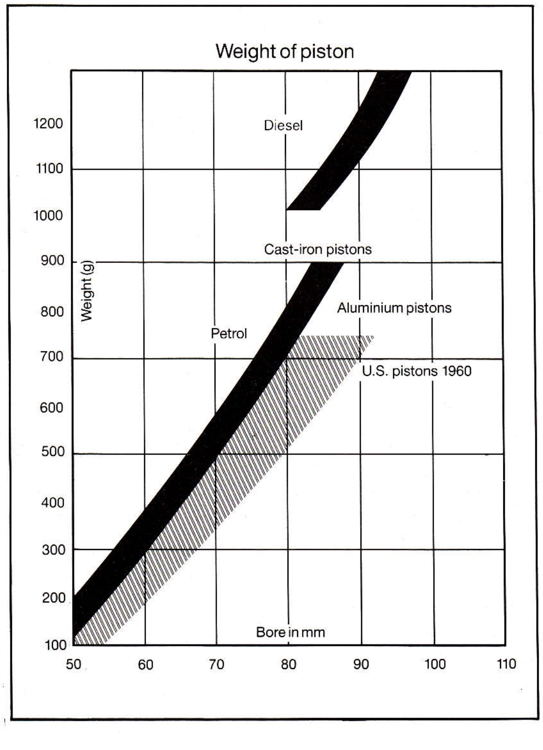


Fig. 5 - Weights of pistons as a function of the material and the type of application.



The table gives the weight limits for different production pistons as a function of the material from which they are made, and of the type of application. As can be seen, pistons for diesel engines are, for the same diameter, much heavier than those for petrol engines.

advantage in lightness. Nevertheless, the higher thermal expansion of aluminium (three times as great as that of cast iron), and the consequent danger of seizure, induced almost all the engine builders to persevere with cast-iron pistons for a further decade, keeping down the weight by reducing thicknesses (Fig. 5).

At the start of 1920, thanks to the new light alloys and to improved melting and working techniques (Fig. 6), the aluminium piston began to replace the cast-iron one, though in the '30s, in the U.S.A., came a return to the latter, for reasons part technical, part economic (Table 1).

Fig. 6 - Casting scheme for pistons with horizontal and vertical axes (Mondial Piston).

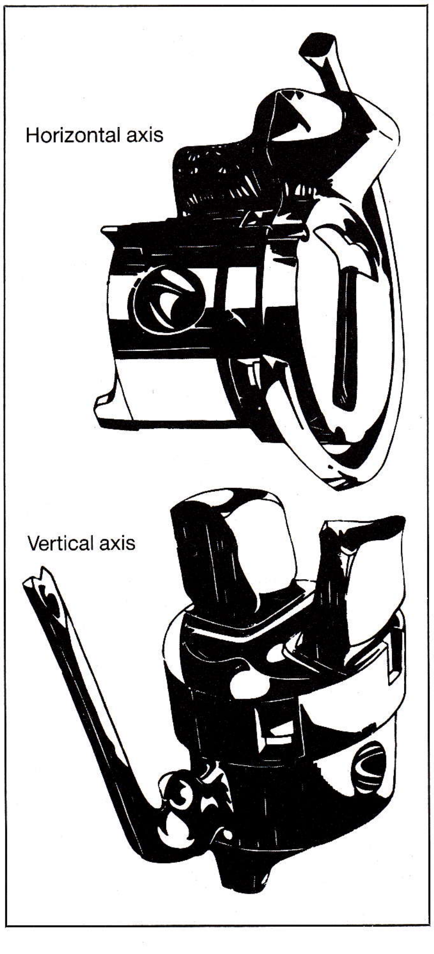
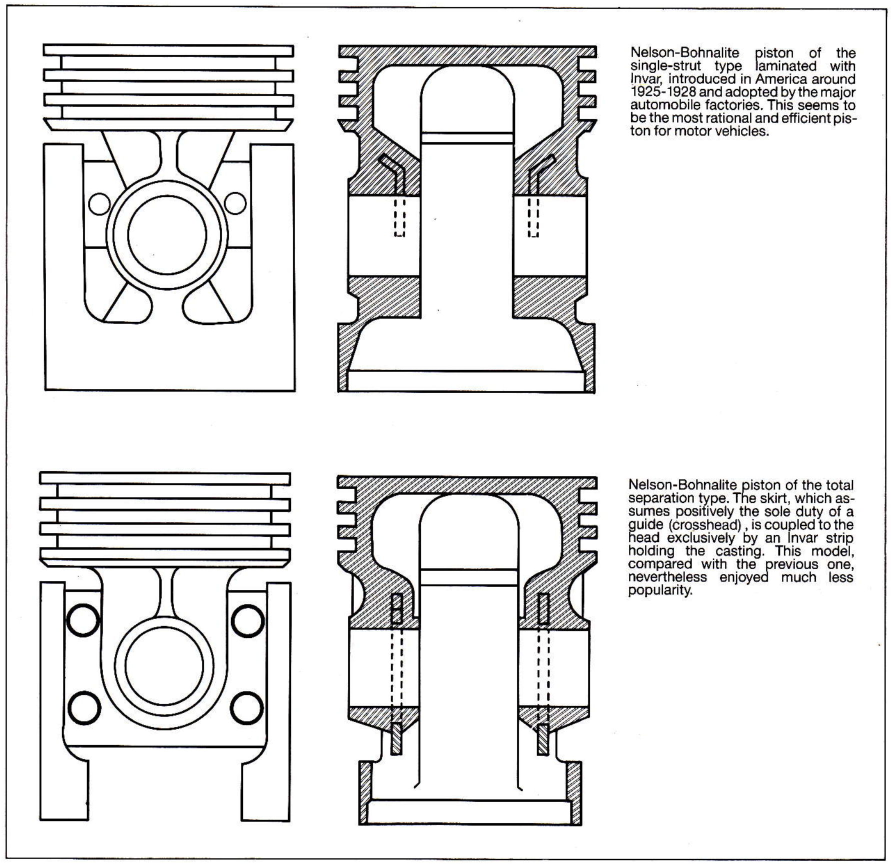


Table 1 - Pistons of American cars of the '30s

Engine	Ø (mm)	Material	Overall length (mm)	Gudgeon-pin Ø and distance from G-pin to crown	Weight (g)	Piston rings	
						Above gudgeon pin	Below gudgeon pin
Cadillac	79.5	Aluminium			582		
Hupmobile	76.2	Cast-iron					
Lycoming	73	Aluminium	89	22.2Ø; 49		4	
»	82.5	»	96	22.2Ø; 59	595	3	
Cadillac	84.9	Cast-iron	85	19 Ø; 38	980	2	1
La Salle	79.2	» »	85	19 Ø; 38	980	2	1
Continental	76.2	Aluminium	80	21.8Ø;		4	
Lincoln	89	»		19 Ø;		3	
Marmon	74.5	»	85	18.7Ø; 50	366	3	
»	70	»	85	19 Ø; 50		3	
Kissel	81	»	89	19 Ø;		3	
Oakland	82.5	Cast-iron	103	27 Ø; 57	730	2	1
Ford	98.5	Aluminium	100	25.4Ø;	505	3	
Essex super	68.2	»	78	19 Ø;	825	3	
Peerless	82.5	Cast-iron	82.5			3	
Studebaker	82.5	Aluminium	108	23.8Ø; 63		4	
Stearns	88.9	Cast-iron	105	24.5Ø; 58.5	1020	4	
Nash	87	» »	101.6	23.8Ø; 29.3	1080	3	1
Franklin	82.5	Aluminium	100	22.2Ø; 57	720	4	
Stud	82.5	»	107	22.2Ø; 63	582	3	
Graham Paige	101	»					
» »	88.9	»	107	25.4Ø; 63.5	620	3	
Chandler	82.5	Cast-iron	101,6	24.6Ø; 72.5	1080	3	
Curmingham	95.2	» »	101.6	23.8Ø; 57	845	3	

Light alloys (aluminium and magnesium) were appreciated at the beginning, primarily for their thermal and metallurgical characteristics, that is, for their high conductivity and low heat absorption, even more than for their low weight compared with cast iron (Fig. 7).
Elektron (magnesium alloy) pistons approached most closely to the behaviour of the ideal piston in pure copper. The temperatures of the head and skirt of the cast-iron piston were a long way apart, while the corresponding temperatures for light alloy pistons were close to uniform. Using pistons in magnesium alloy can bring the final compression to the limits of self-ignition of the mixture in the combustion chamber and the piston head has no incrustation of burnt oil.
Light alloys have been developed expressly for the manufacture of pistons. Moreover, these exhibit a low specific weight, good characteristics of resistance to elevated temperatures, a low tendency to wear, a higher thermal. conductivity than cast iron and a reduction in hot expansion. Two main groups are distinguishable — more precisely the Al-Cu alloys and the Al-Si alloys.
In the first group are found alloys containing from 8% to 15% of copper with small additions of other metals, and the names Titanal, Duralumin, Novalit, Lynite etc.... which held the field at the start of the '20s.
Only later appeared a group of Al-Cu alloys with lower contents of copper, of which a typical example was the famous Y-alloy, which had the following basic composition: Cu = 4%, Ni = 2%, Mg = 1.5% and the rest Al.
In the same period, Al-Si alloys for pistons had as their main characteristic an elevated percentage of silicon, ranging from 15% to 25%. To this group belonged Alusil, Supra and Alpax, among other alloys. The workability of these alloys was inferior to that of the Al-Cu alloys.
Meanwhile, research at firms interested in the manufacture and use of pistons very soon resulted in the achievement of "combined" or bimetallic pistons which exploited the best characteristics of both cast-iron and light alloys. The two types of material were united by fusion or

Fig. 8 - Nelson-Bohnalite types of piston, introduced in the U.S.A. in the years 1925/28.



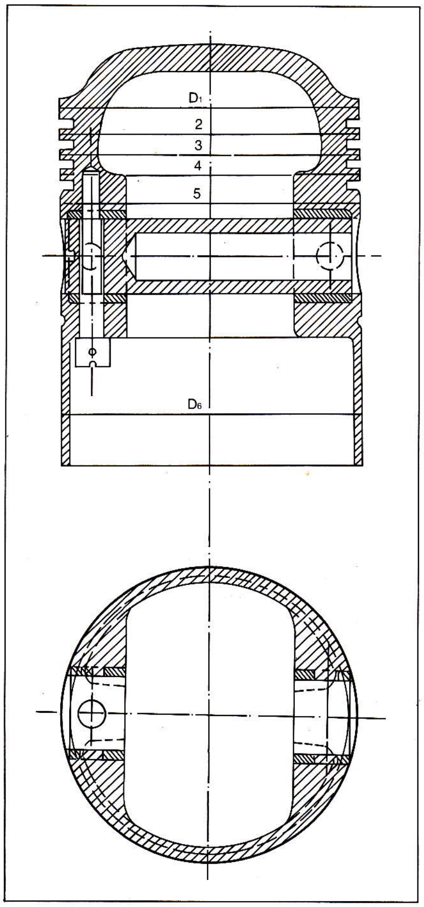
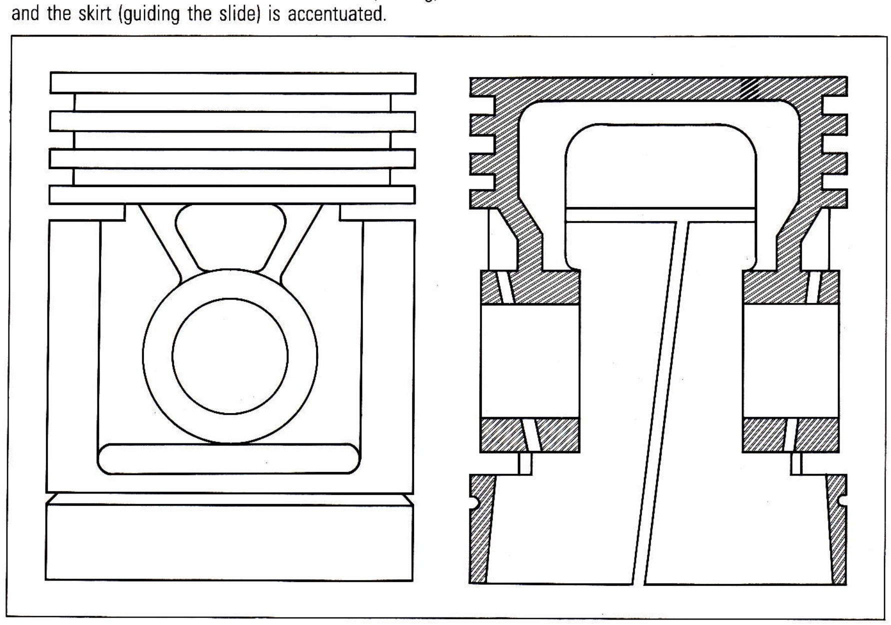


Fig. 7 - Piston in aluminium alloy. Construction 1920/21.

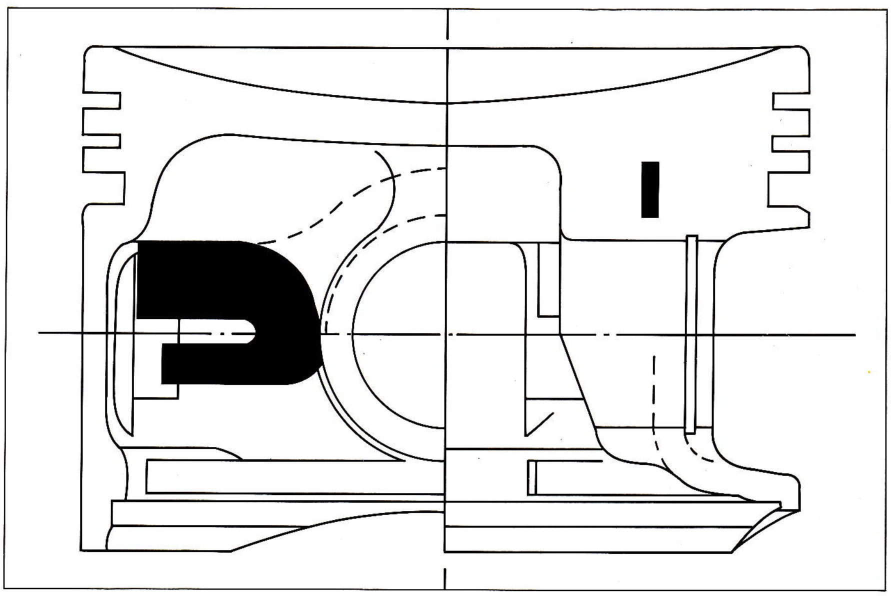
Fig. 9 - Split-skirt piston of American type, brought into use around 1920 and still widely used. In this type the differentiation of duties allotted to the head (sealing) and the skirt (guiding the slide) is accentuated.



by mechanical systems.
In 1923 a combined piston was produced by Daimler-Benz after overcoming remarkable difficulties in joining the two component materials.
From 1925 the Nelson-Bohnalite piston with steel inserts was being produced by the American Bohn Foundry (Fig. 8). The principle of this piston lies in a sharp separation of the head and the skirt, which are connected by means of sheets of virtually non-expandable Invar alloy. With these and other solutions ("Split-skirt" piston with a lateral split) it was sought to overcome the difficulties relating to wear of specific zones of the piston and to the control of expansion (Fig. 9).
At the start of the '50s, Al-Si alloys

predominated greatly over the Al-Cu alloys and cast-iron. Eutectic alloys with about 12% Si and additions of Cu, Ni and Mg were destined for general use in internal combustion engines. Hypereutectic alloys with 18 or 24% Si and additions of other metals were reserved for special uses, as in two-stroke or air-cooled engines.
These hypereutectic alloys show a very reduced thermal expansion, high mechanical characteristics and wear resistance, and good tribological properties. The Al-Cu alloys having Y-alloy-type compositions were then reserved for use in engines subject to high thermal stresses (diesel), because of their elevated heat resistance and high thermal conduction.
Cast-iron was reserved for pistons for mounting in slow diesel engines with moderate stresses.
Over the last forty years, then, Al-Si Eutectic (Lo-Ex) alloys have dominated, but alternative alloys have been used and are still used.
Meanwhile, the engines being evolved are reaching the limits presented by eutectic alloys relating to the various characteristics. For these, new materials are being introduced and new solutions, which can again demand a radical rethinking of the piston.
For petrol engines and fast diesels we can foresee the continued use of Al-Si eutectic alloys, as also for diesel engines of medium revs (200-1000 rpm) and medium power.
Nevertheless, for mono-metallic pistons, aluminium alloys must lose ground before bimetallic combinations (head in ferrous alloy and skirt in aluminium) in diesel engines with medium revs and elevated power. In this sector mono-metallic pistons in spheroidal cast iron could be used, especially to meet the problems of corrosive and abrasive wear associated with the use of heavy oils. Pistons wholly or partly in ceramics have attracted the attention of engineers researching fuel economy.
Something like 60% of the energy produced in conventional engines is lost with the exhaust and in the cooling system. The recovery of this energy would represent a spectacular improvement in engine efficiency.
Insulation of the combustion chamber can be carried out as a means of preventing the loss of heat energy in the cooling system. If this energy can be re-utilised, applying it to the exhaust gases, and using turbo-supercharging, it is possible to have an improvement in the efficiency of the motor itself.
Furthermore, the cooling system can be significantly reduced.
All this, of course, involves a rethinking of the combustion chamber of all engines, inasmuch as the nature of the combustion is changed by the presence of more elevated temperatures. It is necessary, therefore, to re-optimise the operating parameters of the engine.
One achievement in this direction is that presented by Cummins within the framework of putting in hand an engine without cooling equipment, in near adiabatic conditions.
Meanwhile, progress is being made, by means of improvements in the design of pistons, in manufacturing techniques and in metallurgical technology, besides the methods of investigation to obtain an ever better understanding of the phenomena involved.
The pistons, gudgeon pins and piston rings are responsible for about 30% of the mechanical losses in engines. They represent the primary objectives of research for an increase in efficiency.
The losses of this group of components have a complex explanation. Part of the losses is due to friction against the oil film and part to the inertia of the reciprocating masses which reflect their support by the crankshaft.
Therefore both the weights and the areas of contact are important. On the theme of friction of the pistons and piston rings, much has been said but only little quantitative data are available. To-day research efforts are devoted to the reduction of weight of the piston, the reduction of friction of the group and to maintaining or improving the performance and integrity of the parts (Figs. 10 and 11).
Solutions in this direction are presented by various production

Fig. 10 - Weight-reduced piston for an 1850 cc petrol engine (AE).



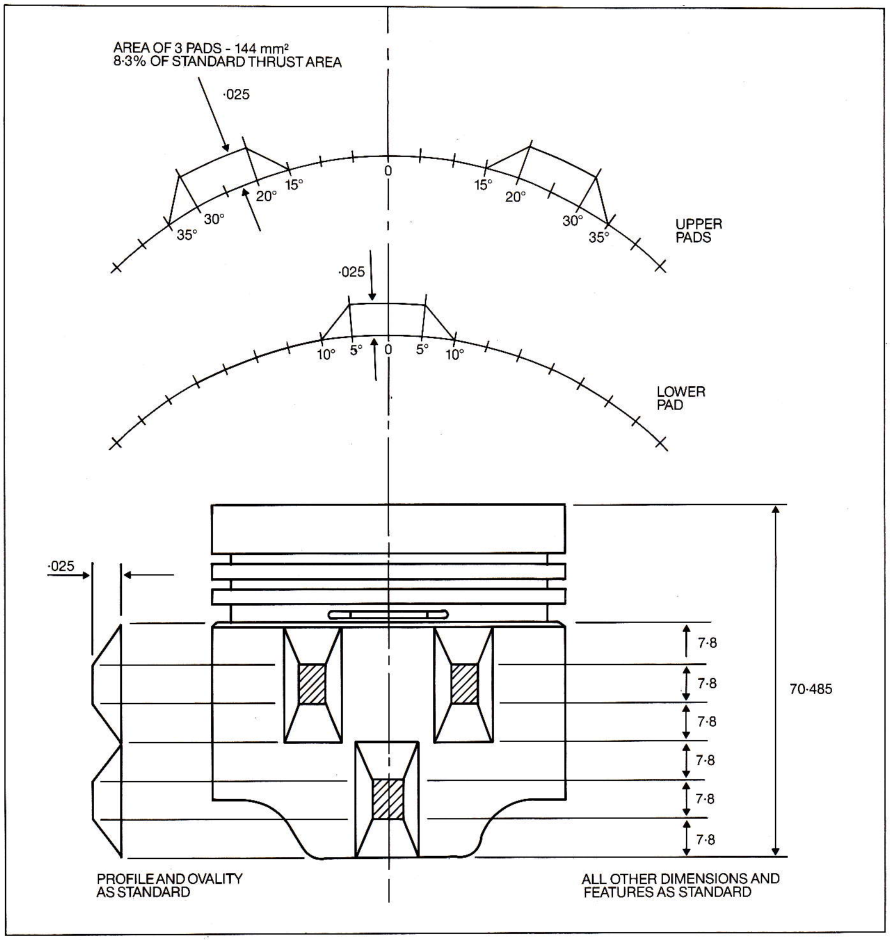


Fig. 11 - AE conoguide piston for petrol engine of 1275 cc with skirt surface reduced.

firms which offer entirely good prospects of a wide industrial application.
The problems of gas-tightness and oil consumption are becoming ever more important for increasing the specific power of engines, especially in relation to pollution of the environment.
We are seeking to understand better the effective behaviour of piston rings and to improve manufacturing processes and inspections.
Pistons for diesel engines warrant particular attention. While the factors that influence the design and development of diesel engines do not change sensationally with time, the order of priorities varies as a function of the demands of customers and of legislation.
The increase in the price of fuel and the attention devoted to pollution of the environment have given more importance to fuel economy, emissions, noise, gas-tightness and oil consumption.
Furthermore, the reliability, life and low cost of motor vehicles are always fundamental requirements (Fig. 12).
As far as pistons are concerned, the objectives of research are: controlled skirt and expansion, strength of through-holes, cracking of the head, insulation of the head, oil cooling and better piston rings (Fig. 13).
The fact, then, that the metallurgy of the conventional alloys has arrived at the limits of possibility, justifies the ever greater space that the recent technique of "squeeze-casting" is acquiring, which provides a material with minimum porosity and maximum mechanical characteristics. However, a special case is presented by the pistons used in engines provided with aluminium cylinders.
The use of aluminium alloys in the manufacture of cylinder blocks with integral barrels offers considerable characteristics of lightness, good heat exchange with means of cooling and an expansion of the cylinders being the same as that of the whole block.
The alloys used for this concept, in the past called for special coating of the pistons and cylinders to avoid seizure, with a sizeable additional cost.
Nowadays new alloys (Silfer) not necessitating further coating, allow direct contact between piston and cylinder. These alloys, of the Al-Si hypereutectic type, present a structure with a large amount of Al-Si-Fe-Mn components and primary silicon grains, which provide excellent wear resistance and reduce the affinity between the piston and cylinder materials.
Finally, piston rings have undergone an instant evolution. With the advent of diesel engines of elevated power, it was discovered that resistance to scuffing and wear was improved and the life of the engine prolonged by using hard coated and wear-resistant piston rings.
Hard chrome gave the optimum results, as also spray-coated molybdenum.
Piston rings of sintered materials are proposed in the most demanding cases.
And, last but not least, is the oil used in the lubrication and cooling of engines. But leaving aside this topic, along with many others that would unduly lengthen it, this will be only a mini history.

Fig. 12 - Connections in the development of diesel engines.

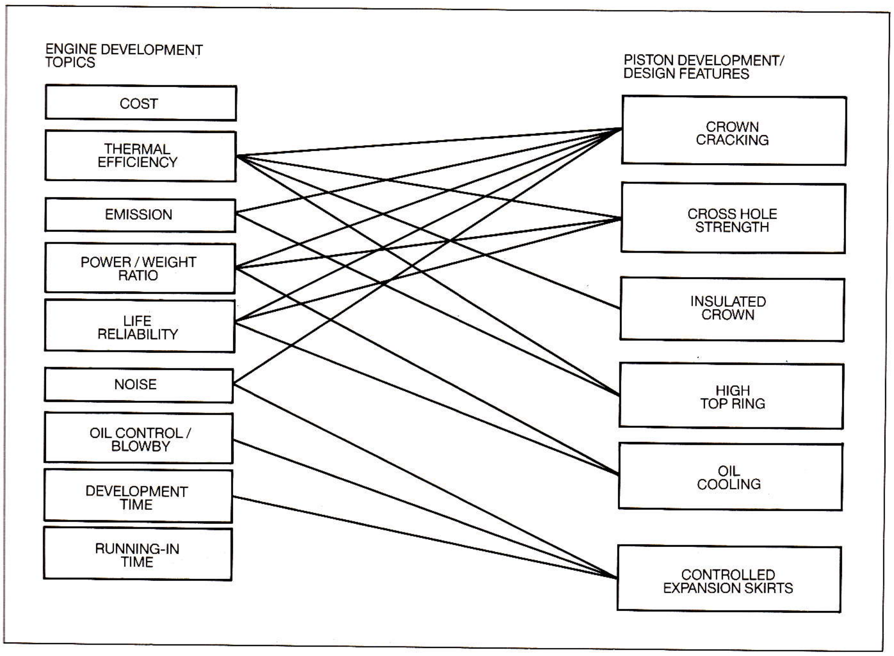
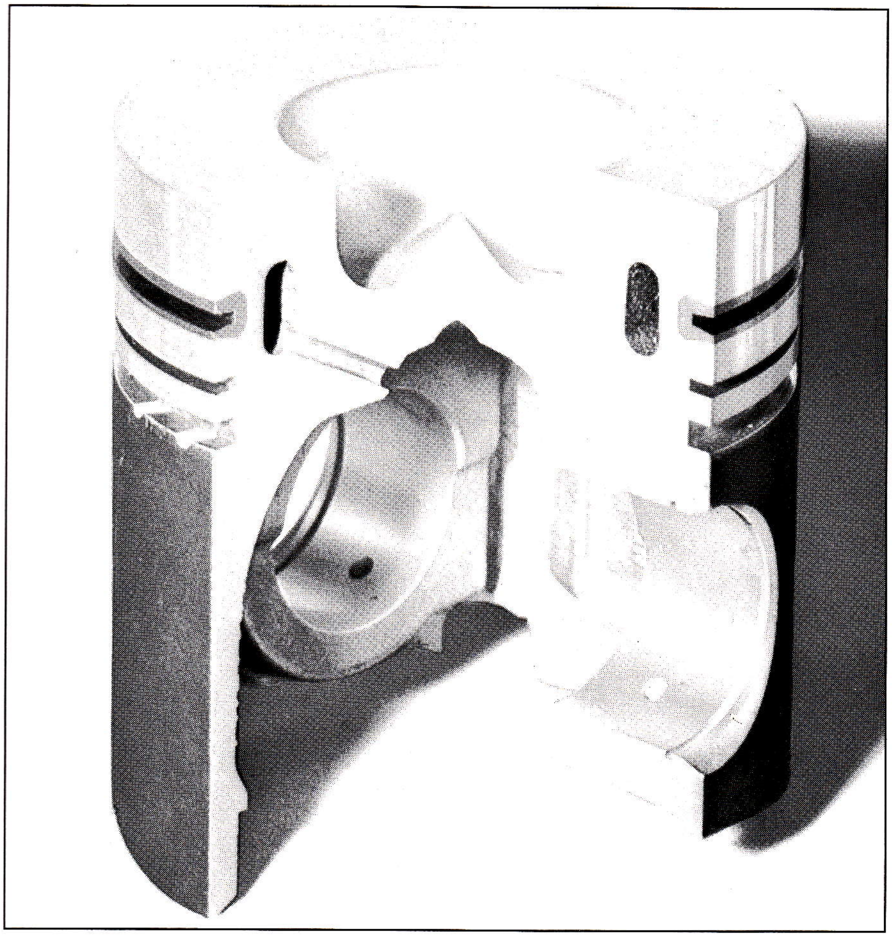


Fig. 13 - Piston with toroidal cavity to lower the temperature with jets of lubricating oil as the cooling medium (Mondial Piston).



REFERENCES

(1) Herman, E. ***L'automobile à essence,*** *Librairie Polytechnique, Ch. Béranger Editeur, Paris, 1908.*

(2) Garuffa, E. ***I motori veloci,*** *Unione Tipografica-Editrice Torinese, Torino, 1909.*

(3) Riedl, C. ***Konstruktion und Berechnung moderner Automobil - und Kraftradmotoren,*** *R.C. Schmidt und Co, Berlin, 1930.*

(4) Heldt, P.M. ***High-speed diesel engines,*** *P.M. Heldt, Philadelphia, Pa., 1932.*

(5) Giacosa, D. ***Motori endotermici,*** *Hoepli, Milano, 1941.*

(6) Panseri, C. ***La fonderia di alluminio,*** *Hoepli, Milano, 1950.*

(7) ***Kleine Kolben-Kunde,*** *Mahle Komm. -Ges., Stuttgart, 1951.*

(8) Caunter, C.F. ***The light car,*** *Her Majesty's Stationery Office, London, 1970.*

(9) Bruni, L. ***Come ridurre perdite per attrito e peso degli stantuffi nei motori a combustione interna.*** *XIX Congresso Nazionale ATA, Modena, 1983.*

(10) Fortina, G., and R. Verdi. ***Sviluppo e potenziamento dei motori diesel per autovettura attraverso l'impiego di pistoni ad elevate prestazioni.*** *Pubblicazione tecnica Mondial Piston, Torino, 1983.*

(11) Parker, D.A. Material innovation and its impact on the development of components for reciprocating engines. ***Int. J. of Materials and Product Technology, 1*** *(1986), 23-49.*