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NUCLEAR REGULATORY COMMISSION
Docket No. 50-322-OL Official Exh. No. Suffolk County Deisel 69
In the matter of Long Island Lighting Co.

Staff		IDENTIFIED	✓
Applicant		RECEIVED	
Intervenor	✓	REJECTED	
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Other		Witness	Panel
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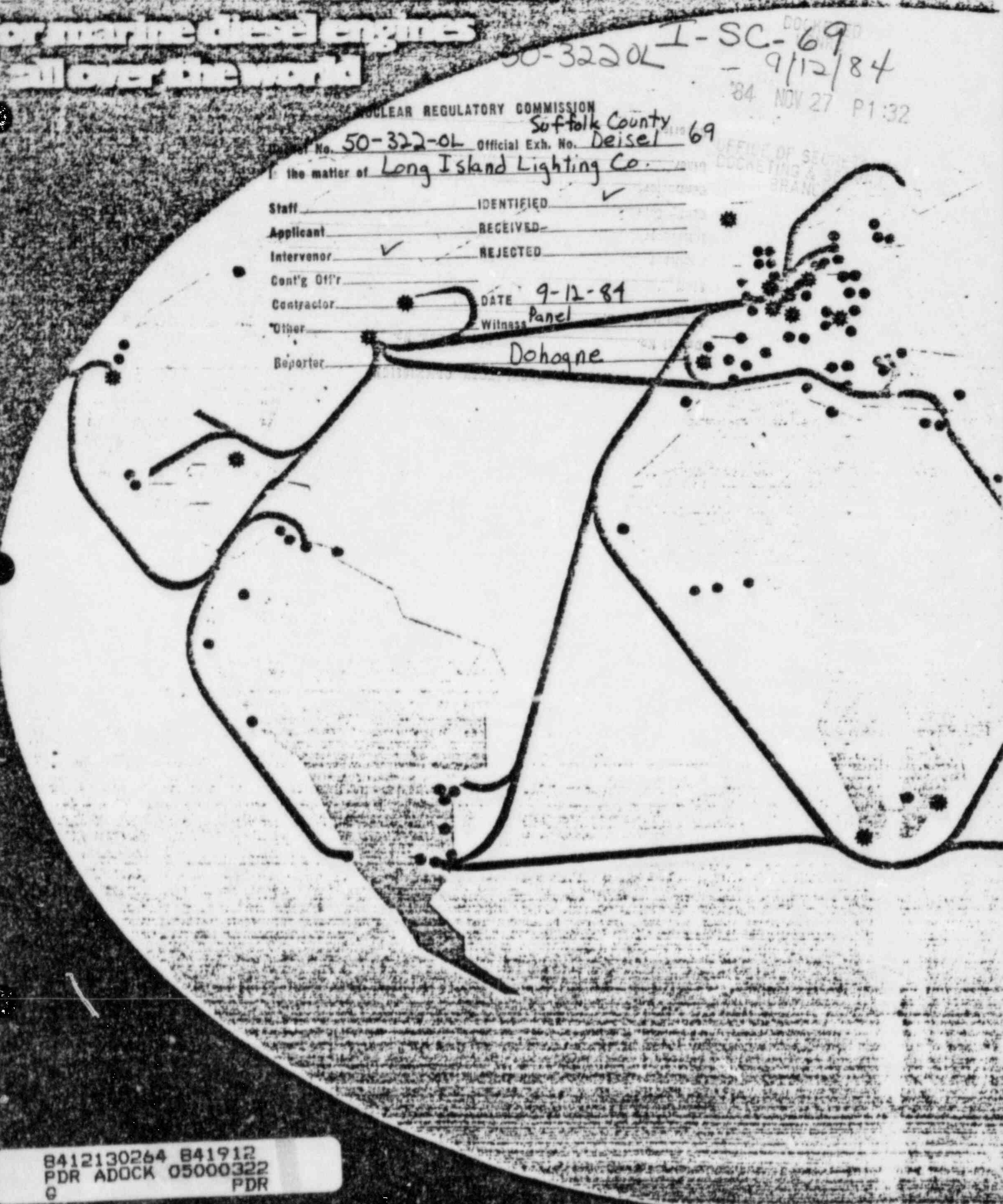


Sulzer's four-stroke high-and medium-speed engine range

by G. Lustgarten* and R. Stoffel**

IN RECENT YEARS the four-stroke diesel engine has consolidated its position in the marine field. Besides its application for auxiliary power generation, the four-stroke engine is an interesting alternative to the two-stroke crosshead diesel where limited space is available for the propulsion unit, for example in roll-on roll-off ships, passenger vessels and ferries. Sulzer has systematically worked to offer an engine programme to meet such demands.

The power range between 620 kW and 15 900 kW is covered by three engine types:

- A-engines for outputs up to 3 600 kW (4 860 bhp)
- Z-engines for outputs up to 9 600 kW (13 050 bhp)
- 65/65 engine for outputs up to 23 850 kW (32 400 bhp).

The first two Sulzer-designed types have now reached an advanced stage with wide service and testbed experience gained over the past ten years. The 65/65 engine—a joint development of Sulzer and M.A.N.—had completed an intensive development programme by the end of 1977.

The AS25/30 and AL20/24 engines

The AS 25/30 design is built in six, eight and 10 cylinder in-line and 12,16 and 18V versions, Figs. 1, 2 and 3. The main features of the engine are a simple and robust design, good accessibility to the parts subject to wear and easy maintenance.

The original cylinder output of the two-valve A 25/30 engine was 135 kW/cyl (184 bhp/cyl). During subsequent development stages, however, the AS 25/30 engine was provided with four valves and the cylinder output increased to 200 kW/cyl (270 bhp/cyl). In the course of developing this originally Sulzer-designed engine, the AS 25/30 was incorporated into the common engine programme with M.A.N., which has also taken up its production. Extensive endurance tests at 220 kW/cyl (300 bhp/cyl) have already been carried out with a view to further uprating. By the middle of 1977 over 1 350 A 25/30 and AS 25/30 engines were in service and the maximum running hours had exceeded 35 000 hours.

When first introduced, the A 25/30 engine was used mainly for auxiliary power generation. Due to the increase in output as well as the subsequent development of the larger V-cylinder units, the AS 25/30 range has also gradually made its mark as a propulsion engine. The smaller AL 20/24 engine (Fig. 4), based on a similar design, is being manufactured in six- and eight-cylinder in-line versions for auxiliary power generation, the propulsion of small ships and for power packages (as illustrated by the 500 kW container unit in Fig. 5).

The Z 40/48 engine

The Z 40/48 engine is offered in six- and eight-cylinder in-line form and 10, 12, 14, 16 and 18 cylinder V-versions (Fig. 6, 7 and

* Head of development and design four-stroke engines

** Head of development test beds

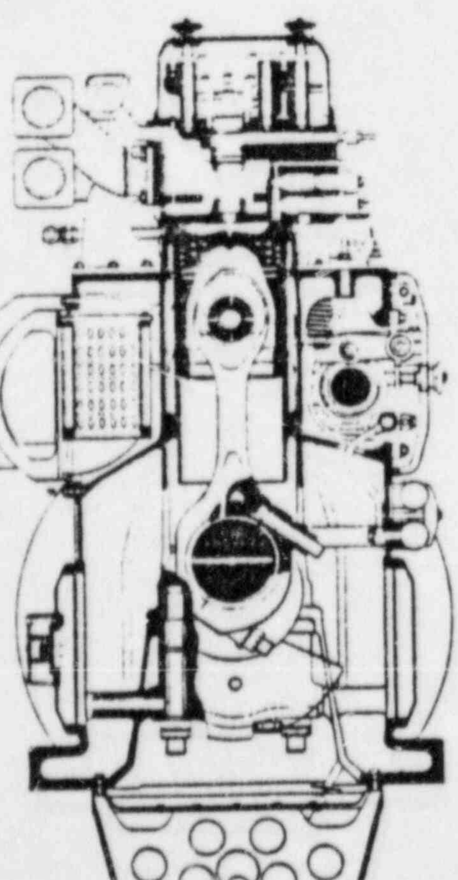


Fig. 1 Cross-section of the ASL 25/30 engine

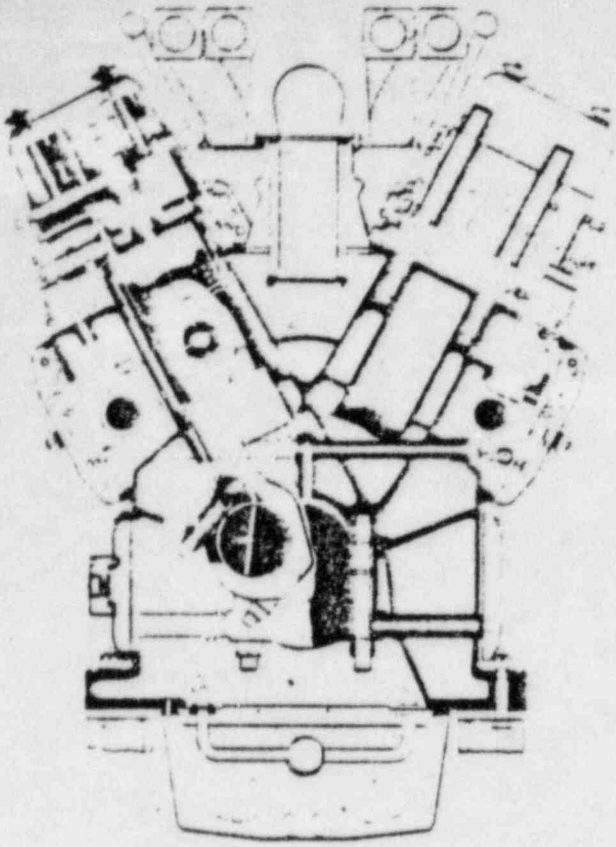


Fig. 2. Cross-section of the ASV 25/30 engine

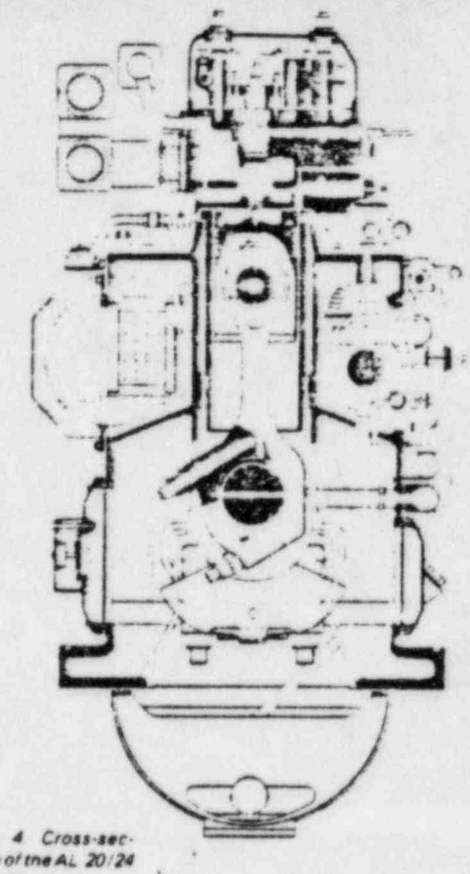


Fig. 4. Cross-section of the AL 20/24 engine

8). This engine, which is the main representative of our medium speed engine programme, was initially introduced as a two-stroke version with 330 kW/cyl. (450 bhp/cyl.). As a four-stroke design, it now has a maximum cylinder output of 550 kW/cyl at 560 rev/min. (For stationary applications only, the maximum nominal speed is 600 rev/min.)

Design has been concentrated on solutions to meet the requirements of high reliability in heavy fuel service. Special measures have been adopted to reduce thermal stresses and achieve low wear rates as well as extremely low lubricating oil consumption: the rotating piston is the most outstanding feature of the Z 40/48 engine.

The number of engines in service by the end of 1977 amounted to some 180 with maximum running periods of 52 000 hours for the two-stroke versions and 24 000 hours for the four-stroke models.

The 65/65 engine

The thorough development tests with the 12-cylinder prototype 65/65 (Fig. 10) by Sulzer in Winterthur as well as with a four-cylinder test engine by M.A.N. in Hamburg were completed by the end of 1977. Many technical solutions, which proved to be very reliable in operation with the Z 40/48-engine, have been adopted for the 65/65 engine. The larger dimensions, however, made it necessary to adopt different solutions for certain components; for example, a welded crankcase with bolted-on cast iron cylinder blocks and constant pressure turbocharging were specified.

Fig. 3. A 16-cylinder ASV 25/30 engine

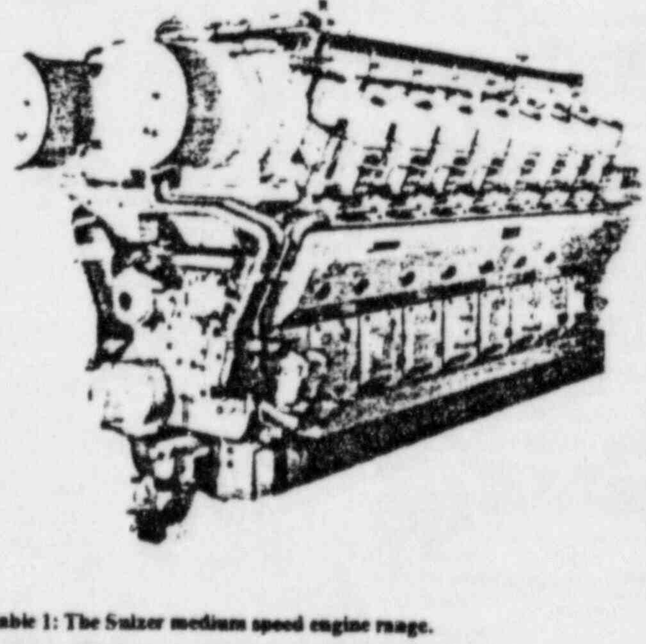
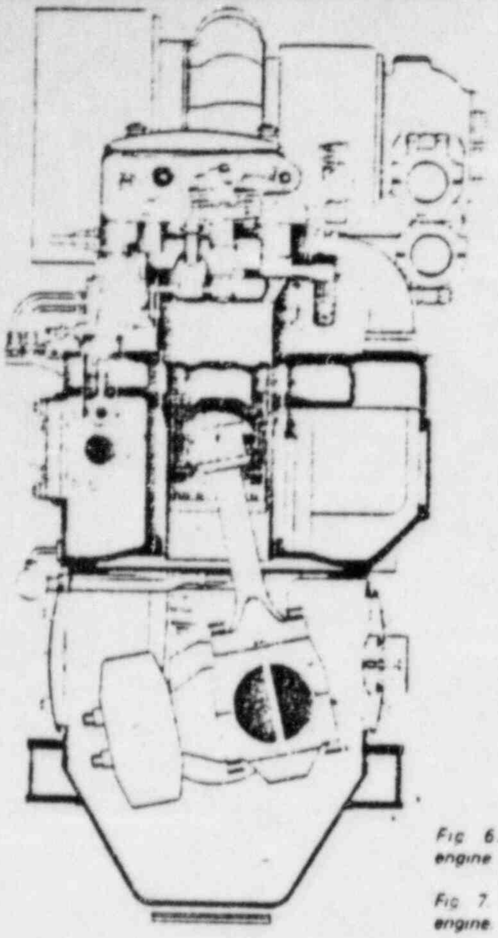


Table 1: The Sulzer medium speed engine range.

Engine Type	Bore/Stroke (mm)	Speed rev/min	b.m.e.p. (bar)	Cyl. output (kW)
AS 25/30	250/300	1000	16·29	200
		900	16·75	185
		750	17·38	160
AL 20/24	200/240	1000	16·31	102·5
Z 40/48	400/480	560*	19·54	550
		530*	20·02	533
65/65	650/650	400	18·43	1 325

** Maximum engine speed for stationary applications is 600 rev/min.*



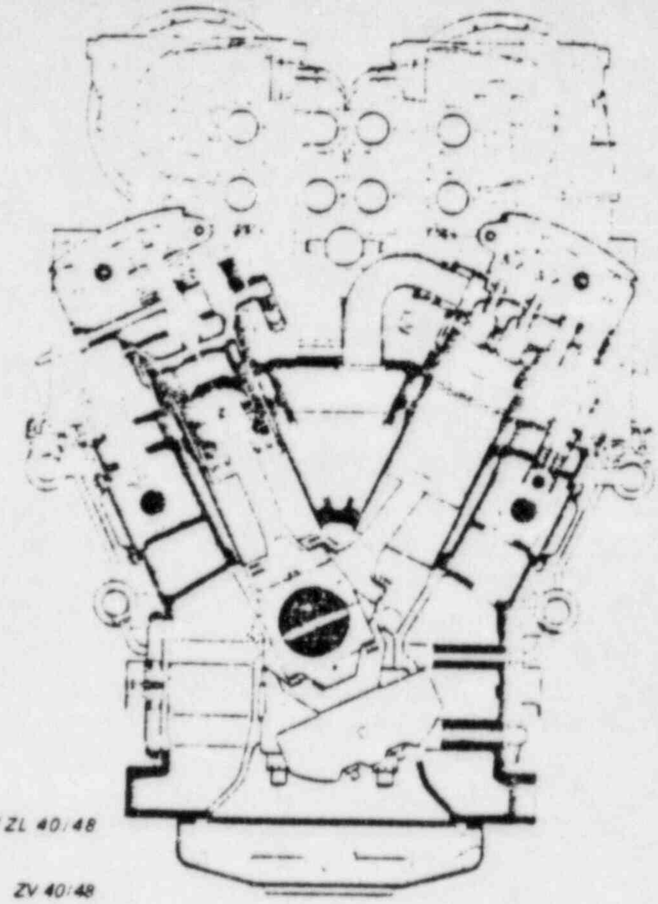
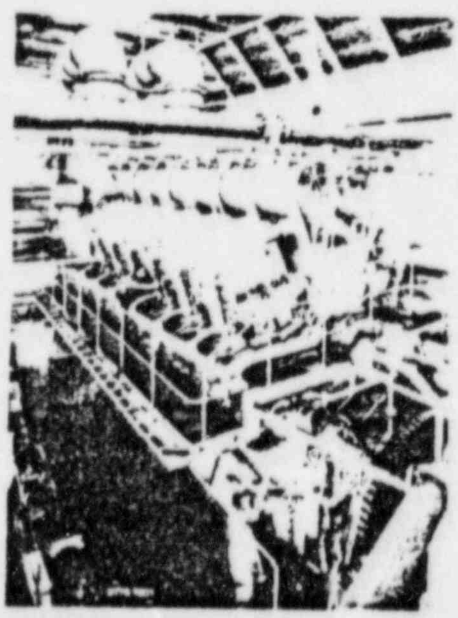
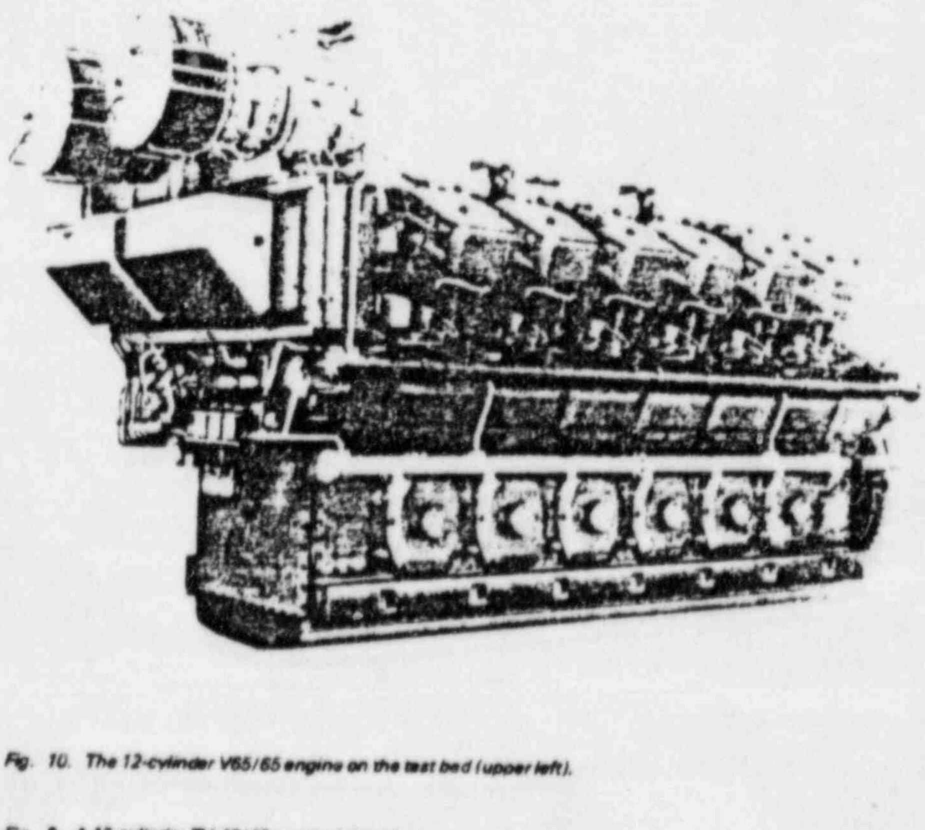


Fig. 6. (Left) Cross-section of ZL 40/48 engine

Fig. 7. (Right) Cross-section of ZV 40/48 engine.





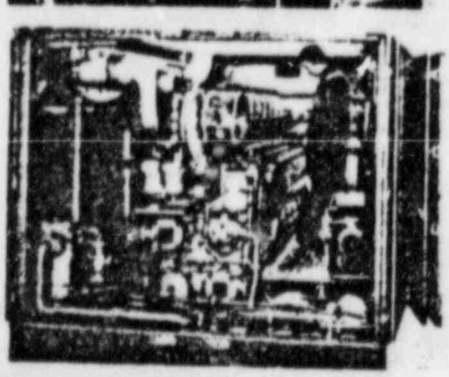


Fig. 10. The 12-cylinder V65/65 engine on the test bed (upper left).

Fig. 8. A 12-cylinder ZV 40/48 engine (above).

Fig. 5. A container fitted out with a six-cylinder ASL 20/24 engine to provide a 500 kW power package (left).

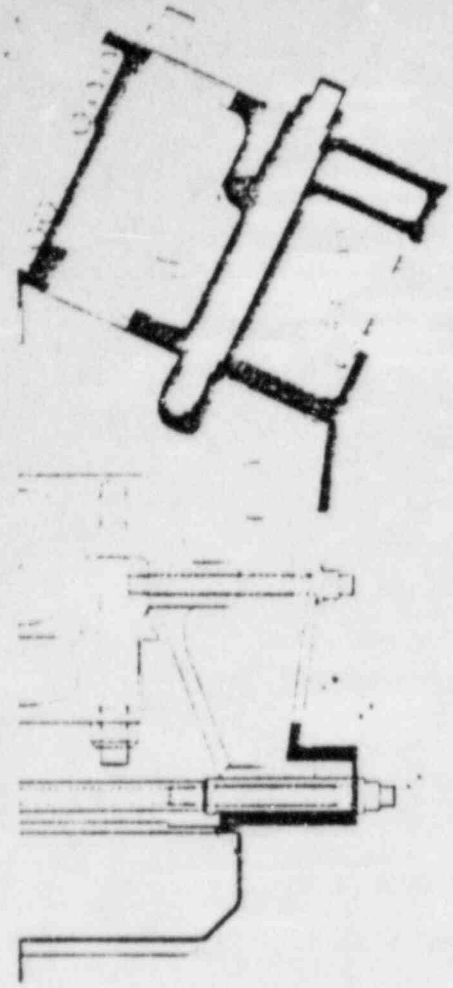


Fig 12 Engine casing design of the V65/65 engine

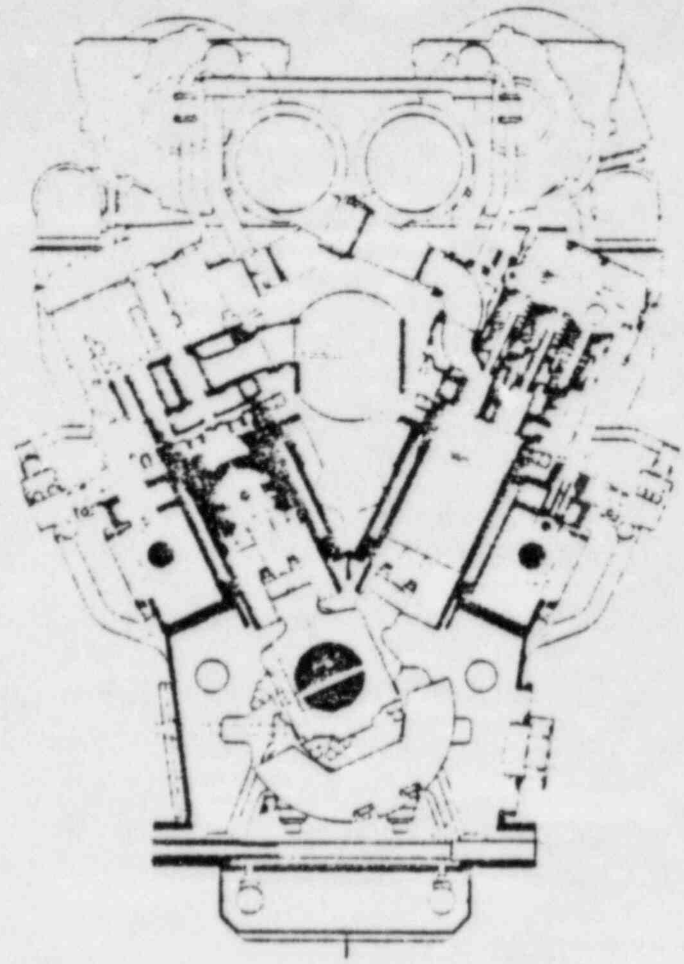


Fig 9 Cross-section of V65/65 engine

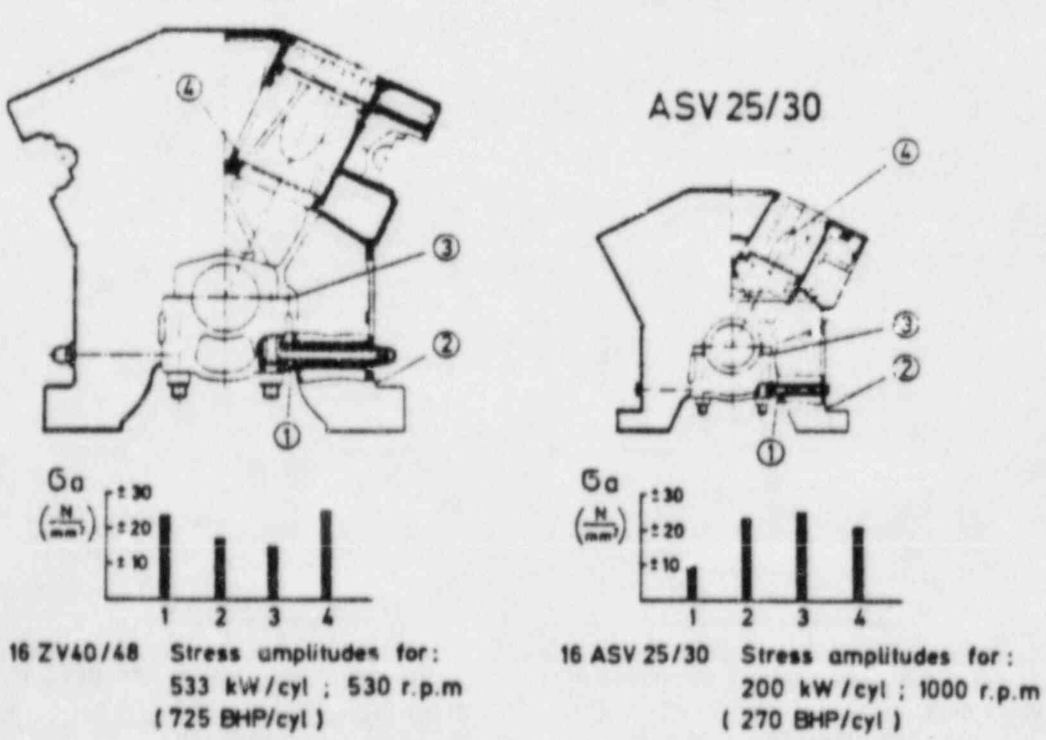


Fig 11 Engine casing design of the ZV 40/48 and ASV 25/30 engines

IMAGE EVALUATION
TEST TARGET (MT-3)

150mm

6"

The following discussion presents some of the specific features of the Sulzer four-stroke engines. Special emphasis will be placed on the Z 40/48 engine, which is the "backbone" of our four-stroke programme.

Low level of mechanical stresses

The incorporation of a high power reserve for future development allows the engine to enter production at a reasonably safe level. Furthermore, the attainment of a higher cylinder output in the course of the final development stages does not negatively affect the operational safety, but represents only the full utilisation of the reliability designed into the engine at an early stage. A low stress level in the major engine components is one of the necessary requirements.

Engine casings: Fig. 11 shows the casings of the ASV 25/30 and ZV 40/48 engines which are, in their basic design, very similar. The underslung crankshaft allows the forces induced into the bearings to be transmitted directly to the cylinder head. Tie rods transmit the horizontal forces of the bearing loads from the bearing caps into the frame. The low stress level is reflected in the maximum amplitudes of less than ±24 N/mm² (± 2·5 kp/mm²) at full load. Even for b.m.e.p.'s of 24·5 bar (2·5 kp/mm²), which corresponds to a cylinder output of 735 kW (1 000 bhp) in the case of the Z 40/48 engine, the safety factor will remain above 2·0. This explains why no mechanical failure of the casings were experienced during service by a Z 40/48 or AS 25/30 engine.

The stress level in the casing of the 65/65 engine is also at a similarly low level.

A new solution was sought for the connecting rod of the 65/65 in order to simplify overhaul work. The shaft is extremely short, allowing the dismantling height of the piston to be reduced to a minimum. The big end is bolted to the shaft by means of eight hydraulically tightened bolts, which are readily accessible.

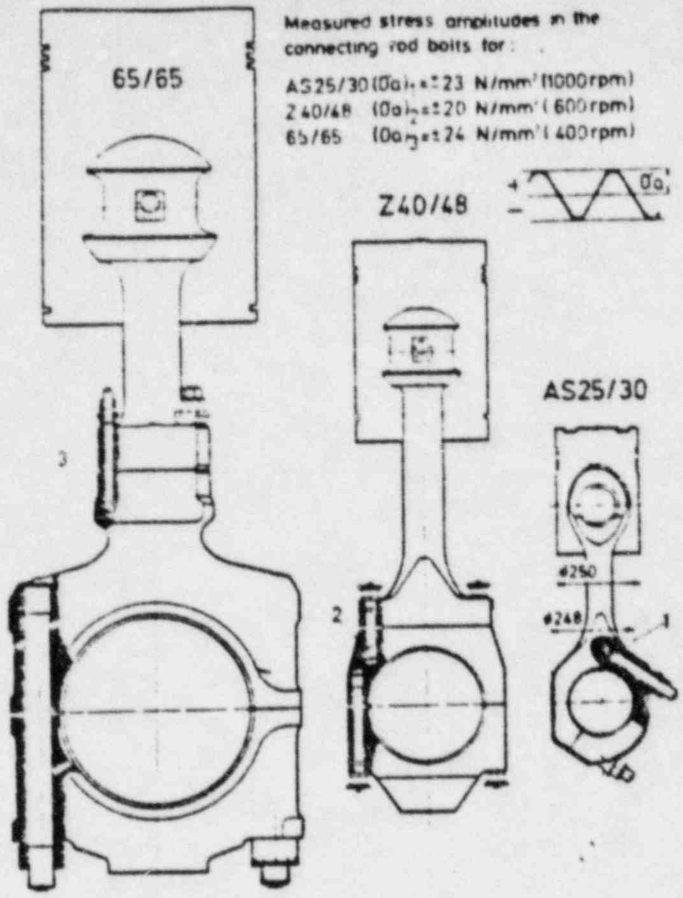


Fig. 13. Comparison of the 65/65, Z40/48 and AS25/30 engine connecting rods.

Low thermal loading

Z 40/48 wall temperatures: an engine with high specific output intended to burn low quality heavy fuels must be provided with adequately-cooled combustion chamber walls in order to avoid thermal cracks and high temperature corrosion. Fig. 14 shows the combustion chamber temperatures of the Z 40/48 engine. The cylinder liner temperatures are kept at an adequate level due to the application of the bore-cooling principle developed at Sulzer many years ago.

The design principle of the double bottom has been applied to the cylinder head and the thin flame plate is intensively cooled. The mechanical loads due to gas pressure are carried by the massive intermediate supporting deck.

Z 40/48 valve seat design: the exhaust valve is one of the most critical parts of the cylinder head, if not of the entire medium speed engine. For reliable performance, a perfect sealing of the seat as well as efficient cooling are necessary. In the case of the Z 40/48, a thorough investigation was carried out in order to find the best design for an engine with a high reliability and capable of burning heavy fuels up to 3 500 sec. Red. I with high sodium and vanadium contents.

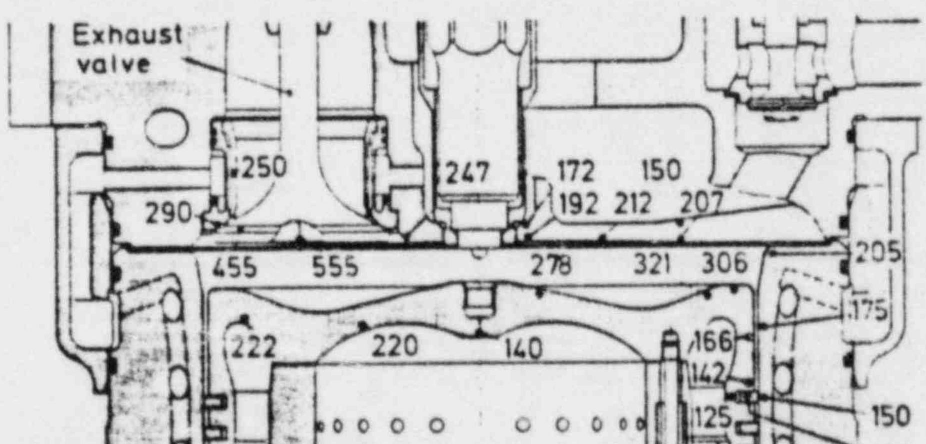


Fig. 14. Measured temperatures (°C) in the combustion chamber area of the Z40/48 engine at operating conditions of 530 rev/min, b.m.e.p. 20 bar, 533 kW/cyl.

At an early design stage, it was realised that the usual design practice, incorporating valve cages, was not the best solution for an engine of the size of the Z 40/48. The cylinder head was therefore provided with press-fitted valve seat inserts (Fig. 15), a design which offers the following advantages.

- The valve seat is fully symmetrical. Therefore, under preloading or gas load, full symmetry of deformation is achieved.
- The cooling of the seat area is very efficient. The temperature distribution around the seat (Fig. 15) is uniform and leads to good sealing properties.
- The water passing through the valve seat inserts flows directly to the centre of the flame plate, ensuring effective cooling of this area.
- Finally, higher gas passage areas are possible in comparison with a cylinder head having valve cages.

The press-fitted valve seat contains an additional inner sleeve in order to prevent sulphur corrosion of the lateral seat surface. This is achieved by the insulating air gap between the overcooled region of the seat and the gas passage. The reliability of the valve for heavy fuel operation was considerably increased by the application of a specially-developed and patented plasma coating for the valve seat. In addition, the Z 40/48 engine is supplied with specially-designed tools for rapid dismantling of the cylinder head during regular inspections.

The application of the above mentioned features made it possible to extend the overhaul intervals of the exhaust valves. On the basis of service experience gained with overhaul intervals initially fixed at 6 000 hours, it was decided by the end of 1976 to extend the recommended valve overhaul periods to between 12 000 and 18 000 hours. This period is also customary for pulling the pistons. This eliminates altogether basic need of valve cages. Subsequent service experience with the exhaust valves on the Z 40/48 engine has generally confirmed the reliability of this design. The few valve failures experienced were explained by faults during the manufacturing process or because non-approved valve makes were used, which did not meet Sulzer requirements.

65/65 wall temperatures:

Because similar principles adopted in the Z 40/48 were applied to the 65/65 engine, the maximum temperatures are remarkably low for an engine of this size. Unlike the Z 40/48 design, however, valve cages are provided on the 65/65 engine in order to keep the fitting and dismantling intervals of the valves acceptably low (the weight of the cylinder head is considerably higher).

The rotating piston

In view of the large power range covered by Sulzer medium speed engines, two different piston designs have been adopted:

- **The requirements of the AS 25/30 engine led to the use of a conventional light alloy gudgeon pin piston (Fig. 16, right), whereby the piston skirt is lubricated by splash oil. The lubricating oil consumption, which ranges between 1·3 to 2·0 g/kWh (1·0 to 1·5 g/bhph), is controlled by the ring package placed above the pin.**

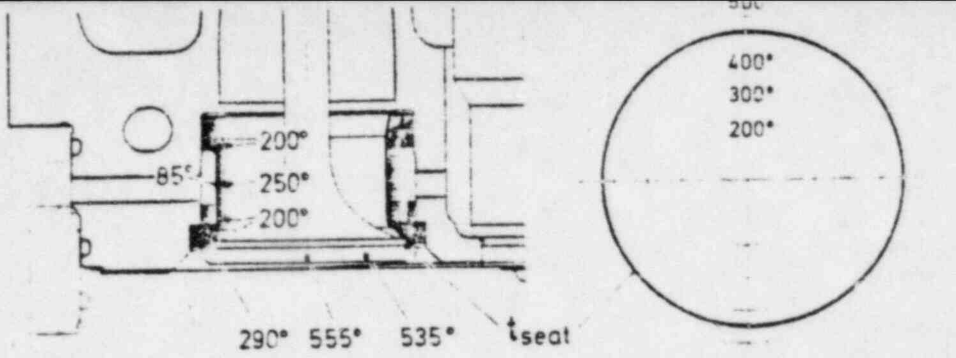


Fig. 15. Z40/48 engine exhaust valve seat temperatures (°C) engine running at 530 rev/min, b.m.e.p. 20 bar

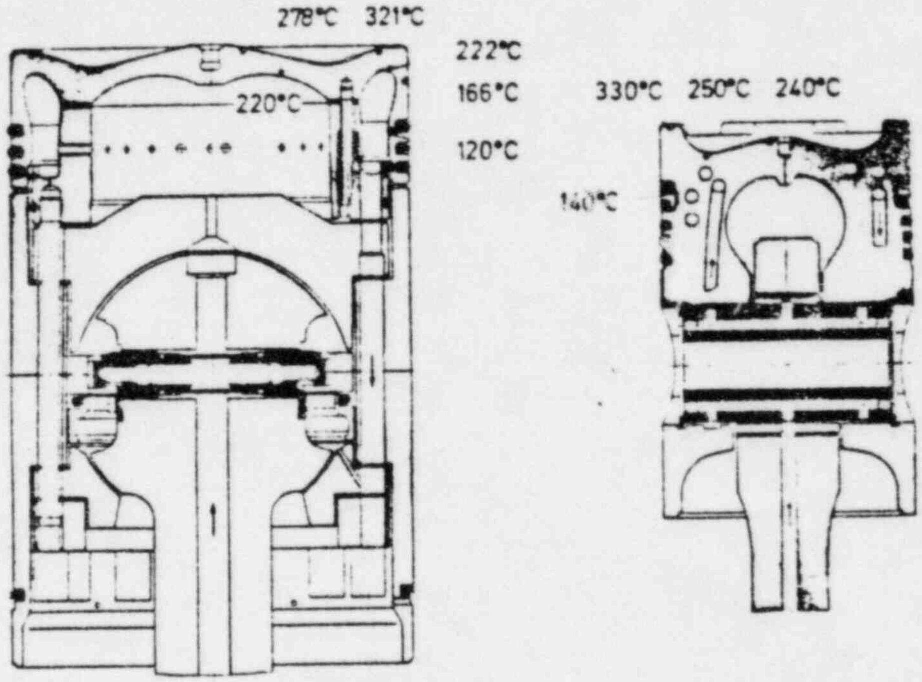


Fig. 16. The rotating piston design of the Z40/48 (left) indicating the temperatures (°C) measured at operating conditions of 530 rev/min, 533 kW/cyl (725 bhp/cyl). Piston with gudgeon pin of the AS 25/30 (right) with temperatures measured at 1 000 rev/min, 200 kW/cyl (270 bhp/cyl).

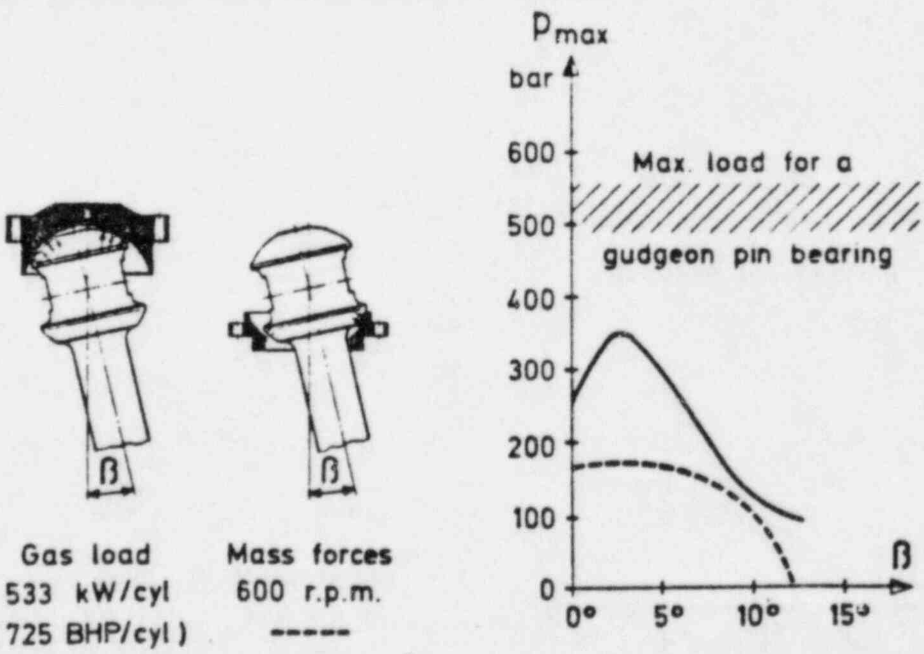


Fig. 17. Specific load of the spherical bearing of the Z40/48 engine.

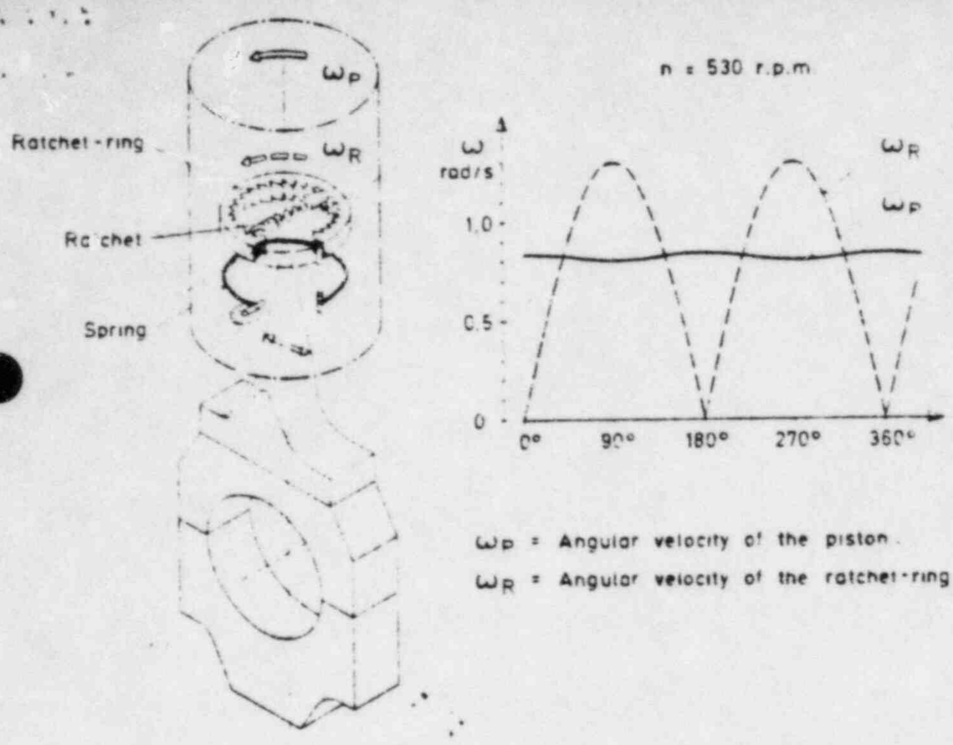


Fig. 18. Rotating mechanism of the Z40/48 piston (left) and a schematic representation showing its very low loading

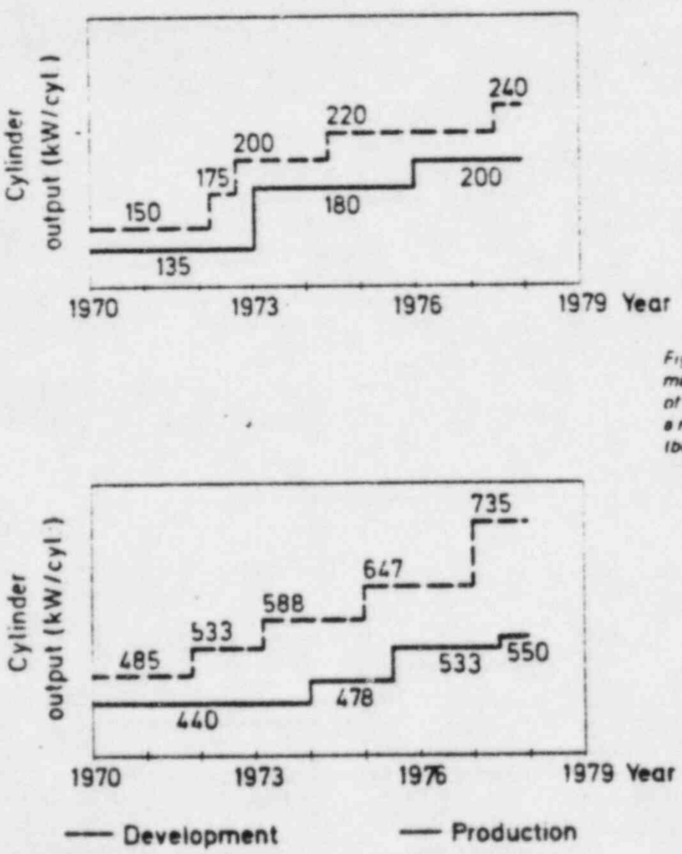


Fig. 19. Evolution of maximum cylinder output of the AS 25 engine (top) and ZV 40/48 engine (bottom)

- The pistons of larger engines are more prone to piston seizure because of the higher deformations involved. The risk of seizure is aggravated by the customer's demand for low lubricating oil consumption and by the requirement to burn low quality heavy fuels.

In order to solve these problems and to satisfy the demands connected with high specific output and good reliability, the well-known rotating piston design was adopted for the Z 40/48 (Fig. 16, left) as well as for the larger 65/65 engine. The advantages of such a design are that local overheating is avoided, due to the rotary movement. Temperatures are symmetrically distributed and thermal deformations are also symmetrical. Thanks to the spherical bearing and the symmetrical form of the skirt, deformations due to gas pressure are symmetrical as well. With every stroke, a fresh oil-wetted part of the skirt is turned into the load-carrying zone, substantially reducing the danger of seizure. Furthermore, piston clearance can be reduced to a minimum due to the symmetrical shape of the skirt.

An improved mechanical reliability is also incorporated in the rotating piston, due to the following characteristics:

- The maximum specific load of the spherical bearing under gas forces is about 30 to 40 per cent lower than in the case of the small end bearing of a conventional gudgeon pin. It is also more evenly distributed (Fig. 17).
- The loading of the rotating mechanism is very low as explained schematically in Fig. 18: the oscillating motion of the connecting rod shaft imposes an intermittent rotation to the ratchet ring. On the other hand, a periodic acceleration and deceleration of the heavy piston skirt should be avoided in order to prevent damage of the rotating mechanism due to high inertia forces. For this purpose, the intermittent motion of the ratchet ring is transmitted to the piston skirt over a circular spring. The spring accumulates the energy transmitted periodically by the rotating mechanism and delivers it smoothly to the piston skirt. According to Fig. 18, the intermittent rotation of the ratchet ring (ω_R) is transformed into an almost steady rotation movement (ω_P) of the piston skirt around its axis. Due to the elimination of inertial forces, the forces induced at the ratchet ring periphery are low.

Lubricating oil consumption: this consideration is one of the most exacting problems which have to be solved during the development of a trunk-piston engine. The unique features of the rotating piston have permitted a much better control of lubricating oil consumption because of the following factors:

- The absolutely symmetrical conditions of the piston skirt as well as the small running clearances result in a reduced piston slap, which can be dampened with comparatively smaller amounts of oil.
- The reduced danger of seizure due to the rotating movement permits a low lubricating oil rate.

In addition, the lubricating oil consumption is exactly controlled by a separate cylinder lubrication system: the rate is automatically adjusted, as a function of the engine load. As a result, the total lubricating oil consumption of the Z 40/48 engine remains below 1·3 g/kWh (1·0 g/bhph). This performance is fully confirmed by long-term service experience with the engine.

Testbed results

As already mentioned, a high power reserve was incorporated in Sulzer engines at the design stage, a principle which allowed the engine to be introduced at a reasonably safe output level in order to gain experience for further power increases. At the same time, tests with much higher ratings were carried out on the testbed. Fig. 19 illustrates the evolution of testbed performance against the production ratings of the AS 25/30 and Z 40/48 engines. The even, increased lead time basically results in successive improve-