Technical Paper

Study of Full Electric Mini Excavator

Kazuhiro Kurihara

Hiroshi Naka

Yoshifumi Shitara

Hideshi Iitani

In the midst of activities toward carbon neutrality, we have created a concept machine of a full electric mini excavator with the image of a future urban construction machine.

This machine is eco-friendly because, unlike conventional machines, it is driven only by electricity without using a hydraulic system.

In addition, we aimed to create an attractive machine through teleoperation using devices that everyone is familiar with and through with a novel design.

Key Words: *Full electric mini excavator, Teleoperation, Electric cylinder*

1. Introduction

As global decarbonization efforts progress, mini excavators used in urban areas and other worksites that are close to *people* are required to reduce the environmental impact on the circumstances of the machine body. Thus, we launched a project for a *fully electrified mini excavator* that significantly reduces the impact on the environment by making greater use of *electrification* technology than before, and started the research.

In this project, we worked from January to June 2019 with the goal of verifying and extracting issues with the actual machine after producing a concept machine in a short period of time that combines existing technology in the world and newly developed technology. As for the concept vehicle, the vehicle classification has been decided as the vehicle size of the 3-ton class mini excavator, which has the most demand in the market. Based on Komatsu's battery-powered forklift and mini-excavator technology, it is equipped with new technology, including a lithium-ion battery and electric cylinder, and is fully electrified to achieve zero exhaust gas. In addition to being an environment-friendly machine with significant reductions in noise and waste heat, it has also been realized as a maintenance-free machine by improving energy efficiency and eliminating hydraulic components. By additionally adopting the non-boarding type, we proposed a non-conventional new form of machine body design and machine operations and controls.

With these features, we aimed to achieve safe and highly productive worksite work.

In recent years, the shortage of labor in the construction industry has also become a serious issue. We hope to present a new way of working in the operation site and play a part in resolving future issues through this machine.

Fig. 1 Full electric mini excavator

Table 1 Main specifications

Item		Unit	Specifications
Bucket capacity		m^3	0.09
Transport dimensions	Overall length	mm	4,750
	Overall width	mm	1,740
	Overall height	mm	1,685
Tail swing radius		mm	970
Number of motors installed			2 for travel, 1 for swing, and 4 for work equipment
Battery capacity		kWh	31.5

2. Aim of research

Electric excavators currently released on the market generally has an electric motor instead of the engine and use conventional hydraulic cylinders and hydraulic motors as actuators.

The full electric mini excavator uses an electric motor for all actuators; it emits no exhaust gas, generate little noise or waste heat, and do not use hydraulic oil, making it more eco-friendly. It is also quieter and more efficient because of not using hydraulic pressure.

Regarding machine operations and controls, by adopting non-boarding type teleoperation, work in closed and dangerous worksites (e.g., indoor demolition, disaster relief) is facilitated; it is a safe and stress-free machine for the operator, who can maneuver it away from the machine from a comfort zone.

In addition, the machine has become easy to make precise movements with high precision by electrifying and electronically controlling all actuators. This may facilitate future technological developments such as autonomy and unmanned operation.

3. Machine Configuration

3.1 Overview of system configuration

Electrifying the components and eliminating the cockpit has enabled this machine to significantly reduce the number of parts compared to conventional machines. In particular, the hydraulic hoses, which occupy a large space in conventional mini excavator structures have been eliminated, and the degree of freedom in arranging components has increased, resulting in a more compact machine body than engine vehicles despite the large-capacity storage battery installed.

In addition, it has adopted an air cooling system with an electric fan or the like. The machine is maintenance-free because it does not use hydraulic oil or refrigerant to cool the equipment, and at the same time, simplification has been enabled in terms of the system configuration. (**Fig. 2**)

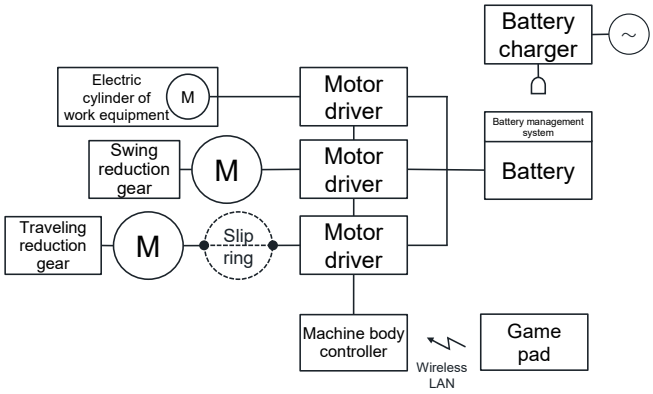

Fig. 2 Overview of system configuration

3.2 Machine configuration components

3.2.1 Electric cylinder

The most difficult thing for us to achieve full electrification was how to handle the structure of the work equipment. The full electric mini excavator uses a new electric cylinder developed by Komatsu instead of a hydraulic cylinder. (**Fig. 3**)

The four cylinders for the boom, arm, bucket, and swing are installed on the machine body to drive the work equipment, and the motor of an electric cylinder is installed on the work equipment or machine body in such a way that it can hardly be susceptible to external damage.

This cylinder consists of an electric motor for driving, a main body, which expands and retracts, and a reduction gear that connects them.

When these components were arranged in series, the overall length was longer than that of a hydraulic cylinder, making it difficult to be installed on the machine; therefore, we placed the motor and cylinder in parallel via the transfer case. In addition, a trunnion structure was adopted for the bottom support in order to install the cylinder compactly on the machine body.

Current hydraulic excavators have cylinders of different dimensions for each piece of work equipment. By contrast, this machine operates with one type of cylinder by regulating the stroke amount under control software.

Configuration details

- Electric motor: Uses an off-the-shelf servo motor.
- Reduction gear: Adopts a newly developed helical gear for new development and noise reduction.
  The bearing stress was set extremely low for grease lubrication (approx. 1/5 of oil immersion lubrication).
- Ball screw: Uses a custom manufactured product.
- Extension/retraction section: New development.

The outer cylinder is designed to be thin enough not to be dented by bouncing stones since it has no internal pressure; the inner one is designed to be thin enough to achieve straightness because it has a margin for buckling load in addition to having no internal pressure.

The electric cylinder developed in this project is a heavy actuator compared to the hydraulic cylinder. However, the torque that can be generated by the combination of the link and the electric cylinder is larger in torque per weight than that of the rotary actuator, and it is relatively light among electric actuators.

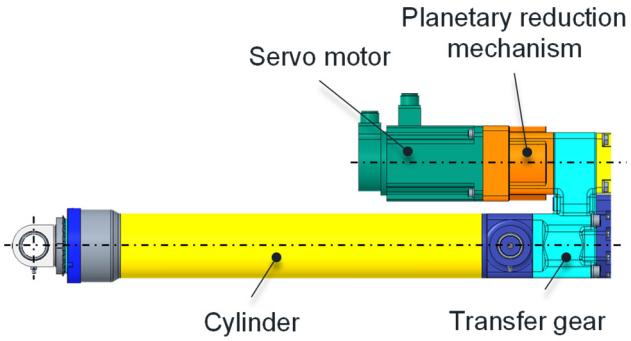

Fig. 3 Electric cylinder

3.2.2 Electric motor

This motor has been newly developed based on the sealed high-efficiency PM motor being used for electric forklifts. One on each of the left and right sides for traveling and one for turning are installed on the machine body. (**Fig. 4**)

The reduction gear has also been newly developed for each component position for the electric motors.

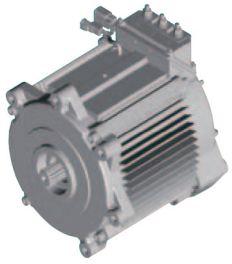

Fig. 4 Closed type high-efficiency PM motor

3.2.3 Battery and charger

A lithium-ion battery with high energy density and long cycle life has been newly developed. The cell is of highly safe iron phosphate type. (**Fig. 5**)

A battery management system (BMS) that monitors charge/discharge and battery status has also been newly developed and built into the battery pack.

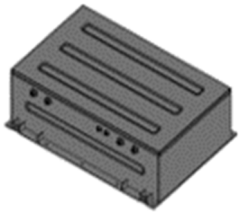

Fig. 5 Lithium-ion battery pack

The stationary fast charger can fully charge the battery in approx. two hours using a three-phase alternating current installed in plants and others as the primary power supply. (**Fig. 6**)

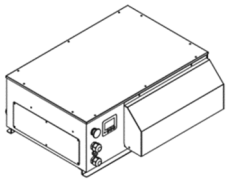

Fig. 6 Stationary fast charger

3.2.4 Slip ring

The slip ring is installed for power supply from the rotating upper structure to the motors and others of the undercarriage and for sensor signal communication. For hydraulic excavators, the slip ring moves the hydraulic oil back and forth with a swivel joint but has an alternative function for electric excavators.

Since a large amount of power needs to be supplied to the two travel motors installed on the undercarriage, a large-capacity and compact slip ring has been developed and installed.

4. Advantages of the Machine

We verified the concept and extracted the issues by actually producing the concept machine this time. For this purpose, we repeated various tests while incorporating improvements into them. (**Fig. 7**)

Although there remained some issues to be addressed for commercialization, we clarified many more advantages.

4.1 Machine operations and controls

The full electrification has greatly changed the operability of the machine.

Unlike hydraulic excavators, this machine does not need to warm up the hydraulic oil when starting up, and can immediately demonstrate sufficient performance in terms of travel speed and work equipment speed.

In addition, it can be easily tuned according to the operator and the work conditions because the speed and acceleration of the machine can be easily changed by changing the motor control parameters.

Despite the adoption of the non-boarding type and the teleoperation system, it can be operated in any working environment without the need to prepare any new facilities or environment, unlike conventional machines, thanks to the machine body controller and the machine's operating device connected by wireless LAN. The operating device can also be freely selected by the operator (e.g., game pad, tablet) for work; in addition, by proposing a new way of working without getting on the machine, it can contribute to reducing operator fatigue and improving productivity at the worksite.

In addition, a boarding type mini excavator must have a space for operator operation in a compact machine body, but there may not be enough space; however, the non-boarding type can solve such issues at the same time.

Fig. 7 A scene of the actual-machine test

4.2 Design and layout

By imagining a future construction machine and designing it as a non-boarding type machine, we succeeded in constructing an advanced design based on the design concept of an electric excavator while maximizing the impact of not having the operator's seat. (**Fig. 8**)

The design concept is a toughness consisting of the powerfulness and electric images fused.

The high degree of freedom in the layout of the electric components also contributes to the realization of this machine body design. With this silhouette, various additional advantages can also be expected (e.g., the low center of gravity of the machine body allows for stable and safe work; or since the overall height of the machine body is low, it does not interfere with the visibility of surrounding workers).

Fig. 8 Appearance design

4.3 System efficiency

The efficiency of every actuator is also significantly improved by driving it electrically, not hydraulically.

By electrifying all the actuators, we found that the hydraulic loss decreased and the system efficiency was improved from 30% to 57% (almost doubled) compared to conventional hydraulic mini excavators. (**Fig. 9**)

Another major feature is the ability to effectively use regenerative energy, that is, the power that is generated by the electric motors to charge the battery when the vehicle decelerates or lowers the work equipment.

With electric excavators, we hear a lot of concerns about up-time; however, these results show that a full electric excavator can achieve twice the up-time of a conventional hydraulic-electric hybrid excavator with the same battery capacity.

It will be an extremely eco-friendly machine that can achieve more work with less energy.

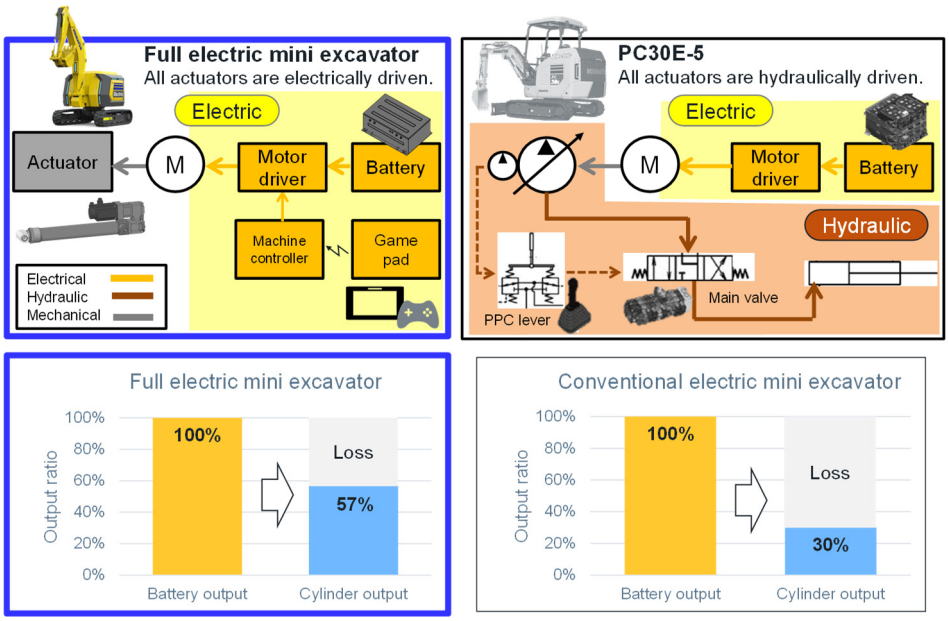

Fig. 9 Comparison of system efficiency with a conventional machine (during boom raising operation)

4.4 Noise

This machine also reduces its noise compared to conventional machines. (**Fig. 10**)

In addition to having no engine or hydraulic noise, the mechanical noise of the electric cylinder has been designed to minimize the noise through noise reduction technology.

Another feature is that, unlike hydraulic excavators, the engine and electric motor do not need to be pre-rotated during idling thanks to the superior response of the electric motor.

The noise reduction reduces construction noise in residential areas, etc., making operators, workers, and people around them stress-free.

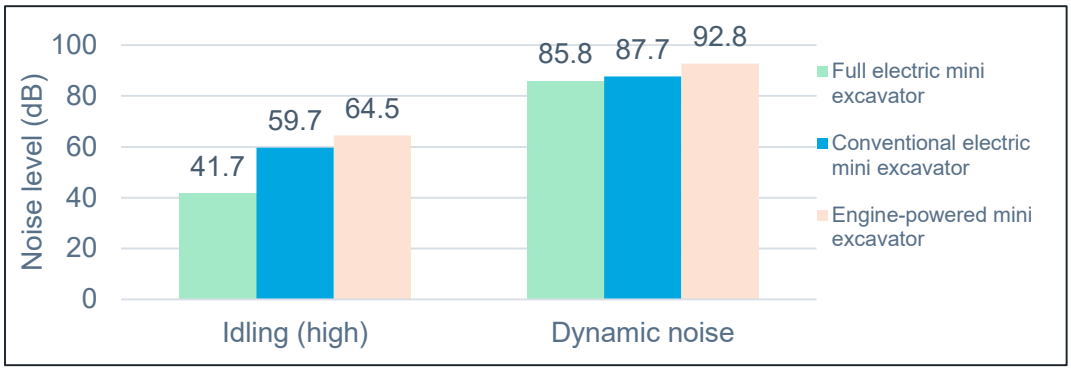

Fig. 10 Comparison of noise with conventional machines

5. Examples of Use at an Operation Site

This machine can be expected to be used in various operation sites by taking advantage of its features. It can be expected to be utilized at almost all sorts of sites, including demolition sites, indoor worksites, residential areas, and disaster recovery sites.

Fig. 11 An example of use at an indoor demolition site (CG)

Fig. 12 An example of use in a residential area (CG)

6. External Exhibition

Since the press release in May 2021, we have introduced this machine to the media, etc., and implemented operating exhibits at various locations in Japan and overseas. We have received a lot of feedback from many people.

At the 2022 German bauma Exhibition, we made an appeal as one of Komatsu's electrification efforts. (**Fig. 13**)

Fig. 13 Actual machine operation exhibition at bauma 2022

7. Conclusion

The production of this concept machine allowed us to verify the many advantages of full electrification and also clarified the issues; we are continuing our activities toward its commercialization.

With this full electric mini excavator, we would like to work together with our customers to achieve a safe, productive, smart, and clean worksite in the future.

Introduction of the authors

Kazuhiro Kurihara
Joined Komatsu Ltd. in 1995.
Vehicle Development Center 4,
Development Division

Hiroshi Naka
Joined Komatsu Ltd. in 2007.
Vehicle Development Center 4,
Development Division

Yoshifumi Shitara
Joined Komatsu Ltd. in 2008.
Vehicle Development Center 4,
Development Division

Hideshi Iitani
Joined Komatsu Ltd. in 1994.
Hydraulic Equipment Technical Center,
Development Division

[A comment from the authors]

We were able to achieve the activities herein with the cooperation of many people such as people of parts manufacturers and in-house people who agreed and cooperated and people who cooperated in PR activities, as well as the project members. We would like to express our gratitude to everyone involved in the activities.

We faced some difficulties during the project period but were encouraged by the children's smiles when they saw the actual machine at the exhibition.