Paper read at the Institute on Tuesday, 28 November 1972

A FACTORY LAYOUT FOR THE PRODUCTION OF LARGE MARINE DIESEL ENGINES

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The paper describes a modern factory, near Trieste, which recently started production of two-stroke slow speed engines, medium speed engines and four-stroke fast running engines for railway and other industrial applications, and will develop its production capacity to about 634 000 kW (850 000 hp)/year.

The larger engines are built with welded main structure and therefore the factory has a very large fabrication shop with modern equipment for high quality weldings using advanced procedures.

The departments for testing the engines, the assembly shops and large machine tool shops are particularly important. Many machine tools are numerically controlled to reduce the cost of the machining jigs as well as machining hours.

There are 33 numerically controlled machines; among these several are real machining centres. The numerical control is of uniform type. Many machines are provided with multiple working stations, double tables and indexing tables, with the purpose of reducing to a minimum the dead times for setting-up the parts.

The engine test shop is equipped with brake and fluid systems which enable the engines to be tested at the same time for a total output of about 45 000 kW (60 000 bhp).

Cranes and transport plant allow loads of up to 203 tonnes (200 tons) to be handled.

In the paper the design principles of the factory are explained and the various sectors into which it is divided are described. Details are given of the welding shop and the large machine tool departments, where components of large dimensions are machined, such as bedplates and A-frames of the large two-stroke engines.

The auxiliary services, including the treatment plant for sewer and industrial waters discharged by the factory, are briefly described.

Mention is made of the factory production organization and the data processing centre, of the quality control organization, and finally of the spare gear, repairs, and after-sale assistance organization.

Mr. Gregoretti

INTRODUCTION

A description of the start of activity of the new large Grandi Motori Trieste Diesel engine factory (Fiat-Ansaldo-C.R.D.A.) gives the opportunity to illustrate its main characteristics. This new factory is considered to be equipped with the most up-to-date available production machinery.

G.M.T. was established, because Fiat, owner of the Grandi Motori workshop in Turin and IRI (Institute of the Industrial Reconstruction) owner of the Ansaldo and C.R.D.A. engine factories, respectively in Genoa and Trieste, decided to concentrate the activity of these three factories in a single modern one. As a result the new factory would be more competitive because of its modern machinery and the higher production volume would allow more development and research.

FACTORY LAYOUT CRITERIA

Types of Engines Manufactured and Productive Capacity

The new factory produces two-stroke slow speed engines, medium speed engines and four-stroke engines for marine propulsion and industrial use. It also produces faster running engines for electric power generation, railway traction and various industrial applications.

The engines produced cover the market demand for outputs ranging from 370 kW (500 hp) to 37 000 kW (50 000 hp).

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The engines are of the well known Fiat design. Fig. 1 shows a cross-section of the largest two-stroke engine with 1060 mm cylinder bore, 3000 kW/cyl (abt. 4000 hp/cyl) 106 rev/min. Fig. 2 shows a cross-section of the four-stroke railway engine, bore 210 mm in line or vee version, 140 kW/cyl (187 hp/cyl) 1500 rev/min. The main structure of the slow engine is fabricated like all the slow speed engines produced by the factory; the railway engine has a cast iron crankcase.

The productive capacity has been determined, taking into account the Italian market characteristics and relying on a greater development of the export sales attainable because of the higher competitiveness of this modern factory.

Consequently the design of the factory has been made for an annual output based on two daily shifts producing:

two-stroke engines	370 000 kW (500 000 hp)
medium speed and medium bore four-stroke engines	261 000 kW (350 000 hp)
total	634 000 kW (850 000 hp)

The sub-division between two-stroke and four-stroke engines is not rigid, depending obviously on the market demand. For this reason appropriate validity verifications have been made for different values of the ratio between the production volume of the two engine types. This might happen as a consequence of an

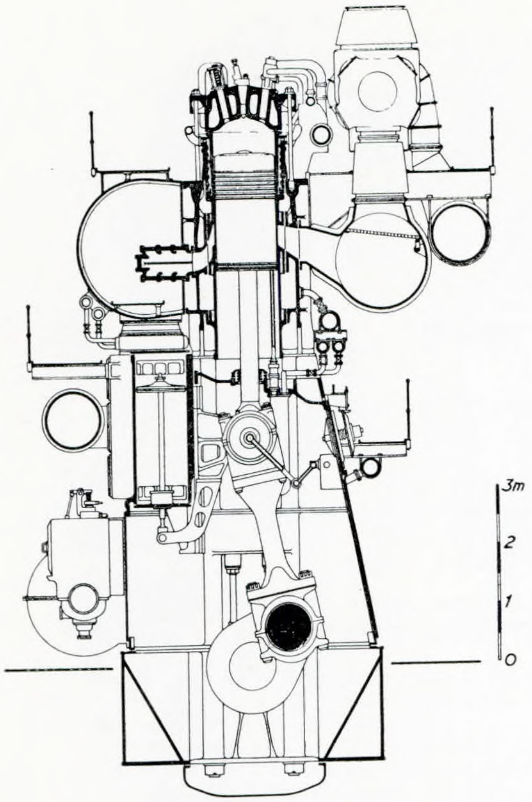


FIG. 1—*Cross-section of 1060 type marine engine 3000 kW/cyl (4000 hp/cyl) 106 rev/min*

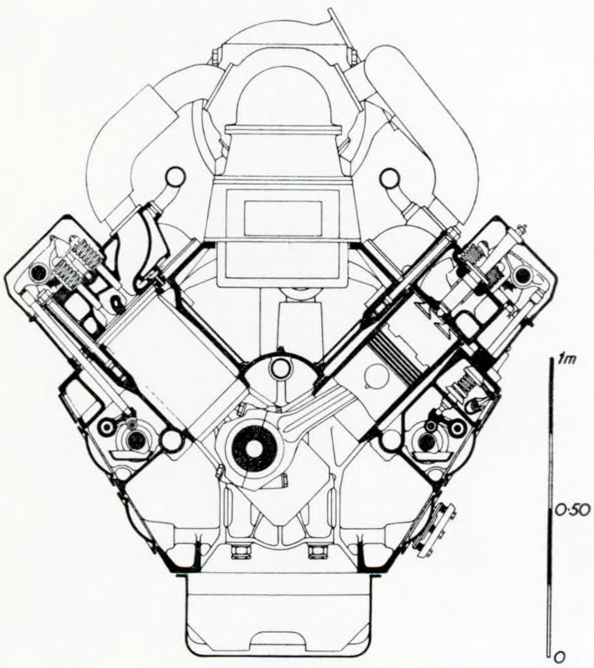


FIG. 2—*Cross-section of 2112 SS F type railway engine 140 kW/cyl (187 hp/cyl) 1500 rev/min*

increase of the medium speed engine demand, possibly prejudicing that of the low speed engines. Consequently the machine tools were accordingly chosen and the workshops were planned bearing in mind the possibility of future enlargements.

In normal production conditions, the factory should employ about 2300 people, including staff employees and manual workers.

Large Use of Welded Structure

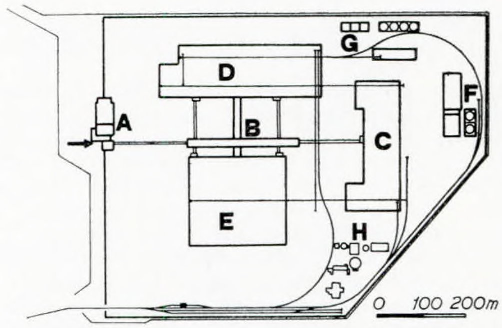
A foundry for cast iron work has not been included, both because of the large use of fabricated main structures for the slow speed engines, and the possibility of relying on other good Italian foundries for the parts which must necessarily be of cast iron, such as cylinder blocks and liners.

Technological Design Criteria

The factory has been technologically designed to take into account the most modern production means available and also using machines specifically designed to reduce the machining time for certain engine components and to improve the production quality as and when required because of the increasingly high performances demanded from the engines.

The undermentioned general criteria have been followed:

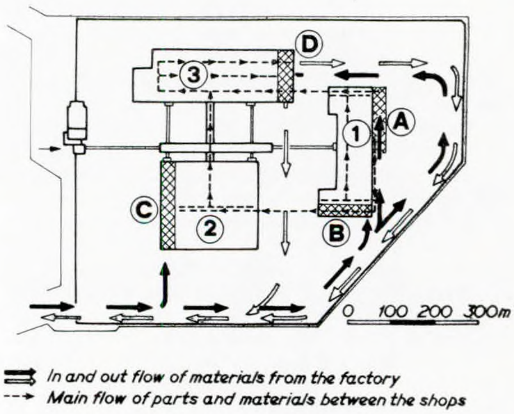
1) Workshop layout planned such as to minimize the material handling and staff movements; for instance social services arrangement located in central position with respect to the workshops (Fig. 3).



A) Main office building and data processing centre
B) Factory offices, laboratories and social facilities building
C) Fabrication shop
D) Large machine tools and engine test room
E) Medium and small size parts machine shop
F) Heating and electric station
G) Water cooling towers, fuel and oil storage
H) Sewage and technological waters treatment system

FIG. 3—*Schematic plan of the factory*

2) As regards large size component machining, all the necessary machines, even if of different type, are installed if possible in the same workshop in order to minimize the material transportation (Fig. 4).



1) Fabrication shop
2) Small and medium size machine tools
3) Large machine tools erection and test room

A) Plates, castings and forging
B) Bars and tubes
C) Small finished parts store
D) Final preparation and shipment

FIG. 4—*Scheme of main flow of materials*

3) Reduction of set-up times, to allow maximum use of machines. For this purpose all the large machines have been equipped with split tables, and many horizontal and vertical drilling machines provided with two or three working places. Much use has also been made of indexing tables.
4) Large amount of high performance lifting equipment to minimize the crane waiting hours and simplify as well as reduce the lifting operations.
5) Since there is no mass production it has been necessary to adopt n.c. machine tools and machining centres to reduce the use of expensive machining jigs.
6) Numerical control standardization; all n.c. machines in the factory have been equipped with numerical controls designed by Fiat, with obvious advantage of use, spare parts and maintenance.

General Layout Plan

The factory has a total area of about 530 000 m² (5 700 000 ft²). The covered area is about 150 000 m² (1 610 000 ft²). It includes (see Fig. 3):

1) management and office building;
2) workshop offices, laboratories and services (locker room, canteens, etc.);
3) fabrication shop, steel sheet and bar storehouse;
4) large machine tools, assembly shop and test shop;
5) small and medium size component machining shop, heat treatment and various stores;
6) thermal power plants, outdoor substation and compressed air production;
7) engine cooling water system and fuel and lubricating oil storage;
8) effluent treatment plant.

BUILDING MAIN CHARACTERISTICS

The covered, extended surface of the single main buildings are given in Table I.

The management, technical and administrative offices building has reinforced concrete load supporting structure and internal partition walls with mobile panels, which give the maximum flexibility to the office layout. There are three floors.

The workshop offices and laboratory building has a structure with concrete prefabricated elements and is divided in two or three floors in conformity to the room utilization needed.

The workshop buildings are divided in three, the welding shop, large machining and test shop and small and medium machining shop. The buildings are of steel frame structure covered by a flat roof with skylights. The large machine shop has particularly important structures on pitches of 32 × 15 m (100 × 49 ft) and 40 × 15 m (130 × 49 ft) with a height of 23 m (75 ft) and 19 m (62 ft). It has lines for two coupleable bridge cranes of 101·5 tonnes (100 tons) capacity and various bridge cranes of 71 tonnes and 30·5 tonnes (70 and 30 tons) capacity.

TABLE I—COVERED AND DEVELOPED AREAS OF THE MAIN BUILDINGS

Building	Covered, developed areas	
	m²	ft²
Office, laboratory and workshop buildings	12·000	130·000
Workshop offices and laboratory building	24·000	260·000
Fabrication shop	28·500	307·000
Large machine tools	40·000	435·000
Small and medium machining shop	44·600	480·000

The small and medium machining and welding shops have a prevalently uniform structure with pitches of 15 × 20 m (49 × 66 ft) 7·50 m (42 ft) and 11 m high (36 ft). The covering structures are suitable for carrying 3 tonne and 10 tonne suspended bridge cranes.

Fig. 5 shows the test shop and large machining building cross-section, while Fig. 6 shows the small and medium machining shop cross-section.

Since the purpose of the paper is to give some indication of the most advanced production means installed in the new factory the more interesting workshops, such as the welding and large machining shops, will be described in detail and the other parts of the factory will be only briefly mentioned.

FABRICATION SHOP

This building is formed by four main flanked bays, 20 m (66 ft) wide and 225 m (740 ft) long, and two transverse bays

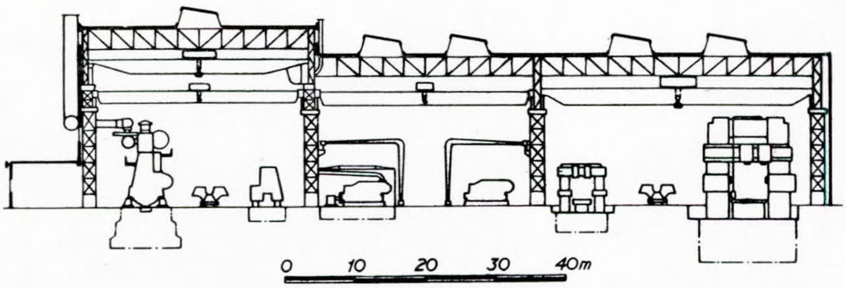


FIG. 5—*Erection, test and large machining building*

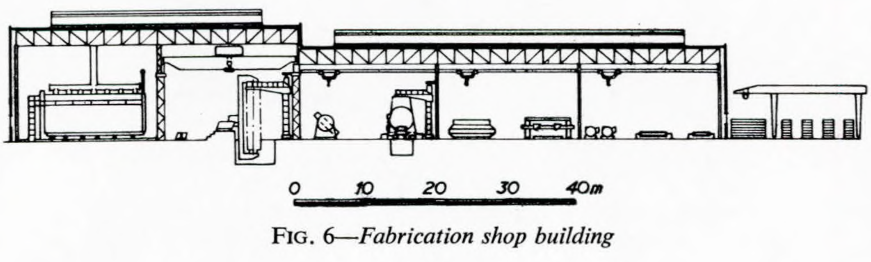


FIG. 6—*Fabrication shop building*

30 m (98 ft) wide and 120 m (394 ft) long placed at one end of the main ones.

The welding and pipe shops are located in the four long bays and the bar, steel section, pipe stores and plate preparation area are in the two transverse bays.

On the outside, adjacent to one of the long sides of the building, there is an area for plate stocks and one for large raw materials, castings or forgings, which are purchased from other factories. This outside area is served by a gantry crane with a 20 tonne hook and a 5 tonne magnetic hoist. The plates are lifted by the magnetic crane onto a roller way to the workshop.

A transport line, remote-controlled by a single operator, distributes the plates, placing them at the head of the single machining lines. The plates are straightened and sandblasted on the same transport line before being distributed.

Particular attention has been paid to the welding shop design in order to obtain high quality production and a functional operation.

The following basic concepts have been taken into account:

1) minimize the material handling by mechanizing and automating as much as possible the single operations;
2) maximum possible use of automatic welding;
3) suitable welding equipment for the construction of large size welding structures, up to 11 m (36 ft) length, since the proximity of the factory to the sea allows the shipment of even very bulky pieces;
4) to have absolute certainty of welding success; therefore large use of chamfered junctions, welding made with materials positioned so to make welding easy and the electrode if possible situated in a vertical position and on the bisecting line of the welding bead angle;
5) wide welding positioner equipment with various capacities, from about several hundreds of kilograms up to 35 tonnes;
6) to make the unavoidable and expensive straightening operations in the large welding structures as easy as possible;
7) to carry out in the same welding workshops machining operations, such as drilling and milling of limited size surfaces, to avoid expensive and troublesome bulky material transportation through other workshops.

The workshop arrangement in the various bays is as follows (see Fig. 7).

Transverse Bays (Bar Store and Plate Preparation)

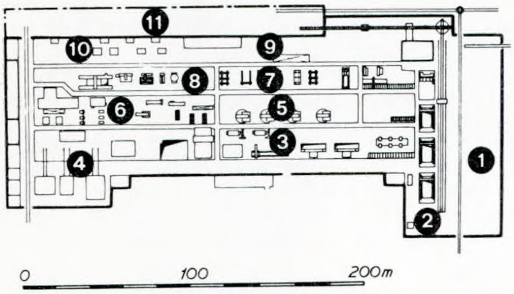
There are two bays, the first containing the store for bars, steel sections and pipes, which are placed on "Christmas tree" supports and handled by a 3 tonne stacker crane, and the second containing the area for plate distribution to welding, served by a 10 tonne magnetic beam. In the plate preparation area there are three oxygen-cutting machines with optical readers capable of cutting plate and single or "X" chamfering simultaneously.

Longitudinal Bays (Welded Structures and Pipe Manufacture)

First Bay (Largest Engine Bedplates Manufacturing Line)

This is equipped essentially for dealing with plates of more than 25 mm thickness.

There are two main welding areas equipped with large jigs (see Figs. 8 and 9) capable of handling the large longitudinal



1) Rolled section store and bar cutting
2) Plate preparation
3) Bedplate fabrication
4) Stress relieving oven, sand blasting and varnishing
5) A-frames for two-stroke engines and crankcases for four-stroke engines
6) Manufacturing of heat exchangers
7) Large scavenging and exhaust manifolds and oil sumps fabrication
8) Machine tools
9) Manufacturing of piping
10) Fabrication of small exhaust pipes and insulation
11) Raw material and plate store

FIG. 7—*Fabrication shop*

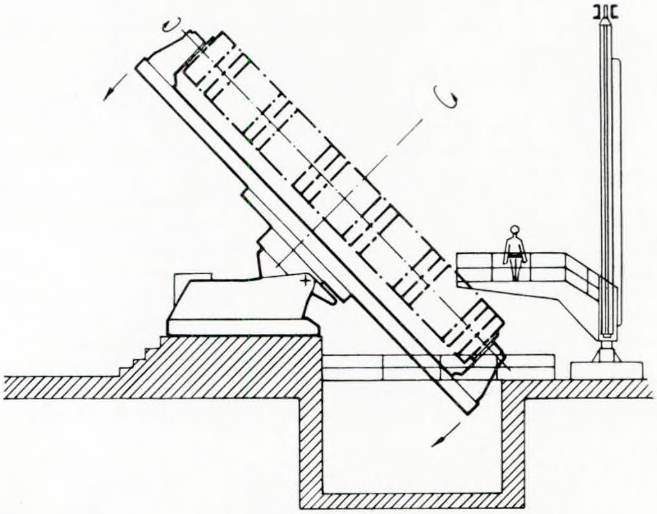
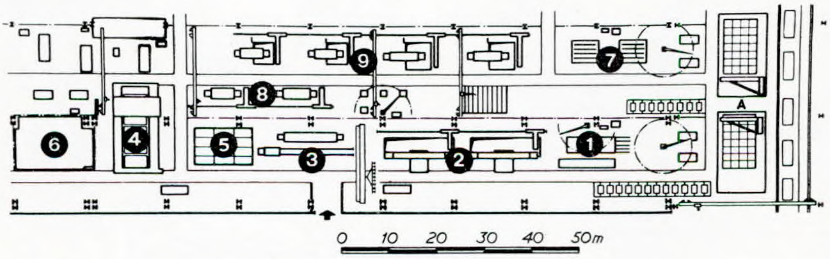


FIG. 8—*Positioning and welding jig for bedplate girders*



Bedplate line
1) Universal assembly jig
2) Welding stations for longitudinal girders
3) Automatic welding completion of the girders
4) Straightening 750 ton press
5) Assembly platform for whole bedplate
6) Pit for completion of welding

A-frame line
7) Assembly jigs
8) Welding stations for sub-assemblies
9) Welding stations for whole A-frames

A) Flame cutting machines

FIG. 9—*Fabrication shop—Bedplate and A-frame fabrication line*

bedplate girders. Each welding area is provided with an operator's platform and a welding head equipped for coated electrode manual welding and for CO_2 protection welding. By moving the jig and the welding head, it is possible to obtain the best welding position. The welding of the girders is completed at a suitable point equipped with a horizontal-axis jig and an automatic welding machine. After welding, the resultant deformations in these large structures must be eliminated. In order to do this without waste of time, a special 760 tonne (750 ton) press, equipped with a device which applies a twisting couple directly to the piece to be straightened, has been placed next to the welding areas.

The final welding of the complete bedplate is made in a suitable pit served by a number of semi-automatic welding machines. The bedplate is afterwards stress-relieved at 650°C in a methane heated furnace; the heating and cooling phases are suitably adjusted to minimize deformation and thermal expansion stress.

Second Bay—A Frame Manufacturing Line (Fig. 9)

The welding is carried out via four main sets, two large and two small, similar to those used for the bedplate welding, provided with manual and automatic welding heads, and operators' platforms.

The straightening, stress-relieving and final treatment are carried out as for the bedplates.

In the second bay also, crankcase welding of some four-stroke engines and similar pieces is carried out, for example, generating set sub-bedplates. Consequently several smaller jigs and various welding equipments for the crankcases and their sub-assemblies are located in this bay, in addition to the A-frame manufacturing equipment.

Third Bay

Here the tools and machinery are suitable for manufacturing parts with 4 mm to 25 mm thick steel plate, such as oil sumps, scavenging and exhaust gas manifolds (see Fig. 7).

Several rotating jigs are installed, together with plate bending machines, rolling machines and positioning equipment for bulky structure fabrication.

Various steel sheet stocks are placed in the first part of this bay. Several machine tools are arranged at the end of the line, past the plate welding area. One group of machines, which includes a n.c. horizontal drilling machine, is used basically for drilling the plates of the water, oil heat exchanger; a second group is used for completing, by mechanical machining, the bulky welded components. These basically require drilling operations and, to a limited extent, some milling operations.

Among the second group must be mentioned a gantry drilling machine with three 22 kW (30 hp) heads, a 4 m (13 ft) port and a 12 m (40 ft) gantry travel (Fig. 10). It has been

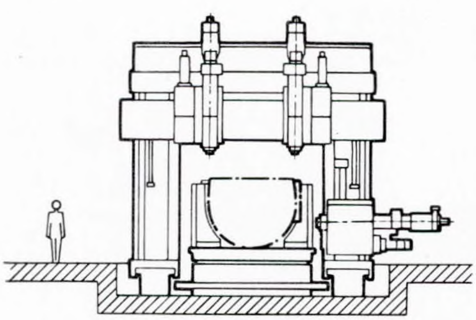


FIG. 10—*N.C. gantry machine for milling, drilling and tapping of large receivers and exhaust pipes, oil pumps etc*

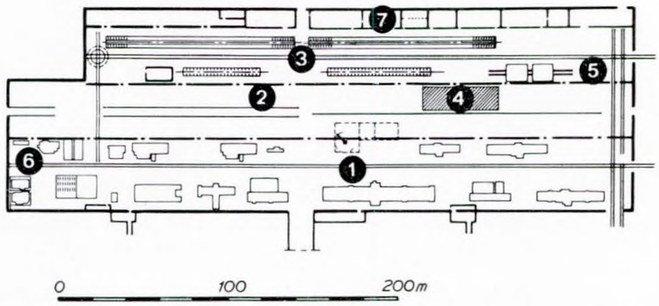
specifically designed and built to finish machining the oil sumps, the scavenging air and exhaust gas manifolds, and other similar components, so as to be able to send these bulky pieces direct to the engine final assembly department.

Fourth Bay

This is in two parts (see Fig. 7).

The first is equipped for pipe fabrication and is provided with positioning and welding equipment, together with other machines, including cold bending machines for tubes up to 135 mm diameter. Past the fabrication area there is a series of pipe cleaning and hot zinc plating tanks.

In the second part the thin plate (up to 4 mm thickness) components are manufactured; the pipe insulation operations have been arranged at the end of the bay.



1) Machining of large two- and four-stroke engine components
2) Assembly of four-stroke engines and two-stroke engine groups
3) Assembly and testing of large two-stroke and four-stroke engines
4) Testing of four-stroke engines
5) Shipment
6) Reduction gear cutting
7) Test room facilities, stores and offices

FIG. 11—*Large machine shop and test room*

LARGE MACHINE TOOLS—ASSEMBLY AND TEST SHOPS

These functions are in three side-by-side bays (Fig. 11). A low building for the test shop and assembly services has been built against the third bay.

This area is particularly interesting for the machines installed and plant characteristics.

The fundamental criterion followed for the arrangement of the machines in this shop is that of minimizing heavy and bulky component movement, during transportation from one machining process to another, so minimizing the dead time.

First Bay—Large Machine Tools

The first bay is 40 m (130 ft) wide, 365 m (1200 ft) long and 19 m (62 ft) high and is the largest in the whole factory. It contains four bridge cranes, including two of 71 tonne (70 ton) capacity (Fig. 12).

The complete machining of the largest engine components, such as bedplates, A-frames, cylinder blocks, scavenging air pump bodies, four-stroke engine frames and other items, is carried out here, with the exception of the crankshafts, which are bought in.

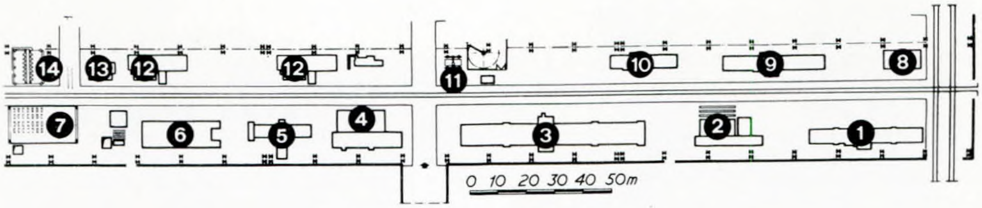
Criteria for Determining Machining Methods for the Largest Components

Milling

The main operations for removing excess material are chiefly carried out by milling, as previously adopted in the workshops of the two partners, where planers were gradually replaced by plane milling machines. The progress in the tooling and in the machine tool capacity today allows much higher performance.

For example, the largest plane milling machine installed in the new factory (No. 3, Fig. 12) is provided with four heads, each of 110 kW (150 hp) compared with the 55 kW (75 hp) vertical heads of the largest milling machine operating in the old factories. This higher power led to a considerable decrease in machining time. Moreover, the adoption of split-tables allows for a further decrease in manufacturing hours: while the machine operates on one end of the table, on the other, idle end, the finished components are unloaded and new components set up.

Powerful motors and split-tables are, therefore, the main characteristics of the large plane milling machines operating in the new factory. It must also be pointed out that the use of large, sturdy milling machines allows also for a greater precision in



1) Four-head adjustable rail mill
2) N.C. horizontal drill with indexing table
3) Four-head adjustable rail mill
4) Horizontal mill and bore
5) Cylinders two-table boring machine
6) N.C. gantry drilling, boring and tapping machine
7) Hydraulic pressure testing
8) Laying-out table
9) Adjustable rail mill
10) Adjustable rail mill
11) Digital read-out and laying-out machine
12) N.C. machining centres for milling, boring, drilling and tapping
13) Horizontal bore and drill
14) Washing station

FIG. 12—*Large machine tool bay*

machining large components. For instance, with the largest plane milling machine operating in the new factory, provided with an 18 m + 12 m = 30 m (59 + 40 ft) split-table, compared with the 16 m (25 ft) of the largest plane milling machine operating in the Turin factory, it is possible, using the twin tables, to work out, with a single setting-up operation, the complete machining of a bedplate complete with thrust bearing, for the longest engine foreseen in the factory production schedule (12 cylinders, bore 1060 mm). Thus, it is possible to obtain perfect alignment of the finished surfaces, including the main bearing housings, which are machined on the same machine tool with a suitable "right-angle attachment". Higher manufacturing precision, apart from the greater speed of the subsequent engine assembly, means a better operation in service, which is very important to the shipowner. In addition to this, a large adjustable rail milling machine, equipped with four 110 kW (140 hp) heads, an 18m + 12 m (59 + 40 ft) table and a 5·5 m (18 ft) port, three other large size adjustable rail milling machines are installed in the same bay (Fig. 12).

Drilling, Boring and Tapping

In the old factories, drilling and tapping on large components were almost completely carried out with radial drills and conventional boring machines.

For the drilling tools, positioning jigs were employed; as there was no mass production these were very expensive, due to the impossibility of amortizating them over a considerable number of parts. Moreover, the design, construction and final procurement of the drilling jigs took up quite long periods of time. Therefore it was decided to adopt n.c. machines for drilling, boring and tapping the largest components as well.

N.C. machines, already used for machining small and medium size components, are becoming more and more numerous, as they do not require costly machining equipment and, above all, give a possibility of economizing on labour. This is a very important factor at the present time, when wages are going up rapidly and skilled personnel are not readily available.

Among the most interesting n.c. machines, chosen with reference to these considerations and installed in the large machining shop, the author wishes to point out the following particularly.

One n.c. horizontal drilling machine, equipped with two working tables, plateau and indexing table (No. 2, Fig. 12) is used mainly for the A-frames, as well as for bedplate face drilling and tapping. Two work positions and the revolving table allow setting-up many components in blocks and then drilling each face, avoiding further setting-up and obtaining an important reduction in manufacturing hours, as well as better production quality.

One n.c. gantry drilling machine equipped with two 30 kW (40 hp) vertical heads, 5·5 m (18 ft) port and capable of machining components up to 15·5 m (54 ft) long. It was specifically designed for drilling and tapping all the components already machined on the large size milling machines, installed in the same shop (Fig. 13).

The selection of this very expensive special machine was decided after careful consideration of alternative solutions with conventional, simpler machines (radial drills and boring machines). The n.c. machine was finally chosen for its noticeable labour saving and, at the same time, for the high precision and machining consistency obtainable, which have important effects on part interchangeability.

Two n.c. machining centres with 30 kW (40 hp) spindle motors and a store capacity of 50 tools (No. 12, Fig. 12). Each centre is equipped with two work places: one plateau and one revolving table. Furthermore, either of the machines can have a horizontal axis n.c. positioner mounted on the plateau for machining the various faces of the four-stroke vee-type engine crankcase. These machining centres are utilized chiefly for milling, boring, drilling and tapping the largest components of the medium speed four-stroke engine.

Among the most interesting machines installed in the large machine shop is a 52 kW (70 hp) horizontal boring machine equipped with two transversally moving tables: one with work in progress and one being set-up. It is used for boring (rough and finish) the large two-stroke cylinder blocks and scavenging air pump bodies. These operations were carried out, in the old factories, on vertical lathes, taking much more time.

Reduction of Manufacturing Time

As an example of the labour saving which will be obtainable with the new manufacturing methods for the largest components, after the start up period, that is with the factory at full production capacity, a reduction of about 75 per cent in manufacturing hours for the three largest parts of the 1060 type engine (bedplate, A-frames, cylinder blocks) is foreseen. The reduction is mainly due to the new machines and adequate machining methods described, but also to other factors, such as internal transportation methods, up-to-date inspection and control devices, i.e., wide use of digital read-out systems, which speed up all the manufacturing operations.

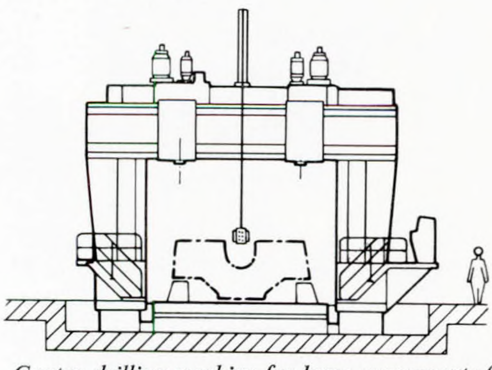


FIG. 13—*Gantry drilling machine for large components (with two 30 kW heads)*

Second Bay—Four-stroke Engine Assembly and Test Shop

The second bay is 32 m (105 ft) wide, 365 m (1200 ft) long and 19 m (62 ft) high and is served by two bridge cranes, one 30 ton and one 80 ton.

Two-thirds of the bay length are reserved for the assembly of the two-stroke engine sub-groups and for the various types of four-stroke engine produced by the factory, with the exception of the large medium speed four-strokes, which are assembled and tested like the larger two-stroke engines.

The remaining part of the bay is the four-stroke engine testing area and the finished part shipment area.

The test shop water, oil and other fluid systems are located in an underfloor room in which tanks, pumps, filters, heat exchangers and services are situated.

Third Bay—Two-stroke Engine Assembly and Test Shop

The third bay is 32 m (105 ft) wide, 320 m (1050 ft) long and 23 m (75 ft) high and is served by two superimposed crane runways. On the upper runway are two 101·5 tonne (100 ton) bridge cranes, which can, if necessary, be automatically coupled to allow lifts up to 203 tonnes (200 tons), as required, for instance, by some larger type engine crankshafts.

Situated towards the second bay are (see Fig. 11) two series of beds of 100 m (327 ft) total length, for the large sub-group pre-assembly, and for holding large components, awaiting assembly. These beds are adjacent to the final erecting and large engine test beds, so that mounting and dismounting can be carried out with minimum time wasting and without keeping cranes and test beds engaged too long. There is also a washing station, and a spray and protection booth for the parts which have to be shipped. Adjacent to the washing station is an area in which the parts are prepared for final despatch to customers.

On the opposite side of the bay are the larger engine assembly and test beds. They are divided into two groups and are 220 m (720 ft) long. All the systems for distribution and recovery of fluids for engine testing (oil, water, air etc) are installed in a main underground duct, running beside the engine test beds.

These systems have been subdivided into eight groups for the two-stroke engines and into four groups for the four-stroke engines. They can be coupled in parallel depending upon the output of the engine to be tested. This plant capacity is such that engines aggregating an output of about 45 000 kW (60 000 hp) can be tested at the same time.

Adjacent to the test shop bay there is a lower building, 11 m (36 ft) wide and as long as the bay in which the assembly and test shop offices are arranged. In this building are the test shop instrumentation and equipment store, the fuel oil and lubricating oil purification systems, and a small packing workshop.

Engine Testing

All engines produced are generally bench tested in the test room coupled to hydraulic brakes, or in the case of generator engines, their electrical machines.

A bench test for a large engine consists of a running-in period of about 20 hours, followed by an official test, generally carried out under the classification societies' control, which lasts about seven hours. Also, on a customer's request, special tests are carried out, for instance with particular fuel types.

The prototype engines, after the assembly, are subjected to a type test which lasts much longer, according to customer or classification societies' specification.

Among these tests, the author mentions for its severity, the rail engine acceptance test, prescribed by the International Railway Organization (O.R.E.) which includes two tests: The first, which lasts about 100 consecutive hours, mostly at 100 per cent load; the second lasts about 840 consecutive hours at variable loads, simulating operation in the locomotive. The factory is specially equipped for this type of testing which rail engines must pass satisfactorily for certification.

Apart from the normal production engine test room, there is also an experimental test room, divided into two sections: one for the larger type engines, is located at the head of the two-stroke engine test benches; the other consists of a number of small test rooms for the smaller engines. In the experimental test rooms tune-up and development tests are carried out on new engine designs and on types of engine already in production.

These tests consist essentially of a first stage, the engine tune-up, at the highest foreseen performance. After this the engine is subjected to long endurance tests at maximum service output and operating conditions under which the engine is to run. For example, for the super large bore 1060 type, the long endurance test was carried out on a two-cylinder experimental engine which ran for about 8000 hours at the effective power of 3300 kW/cyl (4500 bhp/cyl), before the first engine of the type operated.

Of course, a good part of these long endurance tests were carried out in Turin, while the remainder were carried out in the G.M.T. test room in Trieste, where the engine was eventually installed.

The experimental test rooms are provided with some of the most advanced and modern measuring and control devices, some of which were designed and built in the factory's own mechanical and electronic laboratories.

Adequately designed and built devices, easy to transport and independent of any external power source are employed for on-site measurements, for instance during tests on board to measure and record all types of vibration, static and dynamic stress etc.

SMALL AND MEDIUM MACHINE SHOP

This is parallel to the large machining shop and is connected to it by a covered road.

The road is the continuation of a cross passage, which divides the small and medium machine shop into two zones: one with 7·5 m (24·5 ft) high bays and the other with 11 m (36 ft) high bays. The workshop is further divided lengthwise in two halves by an internal railway line, connecting it with the bar and raw material store and the fabrication shop.

Wide Use of N.C. Machines

Here again one of the main differences from the old factories is the wide adoption of n.c. machines, especially for drilling, boring and tapping. These operations were carried out in the old factories with radial drills and normal boring machines. Of 33 n.c. machines installed in the new factory, 25 are in the small and medium machine shop.

For machining medium and small components, including some that weigh up to several tons, methods were studied which led to the adoption of several machining centres, in which, with a minimum of setting up, it is possible to carry out all, or nearly all, the machining operations.

Consequently centres have been established for machining both two-stroke engine cylinder heads, which weigh several tonnes, and four-stroke engine cylinder heads, the smallest of which weighs about 70 kg.

One machining centre has been set up for finishing large two-stroke engine crossheads, in order to machine, with a minimum number of setting up operations, all those surfaces where trueness may influence good engine operation.

Other machining centres (there are 11 in this department) are designated for machining connecting rods, bearings and other parts which generally require several drilling and tapping operations on several faces.

Among the machines in the medium and small machine shop to note particularly is a n.c. contouring lathe for large two-stroke engine cylinder liners (Fig. 14).

The external rough and finishing operations on these components were previously carried out with parallel lathes and boring machines, after the deadhead cut with a suitable machine. The liner centring copper rings were shrunk on using a special installation fitted with a pneumatic hammer. Finally the internal surface was finished on a special boring machine.

In the new factory all these operations are carried out on the n.c. contouring lathe, which has a 100 kW (150 hp) motor. On this lathe deadhead cutting, simultaneous roughing of both the internal and external surfaces, and finally the external and internal finishing of the liner are carried out. The liner centring copper rings are also shrunk on, on the same lathe, by means

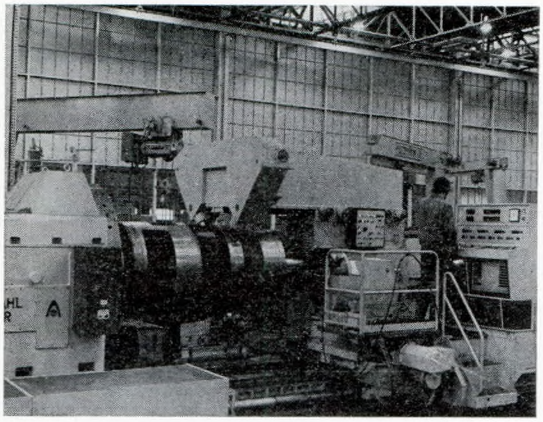


FIG. 14—*N.C. lathe for two-stroke engine cylinder liners*

of a suitable roller. In this way not only is consistency in dimensional and internal surface finish obtained, but also a reduction, by more than half, of the previous manufacturing time.

These are obvious advantages, both in quality and cost of the liners mounted on the engine, and those supplied as spare parts, during the whole engine life.

Space is too limited to mention in detail all the machining centres in the workshop, therefore the author will simply indicate their locations in the individual departments, pointing out only the most interesting machines.

Departments of the Small and Medium Machine Shop (*Fig*. 15)

1) Reception, control and store for bought-in goods—two bays.

2) The finished part store, which occupies two bays and is subdivided into two areas: one equipped with metal structure shelving, served by elevators for setting out pallets, boxes and containers with a capacity of about 1·5 tonnes; the other area is for containers with a capacity of 6 tonnes.

3) Various machine tools for machining four- and two-stroke engine small components such as gears, scavenging valves, bolts etc. A proper machine line is used for machining the fuel oil injection components (pumps and injectors). The machinery in this line has been chosen to obtain the high degree of quality required from these parts, together with good productivity. At the end of the line the fuel injection operational control system is catered for.

4) Workshop equipment store and shop maintenance area—two bays.

5) Auxiliary material store and tool grinding shop, centralized for the whole factory, are placed in proximity to the road, which gives access to the large machine shop also. In this area is also located the tool presetting shop for all the n.c. machines, most of which are installed in the small and medium machine shop.

6) Machine tools for machining two-stroke and four-stroke engine components for which it has not been possible to organize specific production lines. It includes several n.c. machining centres for milling, boring, drilling and tapping.

7) Four-stroke engine liner and connecting rod machining. Among the several machines installed, the more interesting are one profile-copying milling machine, one deep hole drilling machine and a n.c. lathe for the medium speed engine liners.

8) Here the two-stroke engine long tie-rods, the four-stroke engine camshafts and two-stroke engine lub. oil swinging pipes, the four-stroke engine cylinder heads and other components are machined. Some of the most interesting machines installed in this area are two n.c. machining centres with 15 kW (20 hp) spindle motors, capable of carrying out completely the milling, boring, drilling and tapping on the four-stroke engine cylinder heads. They are provided with a store of 50 tool capacity, one working table and two pallet loading stations.

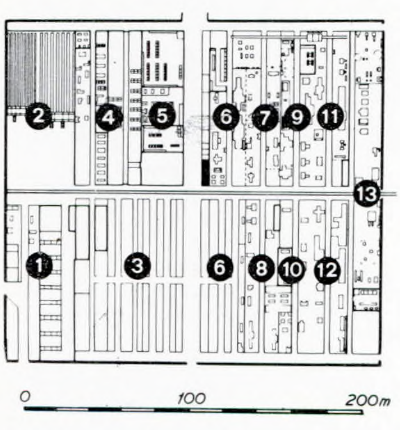
9) Machines for two-stroke engine piston skirt and cylinder liner, upper and lower part, machining. Some of the most interesting machines are four n.c. vertical lathes and the n.c. horizontal lathe, used for the complete turning of two-stroke large engine liners, fitted with a 100 kW (150 hp) motor.

10) Machining of two-stroke engine piston and cylinder heads. Among the most interesting machines are two n.c. vertical lathes and two machining centres provided with a 50 tool store and 30 kW (40 hp) spindle motors, for milling, boring, drilling and tapping. There is also plant for applying a special anti-corrosive metal coating to the piston crown.

11) Machining two-stroke engine main and big-end bearings, and crosshead guide shoes. The most important machines here are one n.c. machining centre provided with a 36 tool store used essentially for finishing and a two-head gantry drilling machine equipped with an 18 kW (25 hp) motor and two working tables for large drillings.

12) Machining two-stroke engine piston rods, connecting rods and crosshead pins. Some interesting machines are in this department, viz, two large lathes, one of which has a copying device, while the other is an n.c. type; one large drilling machine for deep drilling, maximum 5 m (16 ft) deep × 180 mm (7 in) maximum diameter; two n.c. machining centres, one of which has a 30 kW (40 hp) spindle motor and is used essentially for crosshead pin complete finishing and the other, with a 50 tool store and a 22 kW (30 hp) spindle motor, used for large connecting rod and piston rod drilling, boring, tapping and milling.

13) In this outer area plant has been installed for sand-blasting parts as well as for initial protective spraying, and for heat and galvanic treatment, also for babbitting bearings. Great care has been taken in designing the heat treatment plant, to assure the necessary accuracy and to minimize the manual operations, by using, where possible, automatic or mechanized devices for loading, unloading and control (Fig. 16) of the furnaces. The two centrifugal machines installed here were specifically designed and built for babbitting large bearings.



1) Goods receiving and acceptance test department
2) Finished parts store
3) Gears, fuel injection equipment and various components
4) Auxiliary material and shop equipment store, maintenance of tools
5) Tool grinding and presetting for n.c tools
6) Various components for two- and four-stroke engines
7) Cylinder liners and connecting rods for four-stroke engines
8) Tie rods, camshafts and cylinder heads for four-stroke engines
9) Liners, piston skirts and cams for two-stroke engines
10) Cylinder heads and piston heads for four-stroke engines
11) Bearings and sliding shoes for two-stroke engines
12) Piston rods, connecting rods and crosshead pins for two-stroke engines
13) Heat and galvanizing treatments, bearing babbitting

FIG. 15—*Small and medium machine shop*

AUXILIARY SERVICES

Steam Plant, Outdoor Sub-station, Compressed Air Production Plant, Methane and Oxygen Systems

The steam plant, compressed air production plant and electric power distribution room, which feed the factory, have been installed in a single building placed in proximity to the outside high voltage line junction with the factory.

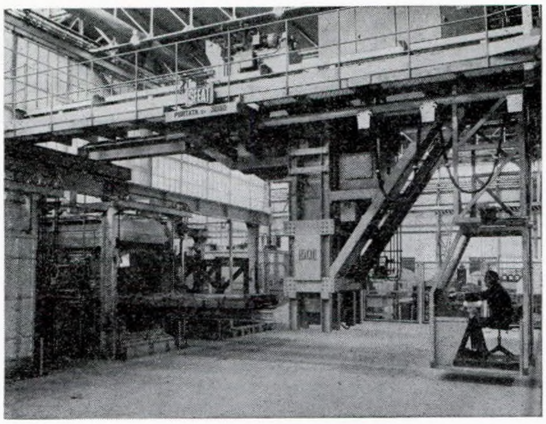


FIG. 16—*Furnaces and tanks for thermal treatment with mechanized material loading*

The electrical sub-station is located outside, adjacent to this building.

The steam needed by the factory is produced by four boilers; three of 30 bars (430 lb/in²) for heating, and one of 10 bars (142 lb/in²) for industrial purposes.

The heating of the separate buildings is by water, heated to 160°C in heat exchangers, fed by the steam from the boilers.

Electric power is fed into the factory via a high voltage line (130 kW), connected to two 15 MVA, 130/15 kV transformers. A 15 kV network brings the power to cabins located in the individual workshops, in proximity to the main areas of consumption. A 380 V metal-enclosed bus duct carries the power from the transformer cabins to the individual users.

Compressed air for factory industrial demands is produced by four electric compressors of 3450 m^3/h (12 200 ft^3/h) capacity each, at 7 bars (100 lb/in²).

The methane pipeline terminal and the pressure reduction cabin are situated not far from the steam plant. The methane is used mainly for the heating treatment furnaces and for oxy-hydrogen cutting.

Oxygen is delivered to the factory also through a pipeline, which connects with a compressed air gas production station, already in existence and located some miles from the factory.

The pipes connecting the central fluid systems with the individual workshops are placed on a pipe track located about 8 m (26 ft) above ground level.

Engine Cooling Water Plant, Fuel and Lubricating Oil Storage

Since there is no adequate natural water source near the factory, it was decided to cool engines under test by a closed circuit. The three cooling towers are capable, even in summer, of dissipating heat corresponding to about 45 000 kW (60 000 hp) of engines simultaneously under test.

Near the cooling towers are four engine fuel tanks: one for gas oil, and three for light and heavy fuel oils.

Lubricating oil is, however, kept in drums, which arrive at the factory by road or rail.

Effluent Water Treatment

The factory is equipped with an effluent water treatment system, including the most effective and up-to-date equipment and technologies. It assures a degree of purification acceptable to present European laws. For the effluent water, there are four distinct piping systems:

a) drainage line for the clear water, with direct discharge to a stream flowing near the factory;
b) sewer line for the hygienic service water; provided with purifying system;
c) general industrial line for oily and muddy water, with purifying system;
d) special industrial water line for the acid, alkaline and cyanide and chromate containing water; provided with an anti-toxic system.

The main characteristics of the treatment system can be summarized as:

Sewer System Purification Plant: This process is carried out in biological oxidization basins by the active mud method. It is possible to perform a final chlorination operation in case of particular need.

Technological Waters Purification Plant: This is capable of purifying a 200 m^3/h (7000 ft^3/h) outflow, polluted by lubricating oil, emulsified oils and various suspended substances. It includes one decantation basin, one tank for mixing with additive, and one clarification basin for vaporization and sedimentation.

Poisonous and Acid Water Purification Plant: This comprises three groups of polluted water treatment.

The treatment of water containing cyanides; it includes one alkalinization basin and one oxidization basin.

The treatment of water containing chromium salts; it includes one acidification basin and one reduction basin.

Sulphuric acid neutralization treatment is needed for water coming from the workshop pickling plant and for the water coming from both the previous treatment plants. This plant is equipped with a neutralization and decantation basin.

Afterwards the deposits which have formed in the various treatments are sent to a concentration and drying plant.

PRODUCTION ORGANIZATION

Production

The super large bore engines, of which a relatively small number of units is built, are produced on single production orders, with one or two engine lots.

For smaller size engines, which are required in larger numbers, production is organized in larger engine lots, or lots of parts common to different engines, when the cylinder numbers cannot be forecast readily.

For instance, for the smaller four-stroke engines, lots of parts common, for 30–40 engines, are put in production and smaller lots of those components, e.g. crankcases and crankshafts, which vary according to the engine cylinder number and, therefore, can only be defined after receipt of the customer's order.

Spare part production is organized by lots, determined by the Technical Assistance Services, on the basis of statistical data and in order to have, in the spare parts store, a fixed minimum stock.

Data Processing Centre

Production is organized with the help of the Data Processing Centre, through which go all the production documents.

The centre's IBM 360/40 computer is not only utilized for administration work, as is usual with this useful auxiliary, but also as a means of programming and controlling production progress.

To this end the centre is connected to 38 terminals located in the workshops.

For scientific calculations, however, the engineering offices are connected by a suitable terminal, to a large computer centre in Turin.

Quality Control

Quality control has been organized in accordance with the most modern concepts of works organization.

It stems directly from the factory general management and is, therefore, completely independent of the production management. From quality control stem both the quality control organization and production inspection.

The quality control organization has been established on the basis of the following fundamental concepts:

a) to assure that during all the productive cycle phases, from purchase order to final inspection, all instructions to guarantee accordance with drawings and standards, are forwarded to the offices concerned;
b) to check, through inspection, that the drawing and standard indications were followed in the manufacturing of components;
c) it is not only necessary that every departure from standards or

drawings be authorized by an inspector, but also by at least a foreman, while for the most important cases a higher authority must be consulted;

d) deviations from drawings or standards must be recorded on proper cards that are sent to all the interested offices; it will thus be possible to avoid future repetition;

e) quality control is responsible for the quality of material from outside suppliers and periodic control of the machine tool operating conditions.

Quality control operates in the workshops, through seven main centres fitted with inspection equipment, completely independent of that of the workshop.

For inspection of large parts there are three machines for tri-dimensional measurement, equipped with digital read-out systems, which allow for quick control of the most complex parts, up to a maximum size of 5 × 2·60 × 2·50 m (about 16 × 8 × 7 ft.)

For control of machine tool working movements, a laser ray interferometer is used, which has proved very useful, even during installation of machine tools.

At the disposal of the quality control organization there is a standard room, with air conditioning, in which are installed modern high precision measurement instruments up to 0·001 mm (0·00004 in), which are required, for example, for control of certain components of the engine injection system.

SPARE GEAR, REPAIRS AND AFTER-SALE ASSISTANCE ORGANIZATION

The aim of this paper has been to give an idea of the most interesting characteristics of the production means installed in the new factory.

Therefore more time has been spent in illustrating the Diesel engine manufacturing cycle and omitting other sectors, which also have a fundamental importance in the new factory, such as: sales and marketing, research and development, administration, after-sale assistance and others.

Even though the matter does not directly concern the subject of this paper, it might be interesting to mention, briefly, a sector, important to the user: the spare gear, repair and after-sales service organization.

Over a period of time a growing organization and world-wide network of assistance centres has been established. This organization was transferred to the new company and in some ways improved in order to meet the new more onerous requirements.

The parent company started an after sales service for its engines, based on maintenance contracts, on which basis the supplier engaged himself, for an annual fixed fee, to keep the engine at normal efficiency, thus avoiding any technical and economic concern for engine operation by the owner.

Customers have much appreciated this kind of assistance and today 95 maintenance contracts for marine propulsion sets are in force.

According to the standard maintenance contracts, which have a five year, renewable duration, it is now the new company, Grandi Motori Trieste, that undertakes:

i) to supply all the spare parts, including a suitable stock of spare parts to be carried on board, and to provide the skilled and qualified labour for all maintenance work, including surveys required by classification societies;

ii) to supply adequate technical assistance for achievement of the guaranteed engine efficiency and, for the use of the most economic fuel of the operator's choice with respect to the adopted engines.

Alternative contracts to the standard one can be arranged, for instance, so as not to include the supply of skilled and qualified labour, at the user's request.

The Technical Assistance Organization

The technical assistance, repair and spare parts service employs about 600 people and is headed by a central office which is located at the G.M.T. works where the engines are built.

The technical assistance work is accomplished through a system of external harbour repair workshops and technical assistance centres world-wide. The system is integrated by a group of inspectors and by a number of experts from head office who travel all over the world to wherever intervention is required.

Central Office

The central organization is divided into four sectors.

Assistance for Two-stroke, Four-stroke, Rail and Naval Engines

This sector co-ordinates the assistance programme for the above groups of engines within the technical outline and the guarantee inspections laid down in the maintenance contract and requested by the operators. It deals with more than 2000 engines aggregating 4 900 000 kW (6 500 000 bhp).

Repairs

The repair of engine parts which can be utilized again (re-babbitting of bearings, reconditioning of cylinder heads, pistons and fuel valves) is carried out, for the greater part, in the technical assistance organization harbour workshops, but a part (general overhauls of four-stroke, high speed engines, reconditioning of large cylinder liners) is carried out in the works at Trieste.

Procurement, Storage, and Distribution of Spares

The sector co-operates with the assistance sector mentioned above to maintain a world-wide programming of spares, which is systematically up-dated, to be able to meet the requirements of the maintenance teams and provide all engines with spare parts, to meet whatever need may arise. For this reason a large central store has been established. Furthermore, stores for immediate use, are distributed at the harbour assistance centres both in Italy and abroad.

Financial, Administrative Sector

This department attends to all the commercial and administration requirements of technical assistance organizations, drawing up the maintenance contracts, evaluating and invoicing for work done, administration of personnel and the economic requirements of the external workshops, fiscal and customs matters.

External Organization

The external organization has six port repair shops and 30 assistance centres. It employs 500 persons throughout the world-wide organization.

The repair shops were established in ports where vessels with engines under maintenance contracts frequently call. The centres are arranged so that they can cope with all the operational requirements being provided with a repair shop, a suitable spare parts stock and manned by skilled staff.

In ports where those requirements are not so great and, therefore, do not justify the establishment of a repair shop, the assistance centres are provided only with a spare parts store and with a number of skilled men from the technical assistance organization. Where requirements of technical assistance cannot readily be forecast, agreement has been made with local repair companies, which work under technical control of G.M.T. engineers, for repairs of G.M.T. engines.

There are six assistance centres of the major type; at present five are in Italian ports (Genoa, Naples, Venice, Trieste and Taranto) and one in Argentina (Buenos Aires). The repair shops at these centres, particularly the more heavily equipped units of Genoa, Naples and Buenos Aires, are able to provide practically all the typical reconditioning services which can be applied to components of the two- and four-stroke engines.

The repair shops are, therefore, provided with adequate machine tools—even those with reasonably large dimensions—and with installations expressly designed for cyclic reconditioning operations.

The assistance centres for the second type, that is without repair shop, are 30, six of which are in Italy and 24 in foreign ports.

With the increase of large vessels now in world-wide service, the frequency of annual repairs in foreign yards has considerably increased and, therefore, it has been necessary to extend the service centres to more foreign ports, a procedure which is still going on.

MISCELLANEOUS

It might be interesting to know how the design and the installation of the new factory and the choice of the personnel have been organized, and the main difficulties met during the first period of activity.

For the technological and specific plant design, an office was created consisting of a team of skilled personnel whose complement varied with the requirements of the different phases of the design. These personnel were particularly expert in this field.

This office also took advantage of studies about new machining methods given to sub-contractors and machine tool builders.

The technological project and the choice of the machine tools were thoroughly discussed with the future responsible staff of the new factory manufacturing sectors.

For the installation of manufacturing resources a second office was subsequently set-up, which operated, for the most part, on the installation site.

During the first stage of activity of the factory, many difficulties were met, due to delays in commissioning and in the setting up of some machine tools: it must be said that most of the suppliers, some very well known, did not fulfil the agreed commissioning dates.

These delays that, for some large machine tools, lasted several months and sometimes for more than a year, caused serious trouble to the initial organization of production, as many machining operations had to be carried out on other less adequate machines, designated for other machining operations; moreover some machining operations had to be transferred to other external, not readily available, workshops.

This caused serious trouble, not only in the production schedule, but also in the installation of the manufacturing plant, the programming of which had to be modified several times.

For setting up the n.c. machines, the choice of a single supplier of n.c. equipment proved very useful, as, with a single team of technicians of the company building them (Fiat) always present at the first period of activity, it was possible to take action at once every time an unavoidable difficulty arose.

The personnel required by the factory were mainly chosen from the Trieste and Turin factories, where personnel were to cease their activity in the Diesel engine field, as the new factory came into production.

From Turin particularly came personnel highly qualified in the following sectors: commercial, design, research and development. Personnel for administration and workshop requirements were mainly chosen from Trieste.

To complete the organization chart of staff employees, new engagements were made and training courses organized by the two partner factories in Turin and Trieste. Courses were organized at Trieste, by an I.R.I. Institute, for training young staff.

Discussion

MR. A. A. J. COUCHMAN, B.Sc., A.M.I.Mar.E., said that the design and layout of a factory the size the author had described was undoubtedly a complex matter, and equally difficult to commit to paper, particularly in a foreign language. He complimented the author for achieving this and for giving the Institute a concise paper which covered an extremely wide sphere.

The paper should be of considerable value, particularly to the more elderly seagoing staff and those marine personnel ashore who did not have the opportunity of visiting such factories.

Perhaps one of the most important aspects of this factory layout was the apparent universal introduction of numerically controlled machines, a subject which could in itself form the basis of a complete paper. The range extended from very large to medium sized installations, all with their inherent complex construction and control systems. Apparently they had not been introduced without some teething troubles, and he wondered if the author could indicate some of the problems encountered in achieving operational satisfaction.

It was particularly noticeable in the paper that machining accuracies and manufacturing tolerances which were associated with numerically controlled machines had not been dealt with in any detail. Mr. Couchman thought this was a rather important omission in a paper of this type, and he hoped that the author would be able to fill in in his reply. Perhaps some values for such items as pistons, cylinder liners and crankshafts could be given as examples.

With such sophisticated machines there must be ways of accommodating the sort of inaccuracies found in the older type of machines. Typical questions were: How did the machine compensate for tool wear? What was the reproduceable accuracy that could be obtained with a temperature rise of, say, 20°C, and could the machine deal with such a temperature rise? What were the influences on machinery accuracy of foundation movement, particularly with the large machines? Finally, how did the operator know when the machine was not working within the given tolerances? Could the author kindly give some information on how these problems had been overcome on the modern machines?

The paper gave the impression that the conventional techniques for marking off and using jigs had been somewhat superseded with the introduction of numerically controlled machines. Parts appeared to be set up on a table and they either moved or revolved into the position to be machined. Mr. Couchman wondered if the author could confirm the correctness of this impression and give more detail on the modern methods and procedures required for mounting parts for machining.

He assumed that the programming of these machines started with the translation to tape of the details of the design drawings, together with the necessary setting up instructions. As a layman in this particular field of programming he would be extremely interested if the author could give simple examples of a programme instruction chart employed on one of the numerically controlled machines.

It was obvious that machines of this calibre required to be maintained to a very high standard, and the use of planned maintenance seemed essential. In this context he asked the author to give some idea of the maintenance system now used, the maintenance man hours required for any particular machine, and the machine dead time that might be expected in a year.

The author had made the point that he foresaw a 75 per cent reduction in manufacturing hours on bedplates, A frames and cylinder blocks on a 1060 mm type engine. Mr. Couchman thought this was a rather amazing improvement in production efficiency, which, if perpetrated throughout the factory, would appear to justify the modern techniques employed and the nitial heavy capital outlay. Could the author say whether at this stage of operation these improvements had been achieved in a new factory, and answer a question which was very pertinent to the shipowners: how much cheaper would the larger marine Diesel engines be?

It would be even more valuable if the author could put these savings into a more detailed perspective. Could he give some idea of the lead time, the work or flow time and the dead time associated with the manufacture of the bedplates, A frames, cylinder blocks, and perhaps the crankshaft liner and connecting rod, in the new factory, and compare them with similar figures achieved with the old techniques?

Turning to three rather direct questions, Mr. Couchman asked the author which items in the new factory still required to be hand finished and fitted? What cladding material was now used for the piston crowns? What method was now used for reconditioning cylinder liners?

He admitted to an element of surprise when he had read in the paper that crankshafts were manufactured outwith the factory. This particular item needed to be manufactured under strict quality control and most managements, he thought, would have preferred to have had direct responsibility for it. It would be interesting if the author could indicate the considerations which had led to the decision to manufacture this item elsewhere.

With a paper of this type he thought it was tempting to continue at length out of sheer interest in the other man's field. Quality control, packaging of finished items and transport difficulties were some of the many subjects that could easily be discussed, but he would content himself with one final point. There was no doubt that the design, planning and layout of such a factory was a tremendous undertaking, but inevitably there were layouts and processes which, in the light of hindsight, might have been improved. He asked the author whether, with present operational experience, and given the opportunity, he would change anything in the new factory?

MR. J. MCAFEE, Vice-President, I.Mar.E., said that the existence of the factory owed much to an Italian idea—the Institute of Industrial Reconstruction. This was a statutory body which stepped in at an early and opportune moment, becoming a major shareholder in industrial organizations, but leaving to private enterprise the responsibility of getting on with the job. In his opinion the results over the last 20 or so years, so far as Italian industry was concerned, appeared to be much better than those from the U.K. system of injecting Government money into an industry only when it was on the point of collapse.

It would seem that a large part of the output of the factory would consist of medium and high speed engines for land purposes produced on a repetitive basis for which no doubt the potential market had been well assessed. Large marine engines were, however, another matter, and shipowners were sometimes actuated by motives no more logical than that of a woman choosing a new hat. The concentration of the Italian Diesel engine industry into this one factory would appear to offer prospective marine clients something analogous to Henry Ford's famous car, that was, any colour one liked, provided it was black! He wondered, therefore, if it was indiscreet to ask what happened to the owner who, however misguided his reasons, wished to install an engine of other than the Fiat type. With the extensive use of numerically controlled machines, the works appeared to be able to produce other types without expensive tooling and jigs, but was this ever likely to arise?

It was noteworthy that the most important part of each engine, the crankshaft, was bought in. In this instance, who was ultimately responsible for quality and, in particular, the soundness of the cast steel combined webs and pins, and for seeing that the shrinkage allowances were within the defined limits?

One of the major ills of the large marine Diesel was malalignment, for which the naval architect was often blamed. The accuracy with which the bedplates of the Fiat engines were machined could be appreciated from the paper. When these were erected on the test bed what was the method of alignment, and how was this reproduced during installation on board?

Finally, he said it was refreshing to note that facilities were being provided for repair in ports of call. One had sometimes been led to believe that engines described in papers would never require any repairs at all, but it was clear that Dr. Gregoretti and his colleagues had a more frank and realistic point of view, which no doubt would be appreciated by owners in days to come.

MR. B. TAYLOR, B.Sc., M.I.Mar.E., said that after listening to the description and seeing the slides of the magnificent facilities that had been built up at the new G.M.T. factory at Trieste one wondered how costs of production compared with the costs of production in the previous works, which presumably were more old-fashioned, had less sophisticated machine tools, and so on.

In one place in the paper Dr. Gregoretti had referred to a saving of 75 per cent in man hours. In other parts he had mentioned considerable reductions in machining times by the use of numerically controlled machines. However, there did not appear to be any information about the overall savings that had been made. Mr. Taylor had tried to make some deductions from the paper and had taken as his basis the number of people employed in the factory, which the author had stated as 2300, including staff employees and manual workers. This did not show the number of people directly employed in production, but assuming that the ratio was somewhat the same as in the U.K. (or at least in his company), it would be about 1000 direct production workers. If the maximum output of the factory, as stated, was 634 000 kW (850 000 hp) per annum, that meant an annual production from each worker equivalent to 634 kW (850 hp). The expectation with conventional machining methods, and in a more traditional or old-fashioned establishment, might be about 40 or 45 kW (550 or 600 hp) per annum for each production worker employed. This would suggest that in the new G.M.T. plant Dr. Gregoretti and his colleagues had increased their productivity by something like 50 per cent or more. He asked the author to give some indication as to whether his guesswork was anywhere near the correct figure. He had taken into account the fact that at the G.M.T. factory the cost of producing crankshafts was not included in the figures given for manpower, and similarly he had made allowances in his estimates for that.

Many of the machines were fitted with split tables and allowed one component to be set up whilst the other was being machined. He asked the author whether he employed two men on a machine like that, or did one operator do the whole job? Also, did the works have some kind of incentive payment system for the men employed on production?

Another interesting comparison was to look at the total covered area of the plant. Again he had made comparisons with his company's engine works. He had found that actually there was little difference when one worked it out on the basis of square metres per kilowatt produced annually. The author stated in the paper that the covered area of the new factory was 150 000 m^2. It worked out at about 4·2 m^2/kW. That was based on the annual output. Looking at the illustrations one was struck by the roominess and space around all the machines. This was rather a surprise to Mr. Taylor, because when he had calculated the floor area of his company's works he had found that it worked out quite close; it was 4·1 m^2/kW.

He had been very interested to read that certain machines were accommodated within the fabrication shop, allowing it to be more or less self-contained. There was also a reference to the shot blasting of plates before fabrication, but he could not see any reference to equipment for shot blasting the finished fabrications, and he wondered whether this was done.

He asked whether the author used numerically controlled burning machines for plate preparation.

In connexion with the fabrication shop he had noticed that the A frames, or columns, were stress relieved. Was there any particular reason for this? It seemed rather unnecessary to go to the expense of heat-treating the columns, because so far as he knew, in the Fiat engine they did not transmit any direct load. The combustion loads were passed through long through bolts to the bedplate.

The other section of the works which was most interesting was the large machining department. He had been particularly interested to read the description of the large facing and boring machines, because such large machines normally determined the total throughput of an engine works producing slow speed engines. He was rather puzzled by the author's description, and would like him, if he could, to describe exactly what he meant by the "adjustable rail milling machines". Would these be the type of machines usually referred to as ram borers?

Finally, he would be interested to have Dr. Gregoretti's views on the value of test bed running of engines. He had noticed that G.M.T. provided magnificent facilities for testing their engines. Did Dr. Gregoretti really think it was necessary? Did they propose to continue to test all engines on the test bed?

Correspondence

Mr. A. Storey wrote that he found the paper of great interest and complimented the author on the comprehensive nature of his descriptions which gave a very clear picture of this new factory and how it was intended to operate.

In earlier days when Mr. Storey was the director in charge of an engine works in Sunderland, he had had the opportunity of putting through what was for that company a large scale extension of manufacturing facilities but without the benefit of such vast sums of money as must have been at the disposal of those responsible for the creation of this splendid new modern factory at Trieste, but at the time the company were not aiming at anything as high in ultimate output, measured in kilowatts.

Later experience, when in control of engineering activities elsewhere, had enabled Mr. Storey to achieve a throughput of one million horsepower per year when producing engines for the large scale British Rail Dieselization Programme. This was achieved mainly by re-routing work and cutting down transport with heavy accent on additional jigging, but with no appreciable additional capital expense on plant outlay and new machine tools.

The factory layout as described appeared to be very convenient and compact although reference to the photographs rather suggested that some engine components, particularly larger units such as bedplates, must have had to be moved considerable distances. This problem was perhaps unavoidable with a plant designed for the production of engines as large as the type 1060S, whilst having in addition to cater for eight other classes of engine with a prospective overall annual production up to 634 000 kW (850 000 hp).

Dr. Gregoretti mentioned that a foundry for cast iron work had not been included and Mr. Storey recalled that Dr. Feri, of the Engine Design Department, in his article in the "Motor Ship" special survey of engines of Grandi Motori Trieste* stated that the production of Diesel main engines expressed in terms of horsepower had remained almost constant in recent years but that the production of 4-stroke engines had constantly increased. In these 4-stroke engines cast iron was used for the two main parts of the structure, i.e. the bedplate and frames, and in view of Dr. Feri's remarks regarding increased production of these engines, it would be interesting if Dr. Gregoretti could expand a little on the reasons governing the decision not to establish a foundry within the new factory.

Referring to the location of the factory, it was presumably not possible to lay down a plant with closer direct access to the sea, so that loading for sea transportation could have been more direct from erection bays with some resultant saving in loading and transporting costs, and in lower prices to customers.

Great credit should be placed on those who had given so much thought to providing such excellent craneage facilities, and it was particularly pleasing to read that the project generally and the choice of machine tools was discussed with future responsible staff. Although adjudication would still be needed on many more very personal requirements this did seem to produce in the final event an overall scheme in which many ideas had been combined to good effect, and would undoubtedly assist in the smooth operation and usefulness of the plant as a whole.

Speaking rather as a potential customer for Fiat engines, it was perhaps a little disappointing to find no indication in the paper of the anticipated reduction in manufacturing lead time brought about by the capital outlay, nor was there any reference to the extent by which the retooling and planning would reduce the fitting and assembly time and/or cost. It would be most helpful if figures could be quoted showing that the increase in capital cost was justified by the reduction in the unit cost and production lead time. Whilst N.C. machines had their place where there was continuous production, orthodox machines and jigs were sometimes preferable and certainly cheaper, which thinking made it difficult to fully support the total theory of eliminating jigs by the purchase of expensive N.C. machines.

It was more likely that in the overall factory design, comfortable margins had been allowed for possible future expansion, which would explain why an apparent over generous use of space had been made, realising that this inevitably meant an increase in the cost of rent and rates of the buildings, at least from the British Industry point of view. Considerable use appeared to have been made of many very heavy machines with Tandem tables and Mr. Storey doubted the wisdom of buying large and expensive N.C. machines capable of milling and drilling since the feeds and speeds were completely different for drilling, and the end result was a very expensive drilling machine.

His inclination would have been towards tooling separately for the drilling operations, but he was sure Dr. Gregoretti could quote some good reasons against such thinking which it would be of interest to hear.

No specific mention had been made of the stores and pre-marshalling of sub-assembly kits both for the fitters and erection teams, and it would be an advantage to be given more details of the X-Ray and laboratory facilities. In addition, some details of complete pipe manufacturing facilities adjacent to the engine assembly and test would add to the value of this extremely attractive paper.

Finally, it was pleasing to note that the very important aspect of spare gear, repairs and after sales service had come in for careful consideration when setting up the new plant. The maintenance contract type of after sales service appeared to be a good idea and perhaps more details, particularly of how it would operate for ships on long term charter, involving voyages between—say—India and U.S.A. or China and South America, would be interesting.

Mr. K. J. O'Neil, in a written contribution, commented on the standard Cathedral type two stroke engine presently under construction at Trieste. Having recently taken delivery of a 786S engine from the Turin factory, which had not been prior shop tested, it was gratifying to report that this engine was performing satisfactorily in service. This in itself spoke highly of the quality control that existed at Turin, even during the transitory period when personnel were being transferred to Trieste. Would Dr. Gregoretti comment if non-shop tested engines were envisaged at Trieste and if so, would there be any monetary inducement offered to owners who took advantage of this facility?

Mr. O'Neil questioned the economics of G.M.T. continuing their policy of supplying the salt water pipes connected to the scavenge air coolers in galvanized iron, since owners today invariably specified for non-ferrous piping to be fitted to all salt water cooling systems. It would appear logic to deliver the engine without the piping. The argument might be carried a stage further by allowing the builder to provide for any sacrificial anodes that might be required in the engine cooling systems. This was preferable to providing standard anodes which might not be compatible with chemical inhibitors introduced as a result of an owner's requirement. It might be said that the points raised were better solved by the engine builder and the ship builder getting together; experience showed that this rarely took place to the degree required. Since cost control was a subject that concerned us all, Dr. Gregoretti's comments on the above points would be most welcome.

Mr. G. Cariou wrote that his remarks would not concern the main subject of Dr. Gregoretti's paper, which was the production of engines at Grandi Motori Trieste's Diesel engine factory, but only the complementary indications given by the author on the after sales assistance organization, which should allow the owners to avoid any technical or economical troubles during the exploitation of their ships.

The maintenance contracts were foreseen to assure the supply of spare parts, the repair works necessary to maintain the

* Feri, V., Dec. 1971, "Engines and Facilities of Grandi Motori Trieste," Supplement to *The Motor Ship*, p.93.

engines in good condition and the execution of the surveys required by the Classification Societies.

Did these contracts contemplate the steps to be taken after damage occurring at sea when the crew was left to itself? He thought in particular of a case when one or several cylinders might be isolated and the running resumed at least to reach a repair harbour. The running and maintenance manuals indicated the general operations to be executed to isolate a cylinder, with or without removal of rods, but did not indicate the maximum authorized rev/min of the engine from then until its repair to avoid any other serious trouble, i.e. torsional vibrations. It was desirable that the manufacturer should give some precise instructions in this respect, both to the owner and to the Classification Society, for the different cases which might occur according to the position of the concerned cylinder or cylinders. This could be a good example of after sale assistance.

A similar problem could be met in case of damage to turboblowers.

Author's Reply

Dr. Gregoretti thanked Mr. Couchman for his interesting contribution to the paper and began his reply by showing Figs. 17 and 18 to illustrate tolerances required for some components of the four-stroke and of the large bore two-stroke engines.

ISO tolerances were used wherever possible:

Nos. 5, 6 and 7 for small engines;

Nos. 5, 6, 7 and 8 for larger engines.

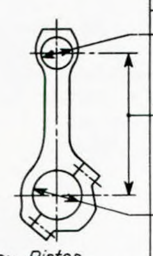
Tolerance No. 5 was used essentially for the high precision borings and for the machining of the cross-head pins.

These tolerances could be obtained without any difficulty on numerically controlled machines whose machining accuracy was high.

Concerning the influence of ambient temperature variations and foundation movements on the machinery accuracy, an inside temperature rise of 20°C was exceptional, because the factory was located not far away from the sea, that is in a site where large ambient temperature rises—as in the continental climates—were not possible.

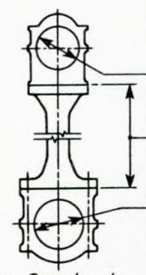
Temperature changes gave some difficulties in the first

4–S. Engine (210mm bore)



	mm	Iso No.	Tolerances mm	Tolerances Inches
	90	H7	0	0
			+0·035	+0·0014
	465	–	+0·03	+0·0012
			−0·03	−0·0012
	164	H6	0	0
			+0·025	+0·0001
Pins:– Piston	80	–	−0·010	+0·0004
			−0·020	−0·0008
– Crankshaft	155	g6	−0·014	−0·0005
			−0·039	−0·0015

Slow speed 2–S. (1060mm bore)



	mm	Iso No.	Tolerances mm	Tolerances Inches
	680	H8	0	
			+0·120	+0·0047
	2188	–	+0·2	+0·008
			−0·2	−0·008
	820	–	0	0
			+0·06	+0·0024
Pins:–Crosshead	680	e5	−0·160	−0·006
			−0·193	−0·0075
–Crankshaft	820	e8	−0·180	−0·007
			−0·310	−0·012

FIG. 17—*Connecting rod machining tolerances*

	mm	Iso No.	Tolerances mm	Tolerances Inches
CYLINDER	1130	H8	0	0
			+0·155	+0·006
	2975	–	+0·1	+0·004
			−0·1	−0·004
	1900	–	+0·05	+0·002
			−0·05	−0·002
'A' FRAME	1130	–	+0·05	+0·002
			−0·05	−0·002
	5000	–	+0·2	+0·008
			−0·2	−0·008
	2825	–	+0·10	+0·004
			−0·10	−0·004
BEDPLATE	1000	H7	0	0
			+0·092	+0·0036
	975	–	0	0
			+0·05	+0·002
	2085	H13	0	0
			+1·87	+0·073
	987	H7	0	0
			+0·84	+0·033

FIG. 18—*Main structure machining—large engine (1060 mm bore)*

alignment operations of the largest machines, because, at that time, the central heating was not in full operation.

Foundation movements of significant value had not been noticed. It should be borne in mind that the very large machine foundations lay on rock or on deep piling and that the percentage of iron in the foundation blocks was relatively high, thus minimizing future adjustment movements.

Marking off the parts was done, where required, by conventional means. However, for the more complex items, for instance, fuel injection pump bodies or crankcases for locomotive engines, the laying out and inspection was done by a digital machine. G.M.T. had four of these, because carrying out inspection of all the dimensions of a large fuel pump injection body on the digital machine reduced the inspection time by about 50 per cent.

With regard to Mr. Couchman's other questions about the numerically controlled machines, drilling tool locating jigs and bushing plates were no longer required by the N.C. machines. For these machine tools only the simpler and therefore far less expensive part positioning jigs were used.

He said that the programming for the N.C. machines was done by a department which employed about 15 people. The starting document for the programming was the Shop Route Sheet, prepared by the Method and Routing Department. The machining route specified the machine and the main machining parameters to be used.

The programmer defined the processing, i.e. all the machining details such as: positioning of the part on the machine, the sequence of the single operations, and the tools to be used; and wrote a manuscript—the processing—in an appropriate language (ADAPT-AUTOSPOT) which could be understood by the computer, which then processed the programme.

From the processing a block of punched cards was obtained in a suitable punching machine (FRIDEN). These were processed in a computer, together with another block of cards—the post-processor—of which there was one for each N.C. machine tool. Normally the post-processors were memorized in advance in the computer. The output was a third block of punched cards and a proof copy of the programmer manuscripts. Comparison of the proof copy with the manuscript completed a first check. This block of cards was then read by a FRIDEN or VARIAN machine and transformed into the final punched tape which would be read by the N.C. machine tool cabinet.

Before sending the tape to the machine tool a second important check was made in a plotter operated by a VARIAN computer. The output indicated, on a large paper sheet, all N.C. machine tool movements and operations.

For correct operation of the N.C. machines all the tools must be preset in a special workshop department from where the tools were sent directly to the machine operators.

When a brand new tape was used each movement and operation was carefully checked and the first piece to be machined was completely inspected. Subsequently, only the more important dimensions and machined surfaces were inspected, particularly those which could be influenced by tool wear.

A detailed list of operations, prepared by the computer at the same time as the punched tape, was sent to the operator, together with the tape. In this way he could ascertain at any moment whether the indication by the displays of the N.C. cabinet corresponded to the written list.

The movement precision of the N.C. machines was checked very carefully by means of a laser-ray measuring device before putting the machines into operation and periodically, from six months to one year, the machine was inspected and checked again. The period between checkings was determined by machine operation experience and all inspections and checks were made by Quality Control personnel.

With regard to Mr. Couchman's question about how long a machine was idle during one year, they had not yet had enough direct experience at Trieste to give an answer, but with the machines in the factory at Turin it was noticed that the utilization time was practically 90 per cent and never less than 80 per cent. When planning the new factory they had taken into account 80 per cent availability of the machines.

Referring to the question about reduction of machining times, at Trieste they had foreseen, for the largest engine components, a reduction of 80 per cent in the milling operations and 85 per cent in the drilling and boring operations. For the hand operations—the loading and setting up of the parts—they had had only a 30 per cent reduction.

Hand fitting was required up to some years ago for better matching of the main bearing and the crosshead bearing surfaces of the largest engines, but today, with the better machining obtainable, this was no longer necessary.

The protective layer applied to the piston heads was a metallic layer applied by spraying a special Cr-Ni-Bo alloy; this was then melted by flame application in order to have penetration of the layer into the ground material of the piston. The thickness of the layer was checked by a magnetic device.

Because of the constructional features of cylinder liners for the large-bore engines, when a liner was worn it was possible to repair it by reconditioning the original steel part; the repair consisted of replacing a cast iron bush in the top liner, shrink-fitted into the steel casing, and coupled to a new cast iron bottom liner. The cylinder liner, thus reconditioned, was practically as good as new, but cost about 30 per cent less.

Mr. Couchman had asked why G.M.T. did not manufacture the crankshafts for their engines. In fact, Fiat had manufactured crankshafts immediately after the war for the two-stroke engines. There had been many reasons for doing this. The parent company had had a large steel foundry and could supply the cast pieces required and there had been difficulty in getting crankshafts from other firms in time. However, later on a large Italian crankshaft manufacturer was able to supply Fiat, so they stopped manufacturing them themselves. With regard to the four-stroke engines, they used to buy only the forgings outside and machine the crankshaft, but had had difficulty with replacement of those which had been shown to be defective during machining and had found it more convenient to buy in the finished crankshafts.

Mr. Couchman's last question about what G.M.T. would change if they were to make a similar factory was a difficult one. Perhaps they had had too much confidence in machine tool suppliers. The supply of many machines had been delayed by many months and in some cases a year, so that it had been impossible to machine some parts in the manner intended. Possibly it would have been useful to have had some conventional machines for carrying out these operations with more flexibility; they could eventually have been used as standby machines.

Mr. McAfee was right in stating that with the extensive use of numerically controlled machines the works were able to produce various types of engines, without expensive tooling and jigs.

The crankshafts were bought in, but in relation to the owner the engine supplier was responsible for the soundness and the manufacturing quality of this very important component of the engine. To this end the Quality Control Department prepared very detailed specifications and inspectors of this department checked very carefully, at the supplier's works, the material quality, the dimensions and the finish of the machined surfaces. Ultrasonic devices and other up-to-date non-destructive inspection means were largely used.

With regard to Mr. McAfee's question about bedplate alignment on board ship, in the workshop, reference lines were marked on the fixed parts of the engines of the bedplate sections and uprights. The alignment was checked by rotating the crankshaft and measuring the deflexion of the webs. So on board ship the best assurance that the alignment was correct, was to check the deflexion of the webs. This had to be done throughout the day because heat from the sun could distort the ship, thus altering the alignment.

The most important thing about having a good technical assistance service was that customers could be sure that the engine would develop the guaranteed power and maintain the guaranteed fuel consumption during its life. Also, the manufacturer would receive continuous feed-back on the behaviour of the engine in service, and that would enable him to improve and develop better engines.

Referring to Mr. Taylor's point about reduction of the total cost of the engine, the cost of the investment was very high. In the new factory it had practically ten times more influence on the cost per manufacturing hour than in the former factories. Mr. Taylor's figure of 1000 direct production workers was correct. The difference between the number employed and the power produced per year in the two factories considered was due to the improved efficiency of the machining methods.

Until recently the factory had been considered as being in a starting up period and they had had no direct incentive scheme, but they had noticed room for improvement in the enthusiasm of the workers, and it had been necessary to introduce an incentive.

With regard to Mr. Taylor's point about the spaciousness of the covered area, G.M.T. had noticed that new shops were generally too small in design and had to be enlarged rather than reduced. More room, especially in the larger machining shops, brought about a reduction in man-hours, especially for handling and setting up large components.

Turning to the fabrication shop, they sand blasted all their welded parts. Their equipment could be seen in Fig. 7, (4).

The flame cutting machines were electronically operated but were not numerically controlled for the moment.

In his opinion stress relieving was very useful. It was the only way to eliminate completely all the stresses that arose during the welding of the component. It was true that the uprights were compressed by the tie rods so that no dangerous stresses could arise normally, but there could be many kinds of vibration on the engine which might cause such stresses. For this reason all the welded structures were stress relieved. On the other hand, having a large stress relieving furnace, they could load it with many parts simultaneously with very little more cost than treating selected parts.

An adjustable rail milling machine had a transverse rail that could be set at the proper height in order to minimize the distance of the tool from the rail, thus providing more accuracy and the possibility of using very powerful spindle motors.

Normally all their engines were tested on the test bed, but they had supplied engines without this and the results were usually good. Use of the test bed ensured that all things were functioning well. The engine had to be erected in the shop in any case and then run for 20 hours, and if not bench tested it had to run longer on sea trials or to have a longer running-in period at the beginning of the first voyage. His company had asked yards if they were prepared to run engines for more hours before ship trials, and had been told that they were not, so normally testing was done on the bench.

Mr. Storey's contribution was very valuable and the author agreed that the paper would have been more interesting if he could have given more details about other items, for instance, laboratories and research departments. But the length of the paper and the number of illustrations had to be limited and he had kept to matters he judged to be of most interest from the manufacturing point of view.

The decision to build a brand new factory was taken because lack of ground at the existing factories in Torino, Genoa and Trieste prevented their enlargement. Further, the adoption of new methods for obtaining a substantial reduction in manufacturing hours would have necessitated many new, modern and more powerful machine tools.

The location of the factory was the result of very long political discussions. For political reasons the factory had to be built in the Province of Trieste. The public authorities had been responsible for the levelling of the site and building a road, a railway line and a small harbour so that engines could be shipped from the factory direct to customers' yards. However, they would have preferred to have been located elsewhere, especially as, because of a shortage of water, they had been obliged to install expensive closed circuit cooling towers for testing the engines.

G.M.T. had no iron foundry because calculations had shown it to be uneconomic to build a new one for the needs of the Trieste factory. This would only have been justified if they could produce and sell items other than Diesel engine cast iron components. They already had iron foundries in Turin and Genoa, which could do a good job, especially in casting cylinder liners, which was not easy.

With regard to investing such a large sum of money for building engines of this capacity, his company had made careful calculations when the factory was being designed and had found that it would be economic. However, as in recent years labour costs rose beyond expectations, there was a point when they began to wonder if they had made a mistake. However, prices of engines had also increased, although not to the same extent, and they were confident that the balance would be regained in the future.

Mr. Storey had asked why there were so many N.C. machines. When one laid out a new factory, one must think not of what the situation was at present but what it would be in the near future. These machines required less-skilled workers, and fewer people designing and manufacturing the building and drilling jigs for the same quantity of production. In some cases, two machines could be operated by one worker. This was important when, as at present, there was a shortage of manpower. They could achieve the same production of certain parts with conventional machines now, but they would not be able to do so in the future. Therefore, the works was to be considered the shop of the near future.

As to why the drilling and milling were done on the same machine, the main milling operations were normally carried out on plano-milling machines but for oil sumps etc, which required mainly drilling and tapping operations and milling of relatively small surfaces, it was more convenient not to set up the parts a second time on a milling machine.

Replying to Mr. Storey's last question, a certain number of maintenance agreements out of the 100 or so in force for marine engines, covered ships trading for long periods of time away from the G.M.T. main service centres and repair workshops located mainly in Italian ports.

Experience showed that, by means of a maintenance agreement, these ships could also be satisfactorily serviced either by the G.M.T. service organization or by teams of skilled men expressly sent to any shipyard where owners might decide to carry out annual surveys. In this latter case, owners only reimbursed travelling and living expenses.

Another kind of maintenance agreement included the supply of all spares needed to ensure regular operation of engines and the assistance of skilled engineers for any necessity which might arise. It was then up to the owner to provide the workers for the execution of maintenance work. The fee for this type of contract was lower than for that of the first type, for which G.M.T. supplied all the labour.

The position of an owner was studied individually in order to choose the best type of agreement for his requirements.

In reply to Mr. O'Neill, it was possible to do without the engine test bed trials, if the customer so wished. Generally it was advisable to test the first units of a new model on the bench in order to check its operation and determine its characteristics (specific fuel consumption, temperatures, pressures and so on). If the engine did not undergo such a trial, it must be suitably run-in before sea trials. A large bore engine required about 20 hours' running-in as stated in his reply to Mr. Taylor. The elimination of the test bed trial involved a certain saving for the customer, even taking into account the longer running-in at sea before trials.

The author confirmed that galvanized steel pipes had been preferred for water circulation to air coolers. This choice was not so much based on economic grounds as on the danger that the use of pipes made of material highly resistant to electrolytic corrosion could entail corrosion of the much more delicate and expensive air cooler tube bundles. It had been found that the engine room staff did not always replace the worn anodes promptly. Consequently, as stray currents were always present, if there were no relatively inexpensive and easily repairable or replaceable weak points, such as steel water pipes, corrosion was likely to attack cooler tube bundles. At customer's request, water tubes made of material highly resistant to corrosion could be adopted, but G.M.T. felt it their duty to point out the risks the cooler might run if the precautions mentioned above were not taken.

Replying to Mr. Cariou, the problem he had raised had been fully considered by the author's company. In all cases where it was necessary to isolate one or more cylinders at sea, instructions were given to the ship staff in a very short time and the ship could reach harbour under her own power. The engineering bureau was well organized for all the calculations relating to balancing of masses and to stresses caused by torsional vibration; these were the two main items affected by the number of cylinders in operation.

For each Diesel engine application, balancing calculations, particularly of shaftline torsional vibrations, were made in advance and all the data could be easily memorized in a computer. It was thus possible to make quick calculations for evaluating the behaviour of any engine running with one or more cylinders out of operation.

To make general calculations in advance, considering all the possibilities that could arise during engine operation, would be complicated and of doubtful practical use, probably confusing the engine room staff who had to choose the right solution. The modern calculation facilities at G.M.T. and the fact that the company was also connected through a terminal to the computers at the Fiat Calculation Centre in Turin gave an owner the assurance that he would receive, in a reasonable time, all the detailed instructions to solve a problem of the kind mentioned.