현대중공업 중속디젤엔진 힘센엔진 패밀리의 신모델 추가 개발

김종석[+] · 김주태[++] · 권오신[+++]

EXPANSION OF HYUNDAI'S MEDIUM SPEED DIESEL ENGINE FAMILY, HiMSEN

J.S.Kim[+], J.T.Kim[++] and O.S.Kwon[+++]

Abstract : Since HiMSEN H21/32, a new medium speed diesel engine of Hyundai's own design, was introduced in 2001, Hyundai has added new models of H25/33 and H17/28 into HiMSEN engine family. These two new engines take after faithfully to the original HiMSEN concept of a PRACTICAL engine by Hi-Touch and Hi-Tech. The prototype of H25/33 was developed jointly with Rolls Royce Bergen originally and also introduced in 2001. But most of the engine design have been changed by Hyundai for the commercial versions to be a member of HiMSEN family, which has little interchangeability with the prototype. H17/28 is now under development as the smallest size of the family. This new engine also has the longest stroke of a class engine, which has been proven as the best basis for future environmental challenge. The higher compression ratio of 17 and optimized Miller Timing with Simplified-pulse turbocharging system applied all HiMSEN engines as which showed the most practical solution against current heavy fuel combustion issues for the time being before introducing digital control system. This paper describes the design and development of these new HiMSEN engines and also reviews the service experiences of H21/32 and H25/33, which launched successfully.

Key words : HiMSEN, H17/28, H21/32, H25/33, Medium speed diesel engine, Hi-touch, Hi-tech, Hi-pulse

INTRODUCTIN

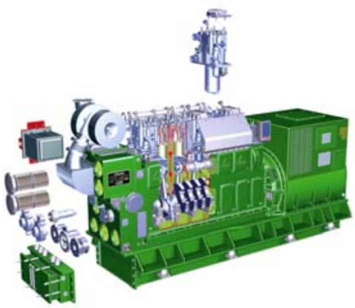
HHI, Hyundai Heavy Industries Co. Ltd., had planned new engine development program with own design in early 1990's. HHI commenced investments for technical background and then tried to establish a new attractive own design concept for future engines. Consequently, HHI could have two kinds of different design concepts and introduced two proto types of the new engines at the same time in 2001, a bore 210 mm engine from HHI in-house team and a bore 250 mm engine from joint-team with Rolls Royce Engine Bergen[1].[2].

After development of these two different design concepts, HHI evaluated the results thoroughly and finally selected one of the concepts for further development in the name of HiMSEN engine family, which mainly came from the idea of in-house team. [Fig.1] shows the design concept of simple, robust and

+ 김종석, 현대중공업㈜, E-mail:bigman@hhi.co.kr, Tel: 052)230-7341
++ 김주태, 현대중공업㈜
+++ 권오신, 현대중공업㈜

smart. [Fig.2] shows easier maintenance concept of modularized feed system and Cylinder unit with direct accessibility.

[Fig. 1] Outline of HiMSEN engine



[Fig. 2] Maintenance Concept of HiMSEN engine

The key design philosophy of HiMSEN engine family can be summarized as 'a most PRACTICAL Engine' concept, which was abstracted from Hyundai's wide experience of modern marine diesel engine production and services. 'Hi-TOUCH' and 'Hi-TECH' approaches were adopted as a leading principle for the design to realize the concept. Hi-TOUCH approach contributed to have simple and smart designs for a customer friendly engine, while Hi-TECH approach, based on the sophisticated modern CAE technology, provided satisfactory results of engine performance and reliability within a short time.

After introduction of the first proto type engines in the year 2001, HHI concentrated company's capabilities to develop more proto type engines for commercialization and could have now three base models of H17/28, H21/32 and H25/33 in the HiMSEN engine family.

Both H21/32 and H25/33 engines were type-approved from major classification societies in 2002 and are in sales actively, while H17/28 is under development and will be available in the market from the beginning of the year 2005.

Huge amount of engineering works also has been poured into the development of every cylinder versions of 5 to 9 cylinder engines and speed range of 720, 750, 900 and 1000 rpm respectively to meet customer's various requirements. Thanks to these efforts, about 650 sets of commercial engines have been ordered so far and more than 400 sets has been launched successfully. Some earliest engines are already in service recording more than 20,000 run-hours in the end of the year 2004, which is also demonstrating the excellent designs of high reliability and performance as well.

This paper mainly describes the development of these various family engines and corresponding service experiences of the elder engines.

HiMSEN FAMILY AND SPECIFICATIONS

Initial application targets for HiMSEN were generator-sets with heavy fuel operation not only on board but also on land, which have been fulfilled faithfully and now have marine propulsion family as well.

The maximum engine outputs are 200kW for H17/28, 200kW/cyl for H21/32 and 300kW/cyl for H25/33 at maximum speed of 1000rpm. Engine speed of 750 rpm and 1000 rpm are available with same power as 720 rpm and 900 rpm respectively.

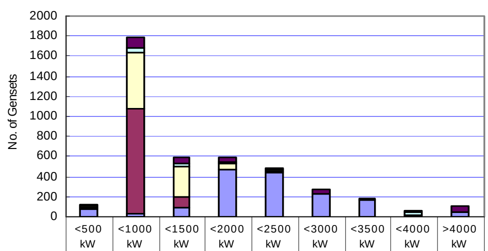
The engine can be run on diesel fuel oil and heavy fuel oil up to ISO 8217, RMK55 class. Dual fuel gas engine is also under development for the minimum modification of existing design.

[Table 1] shows the basic parameters of these engines and some of the backgrounds are described in the following sections.

Engine type		H17/28	H21/32		H25/33	
Bore	mm	170	210		250	
Stroke	mm	280	320		330	
stroke/bore		1.65	1.52		1.32	
Engine speed	rpm	900	720	900	720	900
Output/Cyl	kW	115	160	200	240	300
Piston speed	m/s	8.4	7.7	9.6	7.9	9.9
BMEP	bar	24.1	24.1	24.1	24.7	24.7
Power Density	b.m/s	203	185	231	196	244
Pmax	bar	170	200	200	200	200
SFOC	g/kWh	193	186	187	184	185
Engine Power [kW] Cylinders In Line	5	575	800	1000		
	6	690	960	1200	1440	1800
	7	805	1120	1400	1680	2100
	8	620	1280	1600	1920	2400
	9		1440	1800	2160	2700

[Table 1] Engine Specifications

These specifications are mainly based on the recent trend in domestic marine market. [Table 2] shows the demand of marine genset in Korean shipyards for last four years and the power range of HiMSEN family are well suited for the market clearly.



	<500 kW	<1000 kW	<1500 kW	<2000 kW	<2500 kW	<3000 kW	<3500 kW	<4000 kW	>4000 kW
Others	12	105	53	35	15	45	7	26	68
LNG, LPG	0	40	28	25	8	0	0	30	0
COT	19	567	313	50	21	0	0	2	0
PC,BC	15	1036	101	6	4	0	0	0	0
Container	76	36	89	468	444	221	174	6	38

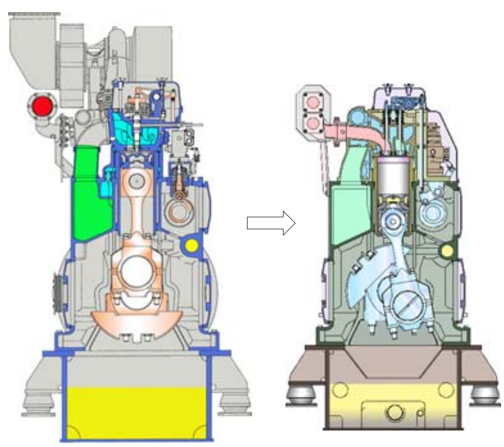
[Table 2] Marine Genset Orders, Year 2000-2003, Total 4,183 sets.

DEVELOPMENT OF H25/33 MODEL

The first proto engine of a 250mm bore engine has been developed jointly with Rolls Royce Engine Bergen and introduced at the same time with H21/32 in the year 2001[2]. Two sets of the proto engines were built and tested at Bergen and Ulsan in parallel. The main parameters for the performance and reliability were evaluated and confirmed through the tests.

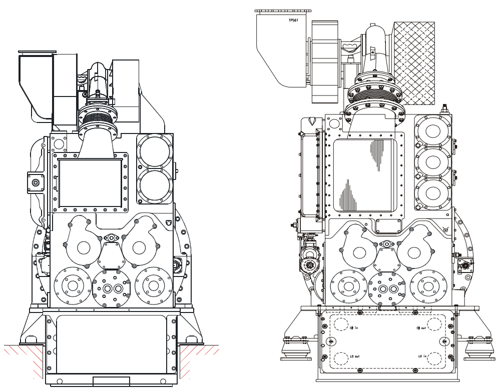
The second proto engine of a 250mm bore engine is 9-cylinder version and has a completely updated design, which mainly originated from improved version of H21/32 engines, that is, simple and smart design features of H21/32 have been adopted into this engine. Hence, the original 250mm bore engine has been grown up independently at both places and now Hyundai named it H25/33 model, while Bergen named C25:33 with their own improvements.

[Fig.3] shows the cross sections of the original design and new H25/33 design.



[Fig. 3] Improvement of H25/33

The feasibility of sharing common components among engine types of HiMSEN family has been investigated and concluded that common Feed Module was feasible and most effective in view of productivity and maintenance. The Feed Module consists of two water pumps, an oil pump, oil filters, and control valves, etc., which integrated into one block as a fully modularized unit without pipe connections. Hence, Feed Modules and Cylinder Block have been designed for sharing each other. [Fig.4] shows two Feed Modules of different capacity of maximum engine power of 1800kW and 2700kW respectively. Hence, the smaller Feed Module can be used for all H21/32 engines and 5, 6 and 7 cylinder H25/33 engines as well, which clearly can provide more competitiveness. Further benefits are also expected as the two Feed Modules also share most of the internal components and machining tools.



[Fig. 4] Feed Modules for Capacity of 1800kW and 2700kW

DEVELOPMENT OF PACKAGED POWER STATION (PPS)

HHI is also very well experienced in power plant business and decided to develop a very economical small size power plant of from 1 MW to 2 MW range to meet some customer’s demands.

Hence, a portable power plant of a container enclosed type, named Packaged Power Station(PPS), was developed by using HiMSEN engine, which consists of a engine-generator unit(EGU) and a heavy fuel oil treatment unit(HTU).

A proto type PPS has been built in house for the reliability test of the total system as shown in [Fig.5], which has 1 MW capacity with a 6H21/32 engine and is now running more than 11,000 hours. This pilot power plant is regarded as a technology demonstrator for HiMSEN engine because various utmost tests could have been carried out as follows;

- Various operators
  - √ specialists
  - √ trainees
- Various loads
  - √ long term idling/over load
  - √ cold run/hot run
  - √ low cycle fatigue tests
  - √ transient loads
- Various media with various pressures and temperatures
  - √ Fuels(HFO, Gas, etc)
  - √ Lub. Oils
  - √ Cooling Waters
- Components Evaluation
  - √ Various qualities and designs
  - √ Various suppliers
- On trailer tests, etc.

Most of the design issues could be disclosed and improved in the very early stage by these tests, which enabled to confirm the commencement of unlimited production and provided enough confidence for the sales activities.

[Fig. 5] Pilot Plant - 1MW Packaged Power Station

QUICK ENGINEERING FOR VARIOUS APPLICATIONS

Though the development of the HiMSEN engines were the first experience of a new engine development, HHI built only limited numbers of proto type engines. Two sets of 6 cylinder engines were built for H21/32 model and two sets of 6 and 9 cylinder engines for H25/33 model. Despite of the limited number of cylinders and rated speeds, most of the design features regarding performance and reliability could be matured in pilot plants in house and in the fields. However, some of critical tasks should be developed for the various applications such as gensets on board or on land, ship propulsion and other various industrial prime movers. Further, HiMSEN engines provides more suitable powers by selecting quantity of cylinders from 5 to 9 cylinders with engine speed from 720 to 1000 rpm respectively.

Hence, HHI also prepared engineering resources to come up with imminent huge tasks to meet such various applications from customers.

HHI reorganized own research centers to concentrate more on HiMSEN engines and to support design engineers for quick development of the commercial engine projects. The important achievements in consequence can be summarized as follows;

Optimization of dynamic behaviors

HHI has accumulated decade-long experiences and knowledge in vibration technology through the design, production and research activities for various marine and industrial machineries, which enabled quickly to have dynamically optimized design of HiMSEN engines with extensive analyses and experiments.

From the prototype engine tests, every dynamic measurement has been evaluated and compared thoroughly with the prediction of design phase for the verification as well as application to the other engines with different cylinder numbers.

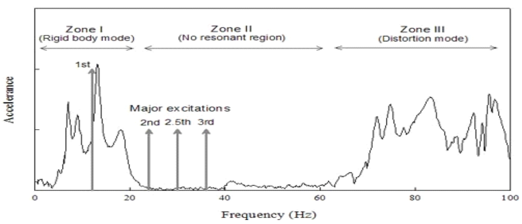
Vibration modes of various engine-generator models were identified by simulations and tests for design optimization. Typical vibration modes of the generator sets are regarded as 'rigid body mode' and 'distortion mode'.

The rigid body modes are the representation of six degree of freedoms of an entire generator set, which comprises 1st and 2nd rolling and pitching respectively, bouncing and yawing modes. Natural frequencies of those modes are low below 20Hz and often resonant with 0.5th and 1st order excitations, which can be easily controlled by modifying the mountings or attaching the balance weight.

The distortion modes are the representation of elastic deformation of the dynamic structures of an engine and generator frame, typically categorized as torsional mode and bending mode. These distortion modes are often resonant with higher frequencies of the dominant engine excitation and result serious frame vibration problems.

Optimization of dynamic structures for the HiMSEN engine family is realized by avoiding possible resonances of these modes with the dominant excitations even for the engines with higher excitation forces such as 5-cylinder and 7- cylinder engines. Major structural components to control the natural frequencies of the distortion modes have been the common base frame as well as flywheel cover connections, letting the engine or generator modification minimal or nearly none.

Optimized dynamic characteristics of typical 5-cylinder engine structure are exampled in [Fig.6] where the major excitations lie in the wide nonresonance region (Zone II) between rigid body modes (Zone I) and distortion modes (Zone III) such that the resulting vibration responses could be shown up in the minimum level.



[Fig. 6] Frequency response of a 5H21/32 Genset

Consequently, vibration levels for all applications could be controlled safely within the range of 18mm/sec[rms]

Optimization of engine performance

During the development test period of the proto type engines, most of the performance parameters regarding a combustion chamber could be cleared.

Besides the high stroke to bore ratio, compression ratio of 17 was finally selected with optimized piston bowl shape and fuel spray parameters in view of combustion characteristics and thermal loading as well. Scavenging air pressure of about 3.8 bar at nominal MCR provides optimum airflow amount, which also leads to the optimized maximum firing pressure of from 180 bar to 200 bar.

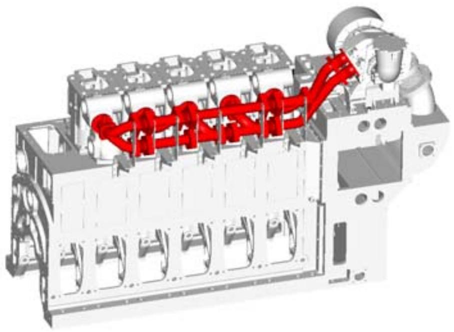
However, as for the turbo charging system, more considerations were required, because a four cycle medium speed diesel engine can have various options of turbo charging system, for instance, constant pressure system, pulse converter systems, pulse system and so on.

Therefore, intensive studies were conducted to find optimum solution and concluded that conventional pulse type turbo charging system can be regarded as best solution only for a 6 or 9 cylinder engines.

However, the pulse system for 5, 7 and 8 cylinder engines revealed not only the complexity of the structure but also higher fuel oil consumption compared to those of 6 or 9 cylinder engines.

This inferior performance is regarded as mainly due to the characteristics of exhaust gas flow to turbine. An engine with 5 or 7 or 8 cylinders has to use one or two pulse in one exhaust pipeline during one cycle, which cause rather intermittent exhaust gas flows into turbine. This can be comparable with 6 and 9 cylinder engines using 3 consecutive pulses per cycle. Hence, one or two pulse system causes lower turbocharger efficiency due to more windage loss of turbine and results slightly increased fuel oil consumption of the engine.

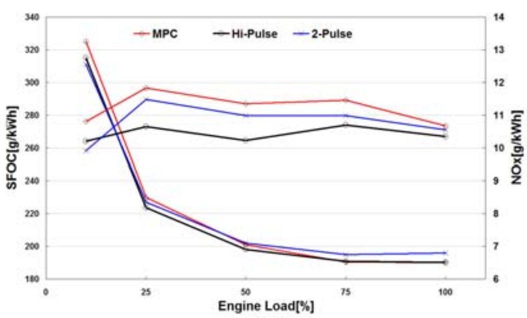
Hence, a unique turbo charging system, named 'Hi-Pulse' system, has been introduced and developed for 5, 7 and 8 cylinder engines.



[Fig. 7]Exhaust pipe arrangement for Hi-Pulse system

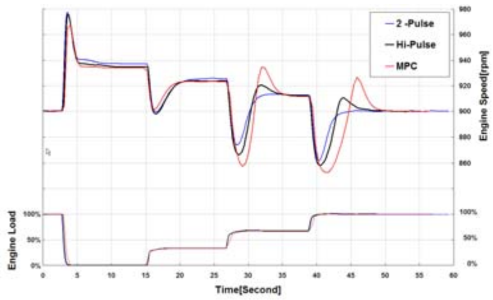
The key idea of 'Hi-Pulse' system is to utilize the benefits of Modular Pulse Converter (MPC) system at higher load and the benefits of pulse system at lower load. To realize this idea, intensive simulations and engine tests were performed. Eventually, the exhaust pipes are optimized by arranging two pipelines such as 3-pulse system for a 6-cylinder engine. However, the exhaust pipe for the farthest cylinder is branched and connected to the both pipelines as illustrated on [Fig.7].

The test results of these exhaust pipe systems are typically shown in [Fig.8] and [Fig.9].



[Fig. 8] Performance Comparison of turbocharging systems – SFOC and NOx.

Hi-pulse system shows improved performance, that is, more improved fuel oil consumption than that of 2-pulse system and less NOx emission than MPC system. Hi-pulse system also shows similar acceleration capability to 2 – pulse system.



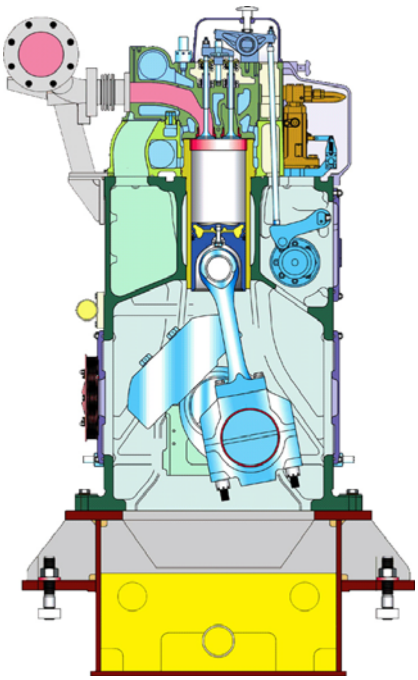
[Fig. 9] Performance Comparison of turbocharging systems - Load response.

DESIGN OF H17/28 MODEL

After successful development of HiMSEN engines, a strong demand for the development of a new smaller engine has been arisen internally. The target markets are marine get sets of power range of below 1,000kW for the product carriers or similar vessels.

This new engine is also designed based on the HiMSEN concept faithfully so that the bore 170 mm and stroke 280 mm has been selected for 115 kW/cyl and about 24 bar BMEP. Hence, this new engine also has the longest stroke of a class engine, which has been proven as the best basis for future environmental challenge.

However, productivity of the engine has been also emphasized from the beginning of the design, as price competition is most critical factor for this size of engines, which often compete with high- speed engines. [Fig.10] shows the simpler designs, for example, plate type lubricating oil cooler is mounted side of the engine block, which provides oil channel for main bearing of each cylinder, hence cylinder block could be free from risky cast-in channels. Proto type of 5 and 8 cylinder engines have been built and under testing.



[Fig. 10] Cross section of H17/28 engine

PRODUCTION AND SERVICE RECORDS

Thanks to the customer' s trust on HHI and its attractive design, many HiMSEN engines have been ordered and launched successfully within a relatively short time despite of HHI' s first new design.

The proto type test engines have been operating under various test programs to demonstrate and improve performance and reliability since the year 2000.

More than 400 sets of HiMSEN engines were already delivered and about 300 engines are in service at the time of December 2004.

All of the service statuses are well within the range of designed performance criteria even including the case of running hours of more than 20,000 hours under the toughest service condition of base load of a power plant in tropical area.

It is meaningful that HiMSEN engines with higher engine speed of 900 or 1000 rpm becomes more and more accepted in the market for the engine power range of 1 to 2 MW with Heavy Fuel Operation.

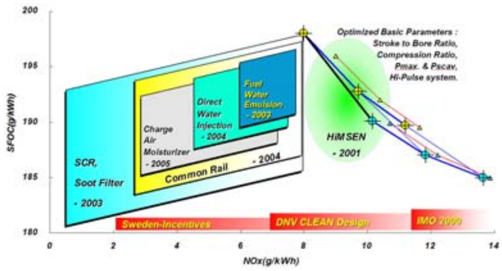
BASIC RESEARCH OF DIESEL COMBUSTION

In parallel with family engine developments for various cylinder versions and applications, some of typical research activities to meet environmental issues are also underway.

For example, common rail fuel injection system, fuel water emulsion system, Charge Air Moisturizer (CAM) system and so on are under research with very promising results.

Besides these measures for the engine itself, new material developments for soot reduction system and Selective Catalytic Reduction (SCR) system are also underway actively. A new reliable and economic material for SCR system has been developed recently, which recorded more than 90% reduction of NOx emission on HiMSEN engine.

These research activities are well organized and controlled under strict time frame by HHI' s engine research institutes, which can be summarized as shown in [Fig.11]



[Fig.11] Program for performance improvement for HiMSEN engines.

CONCLUSIONS

HiMSEN engine families have been launched successfully within relatively short time despite of the HHI's first own design and development.

After proto type engine developments, various applications of all cylinder versions from 5 to 9 cylinder have been developed and launched successfully. Hence, original design concept for the HiMSEN engine has been completed for the entire family of H21/32 and H25/33 engine models, which also has been transferred to a new smaller engine model of H17/28.

These achievements are based on the following technical points;

- Quick development capability is one of key factor for a new engine's successful market introduction. Well-tuned commercial engineering softwares played the key role for this purpose.

- Dynamically optimized structure and Hi-pulse turbocharging system improves engine reliability and performance as well, which contributes to overcome customers' reluctance on the engines of 5 and 7 cylinder versions.

- Earlier HiMSEN engines are in service demonstrating excellent performance and reliability. Further improvements are also under way for more customers' satisfaction and environmental issues.

ACKNOWLEDGEMENTS

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REFERENCES

[1] J.T.Kim, et. al, "Development of a new medium speed diesel engine - Hyundai H21/32.", Vol. 1, Page 47, CIMAC 2001.

[2] L.M.Nerheim, J.T.Kim, et al, " Some experiences of modern design and development method of a new Bergen-Hyundai medium speed marine diesel engine series" Vol. 1, Page 73, CIMAC 2001.