Evolution and Development of iNDr

Kazuhiro UEDA*[1], Tomoyuki TSUCHIHASHI*[2], Hajime NAKASHIMA*[3], Zenzo YAMAGUCHI*[4], Kyoko MASUDA*[5], Satoshi TABUCHI*[5]

*[1] Advanced Technology Department, Design & Development Engineering Division, Global Engineering Center(GEC), KOBELCO CONSTRUCTION MACHINERY CO.,LTD.
*[2] Hydraulic Excavator Engineering Department, Design & Development Engineering Division, Global Engineering Center(GEC), KOBELCO CONSTRUCTION MACHINERY CO.,LTD.
*[3] ICT Promotion Department, KOBELCO CONSTRUCTION MACHINERY CO.,LTD.
*[4] KOBELCO MACHINERY EUROPE GmbH.
*[5] Mechanical Engineering Research Laboratory, Technical Development Group, Kobe Steel, LTD.

Integrated Noise & Dust Reduction (iNDr) is an advanced proprietary cooling system with the two unique functions of noise reduction and dust removal. It is installed in an ultra-low-noise hydraulic excavator launched for the first time in 2007. With its extremely low noise and dust-proof performance, it is used preferentially at many sites. Rather than becoming obsolete, it has gained in popularity, thanks to its performance. Environmental regulations are becoming increasingly stringent, and the constraints on equipment have become increasingly severe in connection with the development of smaller models: for example, the addition of a new function, mixing cooling exhaust and engine exhaust, is now required. Due to these circumstances, design tools based on fundamental theories, which allow more efficient study, are being utilized to evolve the iNDr into a "cross-over duct" with a new structure, while maintaining its extremely low-noise performance.

Introduction

In July 2007, Kobelco Construction Machinery Co., Ltd (hereinafter referred to as the "Company") launched an extremely low-noise-type hydraulic excavator equipped with an integrated noise & dust reduction cooling system (iNDr). The iNDr is a state-of-the-art cooling system uniquely developed by the Company. It combines the two functions of soundproofing and dust removal, contributing to the significant reduction of noise in the surrounding area, while dramatically improving the maintainability of cooling devices such as radiators. With its remarkable, extremely-low noise performance and dustproof performance, it has gradually penetrated the market since its launch. Its extremely low noise performance has been highly evaluated, mainly by general civil engineering customers, and its dustproof performance has been highly evaluated by industrial waste and forestry customers. Meanwhile, the environmental regulations imposed on engines have been strengthened all over the world. The noise regulations that had been enforced in Japan and Europe were also enforced in China in 2012, and three years later, in 2015, the regulation value was further strengthened by 3 dB.

It was against this backdrop that the iNDr technology, which had originally been established for urban-type, general-purpose, heavy equipment excavators, was adapted for mini-excavators, which, among all the types of excavators, are more often used near residential areas. This new iNDr was launched into the market.

In addition, the conventional iNDr for urban-type, general-purpose, heavy equipment excavators has been improved to keep up with engine emission regulations, which are being strengthened step-by-step, while maintaining its extremely low noise, dustproof performance. However, postprocessing apparatuses for exhaust emissions are required to comply with the 4th regulation for engine exhaust emissions. This has imposed extremely severe mounting conditions, making it difficult to arrange the sound absorbing duct that characterizes the iNDr, for example. Hence, a sound-absorbing exhaust duct was newly developed to achieve extremely low noise performance equivalent to that of the conventional machine.

This paper introduces the adoption of iNDr in mini-excavators and the evolution of iNDr associated with compliance with the engine emissions regulations for heavy equipment excavators.

1. Adoption of iNDr in mini-excavators

1.1 Features and challenges for mini-excavators

Mini-excavators belong to a class of excavators whose total body weight is 5 tonne or less, and have been designed differently from heavy equipment excavators because of their machine body structures. Therefore, in order to adapt the iNDr developed for heavy equipment excavators to mini-excavators, it was necessary to review the basic design of mini-excavators and make it as close as possible to that of heavy equipment excavators.

One major difference exists in the cooling systems for engine and hydraulic devices, as seen in the positional relation of the heat exchanger elements such as the cooling fan, driven by the engine, and the radiator that passes the cooling air. A heavy equipment excavator employs a suction type, in which air is suctioned from the outside and first passes the heat exchanger before entering the engine room. In contrast, a mini-excavator adopts a pusher type, in which the air passes through the engine room before being exhausted outside via a heat exchanger. This is due to the fact that a mini-excavator is configured to place the driver's seat directly above the engine room, which is a heat source, and it is necessary to intake the air as close as possible to the engine room to keep the temperature there low. In such a pusher type, the exhaust temperature after the air has been cooled by the heat exchanger is higher than in suction-type heavy equipment excavators. In addition, the exhaust opening is disposed on the upper side of the engine room in a heavy equipment excavator, whereas, in the mini-excavator, it is placed on the right side of the machine body close to ground level. Furthermore, apart from the cooling exhaust, the engine exhaust of a heavy equipment excavator is discharged through a muffler tail pipe to the upper side of the machine body in the same way as the cooling exhaust. In the case of a mini-excavator with a small machine body and a driver's seat disposed on the top of the body, the engine exhaust is discharged at a low position in the rear of the machine and away from the operator.

Mini-excavators are often operated in narrow spaces, and there is a potential problem in that plants, such as hedges, that are close to the excavator may be withered by the hot air from the exhaust (**Fig. 1**), and it is necessary to consider this at the time of adapting the iNDr.

1.2 Adaption of iNDr = "iNDr+E" [1), 2)]

A cooling system has been developed to adapt iNDr to mini-excavators, not just by incorporating the concept of iNDr for heavy equipment excavators but also introducing solutions to potential problems due to exhaust emissions, as described above.

An iNDr comprises a dust filter on the intake side to prevent dust from entering the machine body. In order to apply this structure to mini-excavators, the cooling fan and heat exchanger are configured to be of the same suction type as in heavy equipment. Also, in devising the positions and sizes of the intake and exhaust openings, the duct was configured to fit in the very narrow machine body of each mini-excavator. The problem of heat affecting the driver's seat was solved by installing the seat with a sufficient amount of heat-insulating material.

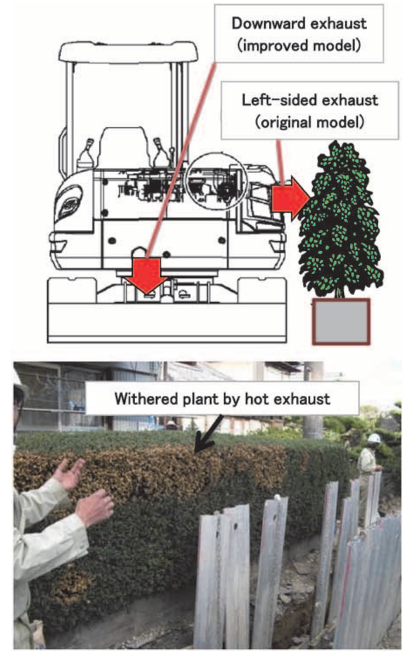


Fig. 1 Example of heat damage caused by mini excavator

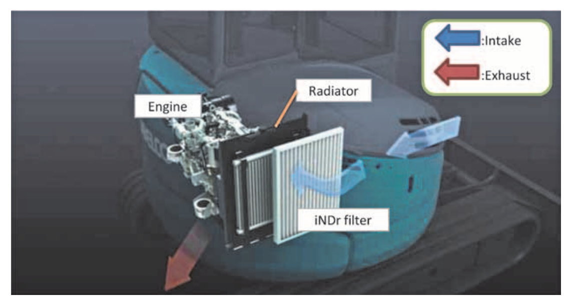


Fig. 2 Cooling air flow of newly developed mini-excavator

In this configuration, the opening on the right side of the machine body, the opening which conventionally has been for exhaust, is used as an intake opening. From this intake opening, a fan, which becomes the source of noise, can be seen directly through the heat exchanger. Hence, as a measure against noise, the duct was offset toward the front so that the internal sound source cannot be seen directly from the opening to reduce the direct sound.

The cooling exhaust, on the other hand, is configured such that its duct fits in the small space around the engine to take into account the previously mentioned harm to plants. The conventional direct exhaust to the left side of the machine body has been changed to an exhaust directed downward from the machine body. **Fig. 2** shows the flow of cooling air in the newly developed mini-excavator.

The hot exhaust gas from the muffler is diffusively discharged into a sound-absorbing exhaust duct installed in the engine room and mixed in the sound-absorbing duct with the exhaust that has passed through the cooling devices, so that the temperature and sound of the exhaust are reduced as a whole (**Fig. 3**). Having the exhaust flow downward from the machine body has completely eliminated the exhaust to the side or to the rear of the machine body. The tail pipe in the duct has been devised to facilitate the mixing of the engine exhaust with the exhaust passing the cooling devices. That is, the structure of a diffusion pipe covered all over with small holes has been adopted, in which the number and arrangement of the holes have been adjusted so that the exhaust gas is discharged uniformly.

The above new function is referred to as "iNDr + E" ("E" for exhaust) and has been set as a standard on-board function for mini-excavators.

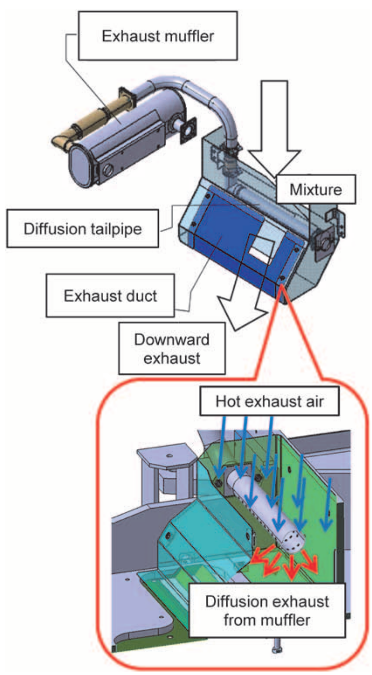
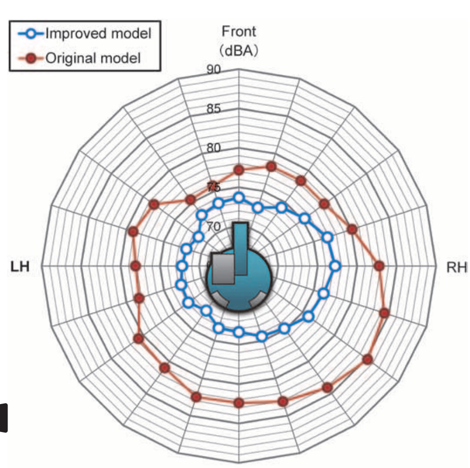


Fig. 3 iNDr+E: Mixing part of diffusion exhaust in exhaust duct



Movie

Fig. 4 Comparison of noise near mini excavator

As described above, the change from the conventional side exhaust to downward exhaust has enabled a significant reduction of noise in the proximal area of the excavator (1 m from the machine side, **Fig. 4**) and has resolved the issue of heat damage to plants, etc.

2. Evolution of iNDr for heavy equipment excavators

2.1 Challenges of iNDr for heavy equipment excavators

Since its launch in 2007, urban-type, general-purpose, heavy equipment excavators, each equipped with an iNDr, have gradually penetrated the market and gained recognition, while repeating minor changes and maintaining iNDr's extremely low noise performance and dustproof performance.

The 4th regulation of engine exhaust emissions, however, requires urea selective catalytic reduction (SCR) in addition to the conventional diesel particulate filter (DPF). The measures taken to comply with the 4th regulation of engine exhaust emissions and the layout of the post-processing apparatus are shown in **Fig. 5**. In the conventional iNDr, the exhaust side had a sound absorbing duct structure fitting the width of the machine body in the lateral direction (the left-to-right direction in Fig. 5) to secure the length and thereby to secure the noise reduction performance. The installation of urea SCR, however, has made it difficult to secure enough length even if a bending duct is constructed before the urea SCR.

In addition, securing the necessary exhaust opening area makes it difficult to maintain extremely low noise performance, because of the difficulty it causes in configuring the engine room such that no part of its interior can be seen from the exhaust opening. Furthermore, regarding the heat balance, the amount of heat generated in the engine body has been increased to comply with the engine emissions regulations, requiring an increase in the amount of cooling air.

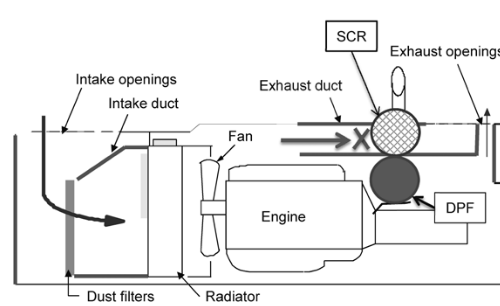


Fig. 5 Influence of SCR addition in heavy equipment excavator

Noise and heat balance are in a trade-off relationship, and the important challenge in this development has been to maintain both the cooling performance and heat balance while maintaining extremely low noise performance in a limited space.

2.2 Utilization of one-dimensional (1 D) design tool

In order to establish the heat balance performance, a sufficient amount of cooling air must be secured. The amount of cooling air can be determined from the capacity of the installed fan and ventilation resistance. The ventilation resistance of the complicated duct structure and the flow passage configuration in the engine room has so far been estimated by repeated verification using simplified bench tests and actual machine mockups based on the design review proposals, and a large amount of time has been spent in model-making for the experiment.

A 1-D design tool for predicting the amount of cooling air was developed and utilized to enable simple examination during the initial stage of the planning. For this tool, the excavator's engine room is first modeled as a piping flow passage connecting the intake opening to the exhaust opening (**Fig. 6**), and the resistances estimated from the resistance coefficients for typical pipeline types are summed up to obtain the ventilation resistance. Then the estimated resistance is matched with the performance diagram of the fan to finally estimate and calculate the air volume.

Fig. 7 shows the calculation results of the ventilation resistance predicted for an iNDr machine equipped with the new sound-absorbing exhaust duct. A complex flow passage configuration has been divided into simple models, and the calculation has been performed on the coupling of these simple models. As a result, a ventilation resistance equal to or less than that of the conventional model has been obtained with the prospect of securing the necessary air volume.

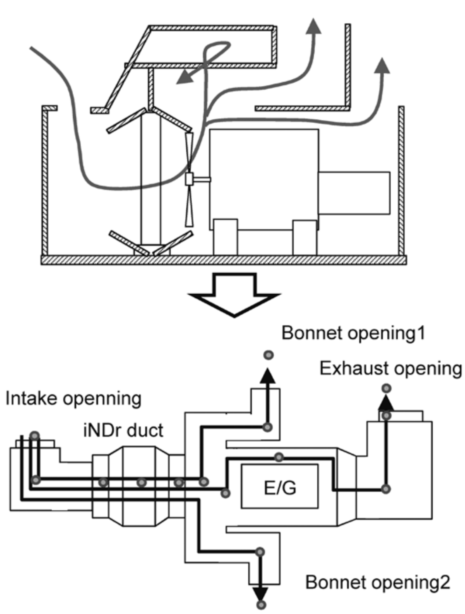


Fig. 6 Modeling of duct for cooling air passage in engine room of heavy equipment excavator

2.3 Installation of new sound-absorbing exhaust duct

In order to make use of the effect of the L-shaped duct conventionally adopted, a study was conducted using the 1-D design tool for a new sound-absorbing exhaust duct with a soundproof structure combining two L shaped ducts, each having an exhaust opening with an area half that of the required area. As a result, it has been revealed that a three-dimensionally crossing arrangement (upward and leftward) of the duct, instead of a unidirectional arrangement of the intake/discharge ports of the duct, realizes an L-shaped duct whose inside is not directly visible, being configured in a very narrow space. The configuration of the newly developed sound-absorbing exhaust duct is shown in **Fig. 8** along with the flow of exhaust cooling air.

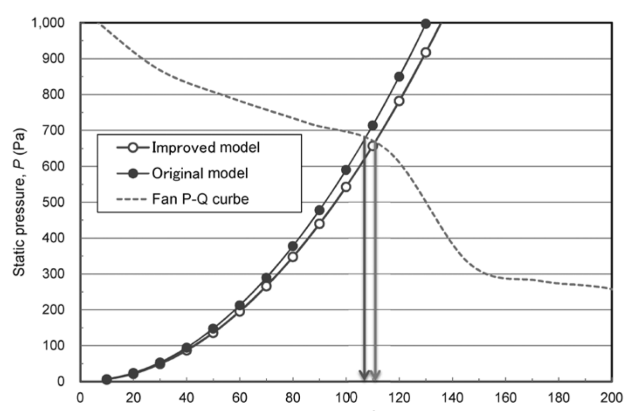


Fig. 7 Calculation results predicting ventilation resistance of conventional and improved excavator models

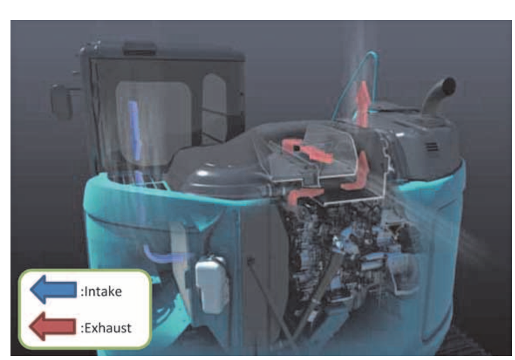


Fig. 8 Cooling air flow of "Cross Over duct" for heavy equipment excavators

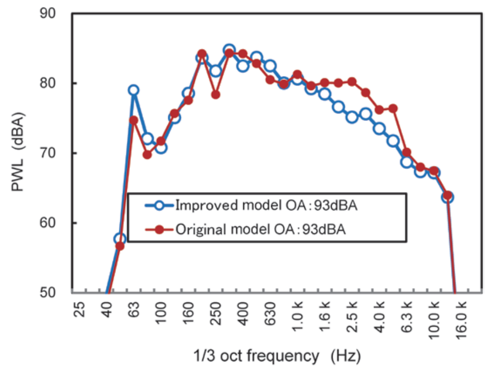


Fig. 9 Comparison of measured sound levels in conventional and in improved model heavy equipment excavators

Thus, the development of a "crossover duct," in which L-shaped ducts are three-dimensionally crossing, has made it possible to simultaneously secure the heat balance and extremely low noise performance, which was the challenge during development.

Fig. 9 compares the acoustic power levels (measured values) of the conventional machine and the new machine. This figure shows that the surrounding area noise of the new machine is 93 dBA, which is equivalent to the value for the conventional machine.

Conclusions

It has been recognized that low noise performance and heat balance are in a trade-off relationship and it is necessary to be constantly aware of and aim at both. This achievement, however, has become more difficult for each new development, and this trend is expected to continue in the future.

As a study tool for this issue, it will be necessary to enhance the 1-D design tool that takes advanced and detailed analysis technology trends into account to find trends with various review conditions in the early stages of designing.

It is also important to improve the work environment from the viewpoint of the labor supply, which is decreasing due to a low birthrate and longevity; and, to this end, the noise of hydraulic excavators must be further reduced in the future.

With regard to the noise in surrounding areas, it is envisaged that not only the noise from the main machine body, but also the noise, including impact sounds, emanating from various parts during actual operation, must be reduced in the future. Moreover, measures against noise in the cabs are required in addition to the measures against surrounding area noise. It is conceivable that, rather than simply reducing the noise level, it will become necessary to improve the sound quality in the driver's cab, making use of the sort of sound that is necessary for operating the machine and is less likely to fatigue the operators. Furthermore, lowering noise will contribute to safety aspects, in that communications in the surrounding area will be improved as the once inaudible sound (voice) becomes audible.

We will continue to develop extremely-low-noise-type hydraulic excavators to contribute to the improvement of the work environment and will strive to improve the technology to realize work sites that are more comfortable and safer.

References

1) H. Nakajima et al. *R&D Kobe Steel Engineering Report*. 2012, Vol.62, No.1, pp.27-31.
2) K. Ueda. *Journal of Japan Construction Mechanization Association, Construction Mechanization*. 2014, Vol.66, No.1, pp.20-23.