Journal of Maritime Research, Vol. II. No. 2, pp. 41-49, 2005

ISSN: 1697-4840

COMBUSTION PROCESS IMPROVEMENT IN A MARINE DIESEL ENGINE

A. Dionis[1], J. C. García[2], E. Arriola[3] and A. P. Franchy[4]

ABSTRACT

This paper presents the modifications carried out on a four years running medium-speed four-stroke propulsion diesel engine for improving its combustion process in order to avoid the damages produced at the piston crowns by the injected fuel jets. The works were carried out under instructions from Wärtsilä NSD using a technology developed by this maker focused to decrease the emissions of soot particles and nitrogen oxides (NOx) without affecting the specific fuel consumption of new production engines and also for upgrading older engines still in operation. Various running parameters were checked before and after modifications while the ship was underway in normal sailing conditions. The values obtained were then compared to find out the results that might be inferred from such modifications

Keywords: marine engines, internal combustion engines, diesel engines, combustion, environmental impact.

INTRODUCTION

The subject of this study is a medium-speed four-stroke propulsion diesel engine which design parameters have been modified while remained installed in the reefer containership *Carmen Dolores H.*

---

1 Profesor Titular, Dpto. Ingeniería Marítima, Universidad De La Laguna, (adionis@ull.es)

2 Profesor Titular, Dpto. Ingeniería Marítima, Universidad De La Laguna, (jgarod@telefonica.net)

3 Profesor Asociado, Dpto. Ingeniería Marítima, Universidad de La Laguna, (earriola@ull.es)

4 Alumno Tercer Ciclo, Dpto. Ingeniería Marítima, Universidad De La Laguna, (earriola@ull.es)

Figure 1: Containership Carmen Dolores H. Source: fieldwork

This engine is a Wärtsilä VASA 9R46B, supercharged and fitted with a fuel oil solid injection system. It drives a shaft generator, a controllable pitch propeller and has the following particulars:

The compression ratio resulting of the compression stroke is determined in this engine by a supplement plate placed between every connecting rod and its big end. Every cylinder liner is provided with an anti-polishing ring on its upper end in order to prevent formation of coal deposits around the piston crown. The supercharging is carried out using the SPEX system, therefore the engine is fitted with a by-pass at the exhaust manifold and a relief valve, called waste gate. This arrangement enables an efficient work of the turbocharger under low engine loads and avoids an excessive exhaust pressure at loads over 85% the rated power by reducing the flow of gases to the turbocharger turbine by means of the by-pass.

Another interesting feature of this engine is the twin-injection system. There are two fuel valves in the cylinder head. A main injector located in the centre of the cylinder head is preset at 450 bars. A pilot injector preset at 320 bars is placed in the cylinder head side and arranged tilted at an angle of 45º. This injector facilitates a pre-mixture burning with smaller ignition delay, which results into a smaller peak pressure and temperature in the cylinder and at last into a small NOx emission.

The decision for improving the behaviour of the engine was imposed by the fact that at every overhaul carried out since the ship began to sail all piston crowns had shown marks corresponding to the fuel jets leaving the orifices of the main injector [*Figure 2*]. The loss of substance in such marks had reached depths up to 3 mm.

Output: 8,775 kW	Number of cylinders: 9 in line
Service speed: 500 rpm	Piston stroke: 580 mm
Cylinder bore: 460 mm	Compression ratio: 12.5:1
Max. compression pressure: 130 bar	Max. combustion pressure: 180 bar
Supercharging air pressure: 3.1 bar	Mean effective pressure: 24.3 bar
Fuel: heavy fuel oil IFO 180	Year of building: 1993

Table 1. Engine particulars Source: fieldwork

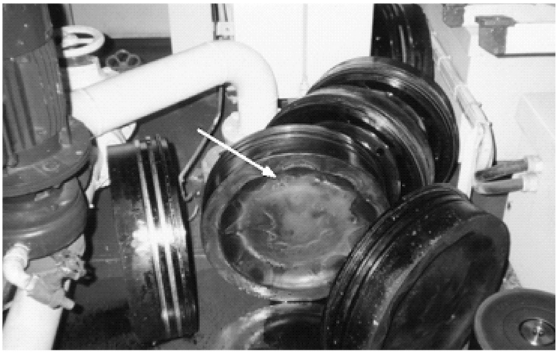

Figure 2: Damaged piston crowns Source: fieldwork

The engine upgrading was carried out under instructions from Wärtsilä NSD in order to obtain an improvement of the combustion process avoiding the damages produced by the injection fuel jets on the piston crowns, a smaller quantity of soot particles and NOx exhausted, a smaller thermal charge of the combustion chamber components, a lower specific fuel consumption at partial loads, a lower turbocharger speed at partial loads, and a higher supercharging air pressure at loads near full power.

METHODS

The following works were carried out for upgrading the engine:

— Modification of the anti-polishing ring
— Replacement of the 5.0 mm thick supplement plates between connecting rods and big ends by new supplements with a thickness of 11.0 mm
— Decrease of the injection start advance from 15.3° to 12.2°
— Renewal of the piston crowns
— Gathering of performance data before and after the mechanical works

We have gathered the performance data while the ship was underway in normal sailing conditions; that is to say, with the engine at a steady speed of 500 rpm and developing any power between 80-85% the rated power, as per the condition of sea and weather. The parameters taken into account for the gathering of data were: engine rpm, turbocharger rpm, supercharging air pressure, engine load, compression pressure at ignition start in every cylinder, maximum pressure in every cylinder, mean pressure in every cylinder, exhaust temperature at every cylinder, exhaust temperature before turbocharger, temperature of main bearings, engine fuel consumption and ship speed.

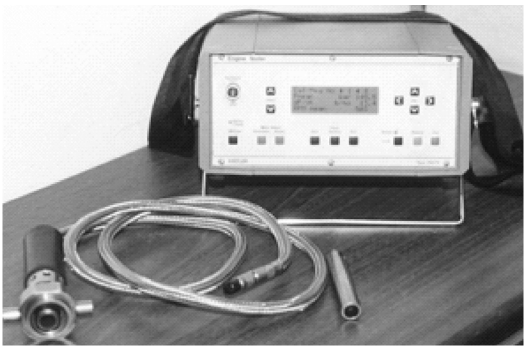

Figure 3: Engine Tester 2507A Source: fieldwork

The gathering and processing of the combustion pressures were carried out using the portable instrument made by

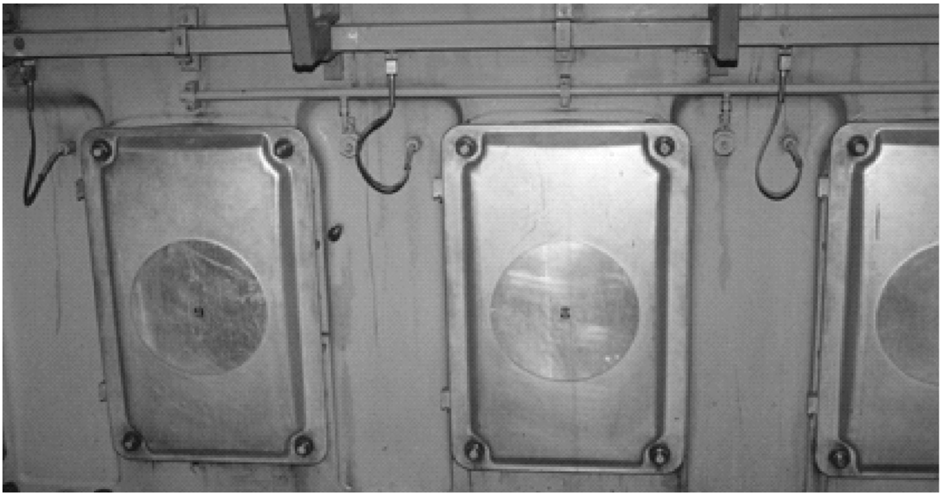

Figure 4: Permanent wiring for main bearing temperature monitoring
Source: fieldwork

Klister Instrument AG named Engine Tester type 2507A, shown in *Figure 3* with the pressure sensor to be connected with the indicator cock of every cylinder.

The temperature of every main bearing was obtained using the engine monitoring system, fitted for such purpose with permanent temperature sensors and electrical wiring [*Figure 4*].

In order to find out the results of the above-cited modifications we have compared the value of the various performance data checked before and after them. The following two graphs show values pertaining to the number 5 cylinder. In *Figure 5* are shown the values obtained for compression pressure at ignition start and for maximum pressure. At the upper zone of the graph appear stated the maximum pressures, while at its lower zone are the compression pressures. The values taken after modification appear at the load range from 83% to 85%, meaning more steady conditions of sea and weather than when taken before the engine modification.

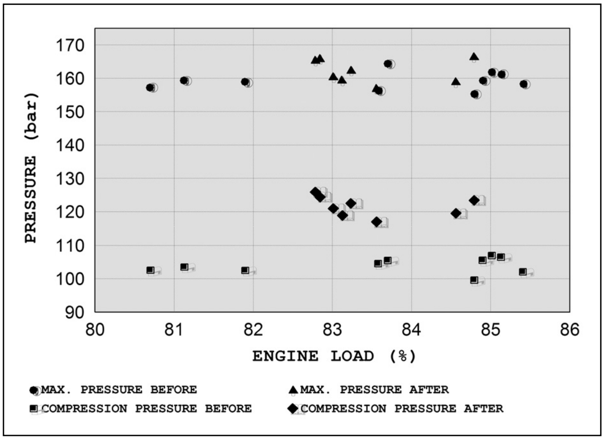

Figure 5: Nr 5 cylinder maximum pressure and compression pressure

Like was found out for the other eight cylinders

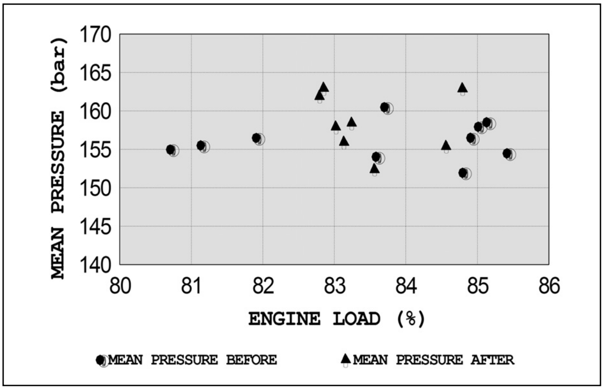

Figure 6: Nr 5 cylinder mean pressure

Source: fieldwork

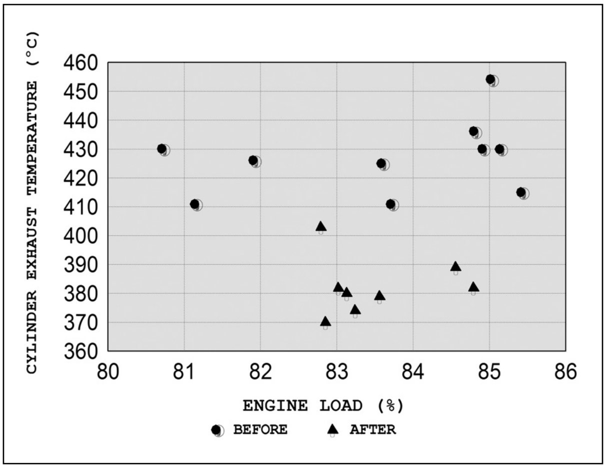

Figure 7: Nr 5 cylinder exhaust temperature

Source: fieldwork

of the engine, this graph shows that the compression pressure at ignition start has suffered a significant increase reaching a mean value of 15.7 bar. The replacement of the 5.0 mm thick supplement plates between connecting rods and big ends by new supplements with a thickness of 11.0 mm has resulted in an increase of the compression ratio and the consequent increase of the compression pressure at ignition start.

On the contrary, the maximum pressure of the working cycle after the modification has not varied in respect to the value found out before it, despite the decrease of the injection start advance from 15.3º to 12.2º. Similar results have been found out for the other eight cylinders of the engine.

Figure 6 shows the values obtained for the mean pressure in the number 5 cylinder also. The mean pressure before the engine modification ranged from 152 to 160 bar and after the modification ranges from 152 to 163 bar, which means no significant variation. Similar ranges were obtained for the other eight cylinders of the engine.

Figure 7 shows the values obtained for the number 5 cylinder exhaust temperature. Like obtained for the other eight cylinders, this graph shows that such temperature is lower after modification than before it.

Figure 8 shows the mean values obtained for the temperature of the engine main bearings. Such values are lower after the modification than before it reflecting that the bearings are suffering a lower thermal charge.

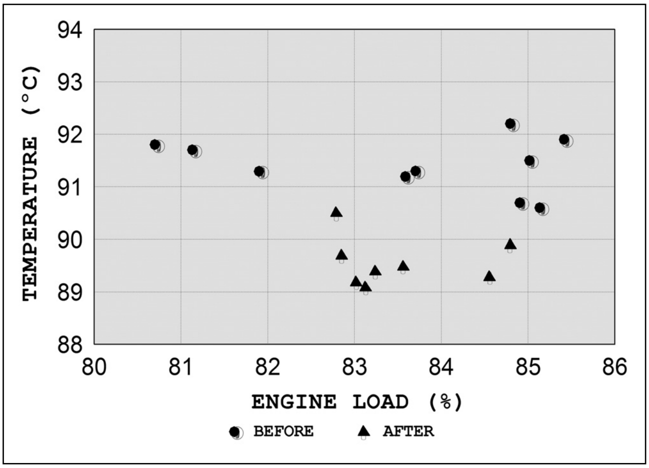

Figure 8: Mean temperature of the engine main bearings

Source: fieldwork

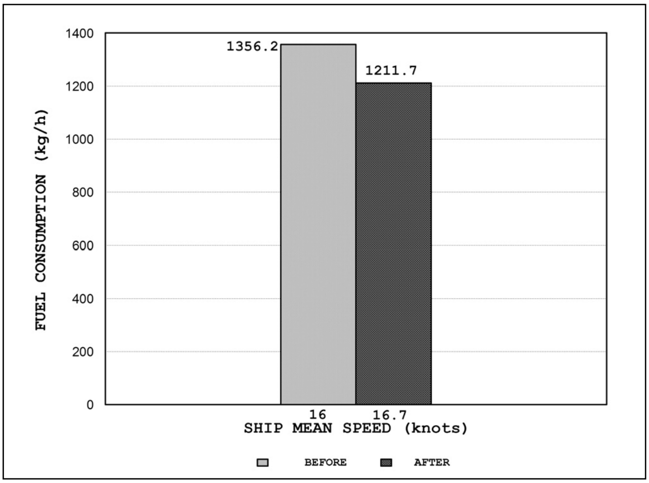

Figure 9: Fuel consumption

Source: fieldwork

The values obtained for the fuel consumption of the engine under normal sailing conditions are lower after the modification than before it and are shown in *Figure 9*, where the ship mean speed has been stated also.

In addition to this lower fuel consumption we have considered another two meaning facts: the former that the gases exhausted through the funnel observed with the naked eye seem to be more clear than before the modification of the engine, the latter that piston crowns have appeared in good condition at the overhauls carried out after the modification, without the damages produced by the fuel jets shown in *Figure 2*.

CONCLUSIONS

— The increase of compression pressure at ignition start with the subsequent increase of temperature at ignition start have resulted in an improved combustion, crisper and faster, without damages by fuel jets on the piston crowns and a lower emission of pollutants with the exhaust gases.

— This improved combustion has resulted in an upgraded efficiency of the engine with a lower thermal charge in its main bearings and a lower fuel consumption.

REFERENCES

Asmus, A., Wellington, B. Motores diesel y sistemas de inyección. Editorial Paraninfo, S.A.

Hellmann, J. O., Aabo, K. (1997) Emission control. Two-stroke low-speed diesel engines. The power engineer 1 (5)

Heywood, J. B. (1988) Internal Combustion Engine Fundamentals, Automotive Technology Series. Singapore: Mc Graw-Hill International Editions.

Hilliard, J.C., Wheeler, R.W. (1979) Nitrogen Dioxide in Engine Exhaust. SAE paper 790691. SAE Trans. 88

Kates, E. J., Luck, W. E. (1982) Motores diesel y de gas de alta compresión. Barcelona: Editorial Reverté, S. A.

Vollenweider, J. (1991) Exhaust emissions and their control. New Sulzer Diesel, Ltd.

Wärtsilä Diesel (1993) Marine Pollution Exhaust Emissions from Large Diesel Engines. The medium-speed engine industry view. London.

Wärtsilä Diesel (1996) Technical Bulletin.

Wärtsilä. Project Guide Wärtsilä Vasa 46.

Wärtsilä. Manual del motor Wärtsilä 9R46B

(1992) Injection developments target reduced emissions. The Motor Ship 72 (859)

(1992) Designers anticipate engine emission controls. The Motor Ship 73 (865)

MEJORA DEL PROCESO DE COMBUSTIÓN EN UN MOTOR DIESEL MARINO

Resumen

Este artículo presenta las modificaciones realizadas en un motor diesel propulsor de cuatro tiempos semi-rápido con cuatro años de funcionamiento instalado en el portacontenedores frigorífico Carmen Dolores H.; a fin de mejorar el proceso de combustión para evitar los daños producidos en las cabezas de los pistones por los chorros de combustible inyectado. Los trabajos se efectuaron según instrucciones de Wärtsilä NSD, usando una tecnología desarrollada por este constructor enfocada a disminuir las emisiones de partículas de hollín y de óxidos de nitrógeno, sin afectar el consumo específico de combustible tanto en los motores de nueva construcción como también para mejorar motores más antiguos aún en funcionamiento.

El motor es un Wärtsilä VASA 9R46B, de 8.775 Kw a 500 rpm, 9 cilindros en línea que acciona un generador de cola y una hélice de paso variable. El grado de compresión está determinado en ese motor por una chapa de suplemento ubicada entre cada biela y su cabeza. Cada camisa está dotada con un aro anti-pulido en su parte superior para evitar la formación de depósitos alrededor de la cabeza del pistón. La sobrealimentación se realiza por el sistema SPEX, estando dotado por tanto en el colector de escape de una válvula de alivio y un by-pass que reduce el flujo de gases hacia la turbo a cargas superiores al 85 % de la nominal. Cada cilindro está dotado de dos inyectores de combustible: un inyector principal en el centro de la culata y un inyector piloto en su costado, inclinado 45º y con menor presión de timbre que el principal. Las cabezas de los pistones venían mostrando daños con pérdida de material de hasta 3 milímetros de profundidad en zonas alcanzadas por los chorros de combustible procedentes del inyector principal.

METODOLOGÍA

Se realizaron los siguientes trabajos: modificación del aro anti-pulido, sustitución del suplemento de 5,0 mm de grosor existente entre cada biela y su cabeza por otro de 11,0 mm, disminución del avance a la inyección de 15.3º a 12.2º, renovación de las cabezas de los nueve pistones y acopio de datos de funcionamiento antes y después de los trabajos de mecánica.

Hemos acopiado los datos de funcionamiento con el buque navegando en condiciones normales; o sea, con el motor a una velocidad estable de 500 rpm y desarrollando cualquier potencia entre el 80 y el 85% de la nominal, según el estado de la mar y el tiempo. Los parámetros contemplados para el acopio de datos fueron: revoluciones por minuto del motor y de la turbo, presión del aire de sobrealimentación, carga del motor, de cada cilindro: presión de compresión al comienzo de la ignición, presión máxima, presión media y temperatura de escape; temperatura de los gases de escape antes de la turbo, temperatura de los cojinetes de bancada del motor, consumo de combustible de éste y la velocidad del buque.

El acopio y procesado de las presiones de combustión se realizó usando un equipo portátil Engine Tester 2507A de Klister Instrument AG con el correspondiente sensor de presión para conexión con el grifo del indicador de cada cilindro. La temperatura de los cojinetes de bancada se obtuvo usando el sistema de monitorización del motor, dotado a tal efecto de una instalación permanente de sensores de temperatura y cableado.

Hemos encontrado que después de realizar las modificaciones en el motor, la presión de compresión al comienzo de la ignición ha experimentado un aumento significativo, alcanzando un valor medio de 15.7 bar. La sustitución de los suplementos de 5,0 mm entre las bielas y sus cabezas por otros de 11,0 mm de grosor ha dado como resultado un aumento del grado de compresión y el consiguiente incremento de la presión de compresión al comienzo de la ignición. Por el contrario, el valor de la presión máxima del ciclo de trabajo no ha variado después de las modificaciones respecto al valor obtenido antes, a pesar de la disminución del avance a la inyección de 15,3º a 12.2º. La presión media antes fluctuaba de 152 a 160 bar y después de las modificaciones fluctúa de 152 a 163 bar, lo que no representa una variación significativa.

Las temperaturas de escape de los cilindros son menores después de las modificaciones que antes. Lo mismo ocurre con las temperaturas de los cojinetes de bancada del motor, reflejando que la carga térmica que soportan es menor. También es menor el consumo específico de combustible después de las modificaciones. Además de este menor consumo de combustible, hemos considerado otros dos hechos significativos: que los gases evacuados por la chimenea del buque parecen más claros a simple vista, y que las cabezas de los pistones han aparecido en buen estado en las revisiones realizadas después de las modificaciones.

CONCLUSIONES

— El aumento de la presión de compresión al comienzo de la ignición con el consiguiente aumento de la temperatura ha dado como resultado una mejor combustión, más enérgica y rápida, sin daños por chorros de combustible sobre las cabezas de los pistones y con una menor emisión de contaminantes con los gases de escape.

— Esta combustión mejorada ha dado como resultado un rendimiento mejorado del motor, con una carga térmica menor en sus cojinetes de bancada y un menor consumo específico de combustible.