Low Noise Design Technology and Development Trend of Marine Diesel Engine

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Abstract: The vibration and noise level of marine diesel has the direct influence on the comfort and acoustic concealment of merchant ships, which has been the important mark of engine performance as well as power density, volume and weight and so on. The development of identification and separation of noise source, the intake and exhaust noise control technique, the modern prediction method of noise and new findings of noise control method are present. Moreover, the future trend of noise control technology of internal combustion engine is proposed. Thus, the guides and basements were provided to assist technology investigation, product developing, and system design.

Key words: marine diesel; vibration; noise.

1. Introduction

Diesel engine is one of the main power sources of ships. Although the radiated noise levels of different types of diesel engines are different, they are generally as high as 105 ~ 110dBA and above. Especially in recent years, with the development of industrial technology, diesel engine's characteristics of high power, high speed and lightweight make the vibration and noise problems become more prominent. High-intensity radiated noise will directly stimulate the hull structure to radiate structural noise to the water or to other cabins, which will directly affect the acoustic stealth performance of the ship and cabin comfort performance; the latter will lead to difficulties in communication and distraction during the work of the crew.

Vibration and noise reduction will be a key issue when many foreign authorities predict the development of diesel engines. RICARDO puts environmental pressure first in predicting the future challenges facing the diesel engine industry. The pressure to reduce the environmental impact of diesel engines is mainly manifested in the formulation and enforcement of strict regulations on diesel engine emissions and noise (1). While discussing the general trend of diesel engine development in recent years, AVL Austria considers that the most challenging requirement in the development of diesel engine is to solve the coordinated relationship among emission pollution control, noise, vibration and ride comfort, as well as the cost of achieving satisfactory performance and the required technology (2). In discussing the development of diesel engine technology, the German FEV Company considers that reducing noise to meet the requirements of regulations is an obvious feature of recent development, and this development will be further strengthened

(3). Therefore, diesel engine vibration and noise reduction technology for quite a long time in the field of diesel engine research and technology development, will still be an important research topic.

In this paper, the research status and development trend of diesel engine vibration and noise control technology are summarized from the aspects of sound source identification technology, intake and exhaust noise control design technology, low noise design and prediction technology, active noise reduction technology and so on.

2. Requirements and necessity for vibration and noise control of diesel engines

Compared with developed countries, the research on diesel engine vibration and noise control technology in our country started late and the foundation is weak. The lack of corresponding noise characteristics database, noise source identification method, accurate noise prediction method and standard design and development system leads to the design of products with low

acoustic performance, design and relatively large prediction error. Therefore, it is urgent to carry out relevant technical research on the basis of existing.

1) The design technology of diesel engine noise control is weak, so it is urgent to break through the key technologies and form design specifications.

From the comparison of diesel engine noise control design technology at home and abroad, it can be seen that the domestic technology's emphasis is mainly local control. Although some achievements have been made in peripheral noise control, the latest achievements and core technologies in this field have not been mastered, the overall noise control concept and process are lacking, and the independent innovation ability is low. It is urgent to carry out the research on key technologies such as noise source identification, combustion noise mechanism, intake and exhaust noise control and sound insulation design of the enclosure. Combined with the existing external noise control design methods, our own diesel engine noise control design methods or specifications can be formed.

2) In the future, the requirement for acoustic stealth performance of ships is increasingly higher, and low noise diesel power and its equipment is urgently needed.

With the planning and construction of large ships, the demand for high-power light-duty diesel engines has increased dramatically. At present, only the second-generation diesel engine can be selected, but the noise level of this kind of diesel engine is relatively high. As a result, it is difficult to meet the requirements of ship acoustic stealth performance and comfort performance. So, it is urgent to study the vibration and noise control of diesel engine to reduce its vibration and noise level.

3) The increasingly stringent regulations on ships require further noise reduction.

In recent years, in order to avoid health problems of crew such as fatigue and insure the safety of navigation, new international codes and conventions on energy-saving and environmental protection of ships have been constantly put forward, especially the requirements of new international codes and conventions on the comfort and safety of ships. International Maritime Organization and classification societies have revised the ship noise and vibration indicators in succession in order to improve ship comfort and protect the physical and mental health of crew.In recent years, CCS, DNV and other classification societies have successively revised the specifications, which limit the vibration and noise of ships, and classify them according to the comfort level.

The IMO recently revised the ship noise classification rules, and the noise limit for work and living compartments has been reduced by 5 dB (A). The new code is expected to be enforced on July 1, 2014. As the diesel engine is the main noise source of ships, the noise control requirements of the new code for diesel engines have been improved accordingly. The new noise standards put forward more stringent requirements for India's shipbuilding enterprises and diesel engines and other supporting enterprises, raising the technical threshold for upgrading. If the vibration and noise of diesel engines and other power equipment cannot be effectively controlled, it will seriously restrict the development of China from a big shipbuilding country to a powerful shipbuilding country.

In recent years, domestic diesel engine research institutes, universities and manufacturers have carried out some research on diesel engine noise control technology by means of source control, propagation path control and so on, some research results having been obtained. However, most of these studies are local and mechanic, not systematic, without the formation of standard design and test verification methods, which makes it difficult to significantly improve the level of diesel engine noise control. Therefore, it is a necessary and urgent task for the development of China's shipbuilding industry and the upgrading of the overall technical level to carry out the design and test verification of diesel engine noise control systematically.

RESEARCH STATUS AT HOME AND ABROAD

In this paper, the research status of diesel engine vibration and noise control technology at home and abroad is expounded and analysed from five aspects: sound source identification technology, intake and exhaust noise control design technology, low noise design and prediction technology, box sound insulation design technology, active noise reduction technology.

3. Research Status at Home and Abroad

1) Identification technology of diesel engine sound source

In order to control the noise of diesel engine, it is necessary to study the mechanism of various kinds of noise and its identification technology, prediction method and corresponding control method. Industrial developed countries have always attached great importance to the design and development of low noise diesel engines. They have invested a lot of manpower, material and financial resources in this area, and established more accurate noise identification methods, noise prediction methods and advanced noise control technology. International famous universities such as Georgia Institute of Technology, Pennsylvania State University, Southampton University, Liverpool University, Shebrook University of Canada, Tokyo University of Japan, Korea Polytechnic Institute and so on have already carried out research on noise source identification methods and characteristic measurement methods as early as the 1960s.

After the development of half a century, they have made great progress in the identification and separation of noise sources, measurement and analysis of noise characteristics, and have mastered almost all the latest technologies and achievements in this field. In the coming decades, diesel engine noise sources and characteristics identification technology will continue to be an important research in developed countries. The research will play a positive role in promoting and upgrading the quality of products.

2) Diesel engine intake and exhaust noise control design technology

Diesel engine intake and exhaust noise is one of the main sources of diesel engine noise. In terms of intake and exhaust noise prediction and muffler design research, foreign countries have been at the forefront. The Institute of Sound and Vibration Research (ISVR) of the University of Southampton, UK, has been at the forefront of research and development in the acoustic design of engine intake and exhaust systems. He pointed out that the reasonable design process is based on the use of predictable acoustic simulation technology, that any complex geometric model can be decomposed into a series of simple elements or cavities to simulate. The Mars extinguishing muffler developed by Universal Silencer in the United States has a Mars extinguishing rate of over 98% and a muffling capacity of up to 30 dBA. The University of Kentucky in the United States, in collaboration with Universal Silencer and Cummins, has developed an acoustic prediction program for mufflers based on boundary element method, Ohio State University in collaboration with Owens-Corning has developed a three-dimensional acoustic calculation program for mufflers. The University of Loughborough in the United Kingdom, with the support of a number of companies, has developed an acoustic prediction program for mufflers based on boundary element method. The British University of Southampton, Sweden's Royal Institute of Technology, Korea's National University of Science and Technology, etc. have also developed various acoustic calculation programs for intake and exhaust systems.

3) Low noise design and prediction technology for diesel engine

Foreign research institutions attach great importance to the design and development of low noise diesel engines, especially marine low noise diesel engines. From the early 1980s to the

present, the development of marine diesel engine has experienced three periods of technological development, as shown in table 1. It can be seen that from the second-generation engine, foreign countries have paid close attention to the requirements of diesel engine low noise design, but the control technology mainly concentrated in the periphery of the diesel engine. It adopts passive means, and its noise control level is limited. By comparison, in the design and development process of the third-generation engine, the vibration and noise index has been carried out from the design stage. Diesel engine performance design and low noise design are carried out in parallel.

Tab. 1Development history of foreign marine diesel engines

Time	1980s	1990s	21century
Strengthening index	20~24	24~28	28~32
Research and development timeof new diesel engine	About 10 years or so		3~4年
Key technology	High efficiency turbocharger technology and single stage supercharging Technology	High pressure technology, mechanical high pressure fuel injection technology, vibration reduction, noise reduction and resistance impact technology.	Super high pressure technology and intelligent technology
Typical diesel engine	TBD234 ect.	MTU956、MTU396、20VPA6B ect.	MTU8000、MAN28/33D ect.
	The first generati	The second	The third

Abbrevi ation	 on engine	generation engine	 generation engine

Aiming at the second and third generation diesel engines, the advanced design means and modern technology make the marine diesel engines have reached lower noise. For example, Caterpillar, MTU, SEMT, AVL, FEV and other companies have formed relatively mature, practical low noise and high-power diesel engines with their advanced design means and methods. The design method has been changed from "experiment + experience design" to "prediction design".

Here are some examples. FEV developed high-performance numerical analysis software; AVL developed diesel engine working process prediction software, involving diesel engine combustion, piston movement, vibration and noise, and other aspects; in the design of diesel engine, Wartsila takes vibration noise and shock resistance as one of the important indexes of diesel engine, uses noise prediction technology to guide the design of diesel engine, and forms a low noise design method for acoustic prediction, shock assessment, optimization design and test verification of diesel engine power plant. The whole process of design, testing and application is closely integrated. (Fig. 1). In the process of low noise design, through the research and application of new silencing device, combustion chamber structure, fuel injection mode, high temperature resistant polymer damping material and other technologies, the noise of foreign diesel engine has reached a higher level, among which the noise of marine medium and low speed diesel engine has been reduced by more than 5 dBA.

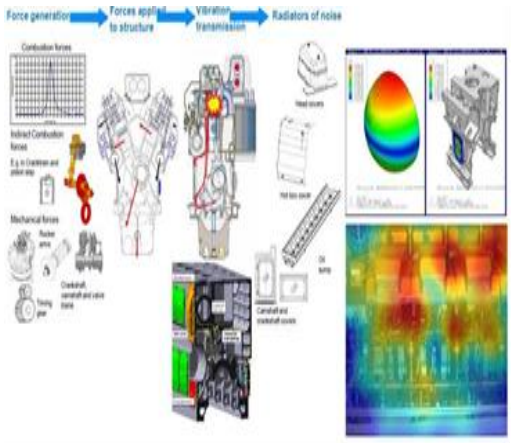

Fig. 1Design process of Wartsila low noise diesel engine

1) Active noise control technology of diesel engine

In recent years, active noise control technology has developed rapidly. This technology has the characteristics of strong pertinence and good effect. It can effectively complement the disadvantages of passive sound insulation technology in low frequency band.

Because the active noise control technology has obvious advantages over the traditional passive control technology, most developed and developing countries have invested a lot of manpower and material resources to carry out research. Overall, the research level of foreign countries is much higher than that of domestic countries, mainly in basic theory, simulation analysis, control technology and design level. Famous research teams, such as the Institute of Sound and Vibration, University of Southampton, Virginia Technologies and Adelaide University in Australia, have been working tirelessly on the basic theory and application technology of active noise control. In the United States, Europe, Japan and South Korea, active

mufflers have been developed for vehicle exhaust noise. At present, the active noise reduction technology mainly focuses on the acoustic control of pipeline noise reduction and small enclosure, and its application in diesel engine enclosure noise reduction is less [4]. Among them, Birmingham Youth University has carried out active noise control technology research on diesel engine box. By controlling the energy density of diesel engine radiated noise, the total radiated noise of diesel engine box can be reduced by more than 2 dBA, and some characteristic frequencies can be reduced by more than 15 dB, as shown in Figure 2.

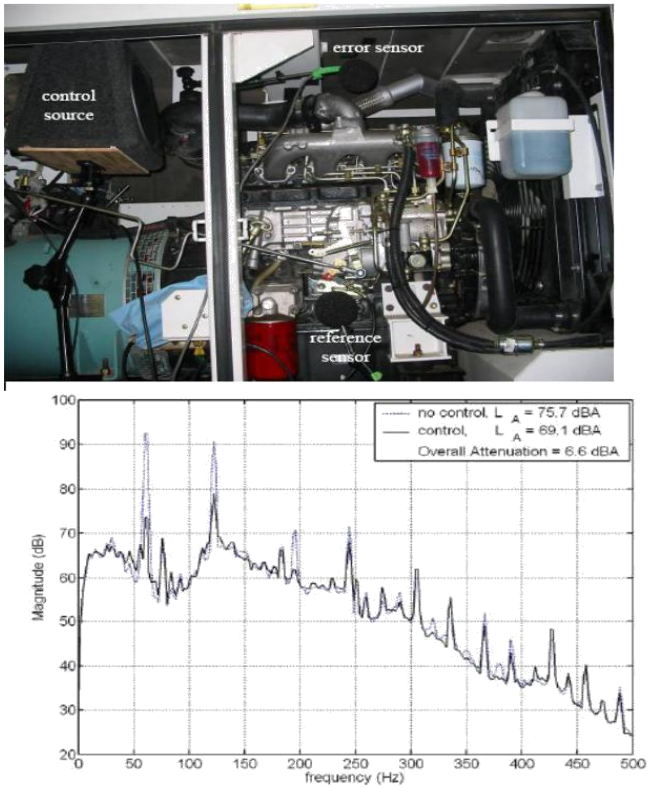

Fig. 2Active noise control of diesel electric generating set

Domestic Research Status

Domestic marine diesel engine research has mainly experienced the development process of imitation, digestion and absorption, and technological innovation. The state has also invested some funds for the introduction of diesel engine anti-design research, including anti-design of vibration and noise, having achieved some results.

1) Identification technology of diesel engine sound source Since the 1980s, some universities, such as Tsinghua University, Hefei University of Technology, Beijing University of Aeronautics and Astronautics, Harbin University of Engineering, Jiaotong University, Tianjin University, Tongji University, have carried out noise source identification research, and have achieved some research results.

For example, Harbin Engineering University has done a more in-depth study on the identification, prediction and control of diesel engine noise sources, having a good research foundation and rich practical experience. Tianjin University has carried out the research on diesel engine noise source identification method based on inverse boundary element method. However, no one has done a systematic research on the identification of diesel engine noise sources and characteristics so far. In a word, the research on the main noise sources and characteristics identification technology of diesel engines in India is not comprehensive and thorough enough, the achievements of leading international level are few, the talent team and level are not ideal, the infrastructure is poor, and the research funds are not much. Therefore, if the domestic manpower and material resources can be well integrated, the research input can

be increased, and the systematic and in-depth research can be carried out, it will play a positive role in the identification technology of main noise sources and characteristics of diesel engines in India, shortening the gap between India and developed countries, and reaching or approaching the international advanced level in a relatively short period of time.

2) Design technology of intake and exhaust muffler system for diesel engine

Domestic diesel engine intake and exhaust muffling system design technology units mainly by Harbin Engineering University, Tsinghua University, Jilin University, Zhejiang University, Beijing University of Technology and Shanghai Marine Diesel Engine Research Institute, etc. Harbin Engineering University has been devoting itself to the study of intake and exhaust mufflers since the 1980s. It has made a great deal of research achievements in the aspects of muffler performance prediction, test and design. It is the most influential research group in this field in the world. It has undertaken the design and development of intake and exhaust mufflers for marine diesel engines. No. production task. Marine Diesel Engine Research Institute has developed a series of mufflers with different grades and Martian extinguishing mufflers through domestic research fund projects. They have been applied to MAN, Vasiland, Caterpillar and other diesel engine sets respectively, and have achieved very good acoustical result.

However, from the comparison of structure and performance, it can be seen that the domestic diesel engine intake and exhaust mufflers still have some shortcomings, such as too large structure size, high resistance, low muffling capacity at individual frequencies, unstable dynamic muffling performance and so on. Especially, the Mars extinguishing mufflers under the same back pressure have much lower Mars capture and collection rate than the foreign level. The reason is that the prediction method is not accurate enough, the design idea is not advanced enough, and the influence of internal structure and components on the sound field and flow field is not thoroughly studied.

3) Low noise design technology for diesel engine

At present, the diesel engine technology of large ships in India is basically at the level of the second generation, and the noise level is higher than 105dBA.The work mainly focuses on the digestion and absorption of imported diesel engines, focusing on the control of vibration and noise around the diesel engine, the structural dynamic analysis of the important parts of the diesel engine, the classical analysis of excitation force, etc. It has not fundamentally solved the problem of vibration and noise control of the diesel engine

4) Active noise control technology of diesel engine

Engineering University has been engaged in active vibration and noise control technology since 1985. It is one of the earliest research institutes to carry out active vibration and noise control technology. In 1992, the preliminary research project "Active (Active) Acoustic Control of Aerodynamic Noise in Pipes" won the third prize of ministerial scientific and technological progress. They have carried out long-term and sustained research on active noise reduction in enclosed space, transmission and radiation control of structural sound.

However, in the world, the research on active noise control of diesel engine is generally confined to the active noise reduction of the intake and exhaust system of diesel engine, and the research on active noise reduction and active sound insulation technology using diesel engine as noise source is relatively rare.

4. Technology development trend

From the development trend of diesel engine vibration and noise control technology, the following aspects will be paid enough attention in the future development：

1) Generating mechanism of noise source of diesel engine

To study the mechanism of diesel engine noise source, and to raise the understanding of diesel engine noise. For example, the current research on the mechanism of combustion noise is based on experiments, and it is helpful to improve the understanding of the mechanism of combustion noise by studying the characteristic factors affecting combustion noise from the viewpoint of combustion and acoustic theory; the source and formation mechanism of intake noise of diesel engine should be explored, providing technical support for reasonable noise reduction.

2) Identification technology of diesel engine sound source

◦ The accuracy of the identification of various mechanical and combustion noises and their characteristics will directly affect the design of diesel engine noise control and low noise design, and whether the measurement results can be used to verify the noise prediction. In recent years, the development of acoustic array testing technology, spectrum measurement and analysis method, sound source separation method, sound field reconstruction, beamforming, wavelet analysis and other methods have made it possible to identify and separate mechanical noise sources in mild reverberation environment. It is the trend of technical development to establish a more accurate identification method for various kinds of mechanical noise, combustion noise and their characteristics of diesel engines.

To study and popularize more effective noise measurement methods, to master the spatial distribution and flow direction of diesel engine noise, to locate the noise sources more accurately, to study the identification principle and fast separation technology of diesel engine combustion noise and mechanical noise, and to understand clearly the characteristics of noise is the key to control diesel engine vibration and noise.

3) Design technology of intake and exhaust muffler system for diesel engine

Acoustic performance, drag loss and Martian extinguishing efficiency calculation method and experimental measurement method are the basis for the design of diesel engine intake and exhaust mufflers and Martian extinguishing mufflers. The effects of various factors (three-dimensional gas flow effects, perforated components, sound absorbing materials, purification carriers, drag reducing components, Martian extinguishing) are considered comprehensively, establishing efficient and accurate calculation methods and experimental measurements are the key technologies and challenging research contents. It is a trend to design intake and exhaust mufflers with compact structure, low flow resistance, high noise reduction and stable dynamic insertion loss. In order to predict the insertion loss of muffler, the noise source impedance of diesel engine intake and exhaust must be obtained. It is a feasible method to extract the acoustic source impedance by multi-load method. Reasonable load matching becomes the key technology to obtain the accurate acoustic source impedance of diesel engine intake and exhaust.

4) Low noise design and prediction technology for diesel engine

The research of diesel engine noise prediction technology should be carried out to solve the difficulties faced by current noise prediction technology and improve the accuracy of prediction results. For example, the non-uniqueness of the solution at the characteristic wavenumber is a key technical problem to be solved in the study of boundary element method for accurately calculating the acoustic radiation of vibration in the full wavenumber range; there are various random exciting forces in the working process of diesel engine, and reasonable loading of the model is an important problem in noise prediction; in the prediction of the whole engine, the method is adopted. Using substructure method, considering the combined action of block, crankshaft, connecting rod, cylinder head, cylinder liner, main bearing cover, main bearing bush and main bolts, and more precise simulation of external force transmission is also the key problem to improve prediction accuracy. The application of acoustic radiation modal method in noise control of diesel engine should be studied. Acoustic performance, drag loss and Mars extinguishing efficiency calculation method and experimental measurement method are the basis of diesel engine intake and exhaust muffler and Mars extinguishing muffler design. Considering the influence of various factors (three-dimensional

gas flow effect, perforated components, sound absorbing materials, purification carrier, drag reducing components, Martian extinguishing) comprehensively, it is the key technology and challenging research content to establish efficient and accurate calculation method and experimental measurement means. It is a trend to design intake and exhaust mufflers with compact structure, low flow resistance, high noise reduction and stable dynamic insertion loss. In order to predict the insertion loss of muffler, the noise source impedance of diesel engine intake and exhaust must be obtained. It is a feasible method to extract the acoustic source impedance by multi-load method. Reasonable load matching becomes the key technology to obtain the accurate acoustic source impedance of diesel engine intake and exhaust.

5) Active noise control technology of diesel engine

Active noise reduction technology is a new research direction in the field of noise control, and its engineering application is the most important task at present.

6) Materials

On the premise of rapid development of material science, new sound insulation materials are explored, new sound insulation components are developed to reduce the transmission of diesel engine noise.

Conclusion

This paper summarizes the research status and development trend of diesel engine vibration and noise control technology from the aspects of sound source identification technology, intake and exhaust noise control design technology, low noise design and prediction technology, active noise reduction technology and so on.

It should be pointed out that the vibration and noise control of diesel engine should be considered in the top design stage of diesel engine development. Vibration and noise design of diesel engine during the whole design process is to provide comprehensive analysis results including various parts, components or design schemes of various specialties and stages as soon as possible. The vibration and noise control of diesel engine requires the mass, stiffness, damping coefficient, connection mode and related loads of each component. All of these require very detailed design and the matching of parameters. But it is unrealistic to wait for such detailed design in the whole design process, so the design is not practical. Therefore, at different stages of design, the structure and performance results of different degrees of detail should be used, and it needs to be repeated and verified many times. Such repeating and verifying progress is obviously not a simple calculation or test can bear. It needs to cross each other, which makes this study more complex. The importance of coordination and communication is also reflected in this process.

Reference

[1]YamazakiTatsuoMaedaRyouiehiYamashitaKikuo.Noiseandvib rationreductiontechniquesadopted forthenewV6Twin-CamVQengine[J]. JSAE Review199516(l):96-97. [2]FrenehC.Advancedtechniquesforengineresearchanddesign[J]. Proc Instn Mechs Engrs 2009203(2):169-183

[3] Vibration Archives Vol.39 No.4,2006

[4]T DawnActive Noise Control on the BrinkNoise&Vibration Worldwide199425(12)