

Core Technologies for Innovation in Industrial Machinery

Tomoji Watanabe
Kazuhiro Umekita
Masayuki Kaiho, Dr. Eng.

OVERVIEW: The industrial machinery sector supports Social Innovation Business and in doing so it needs to deal with issues such as environmental problems and the growing diversity of requirements resulting from market globalization. Hitachi is working on the development of innovative core technologies to accelerate the environmental performance and global suitability of its industrial machinery products. One example is analysis-based design that utilizes sophisticated numerical simulations. Use of numerical simulations in the early stages of design and development allows a thorough understanding of product behavior to be obtained and makes it possible to develop products quickly that satisfy requirements for performance, reliability, and economics.

INTRODUCTION

WITH the growing awareness of environmental problems such as global warming in recent years, the products produced by the industrial machinery sector are undergoing major changes driven by progress in globalization and technical innovation. To accelerate the environmental performance and global suitability of these products,

Hitachi is working on the development of innovative core technologies. One example is analysis-based design that utilizes sophisticated numerical simulations. Hitachi is also developing technologies to improve safety and comfort as well as technologies that reduce the burden on the environment in many different ways, not just by reducing CO₂ (carbon dioxide) emissions.

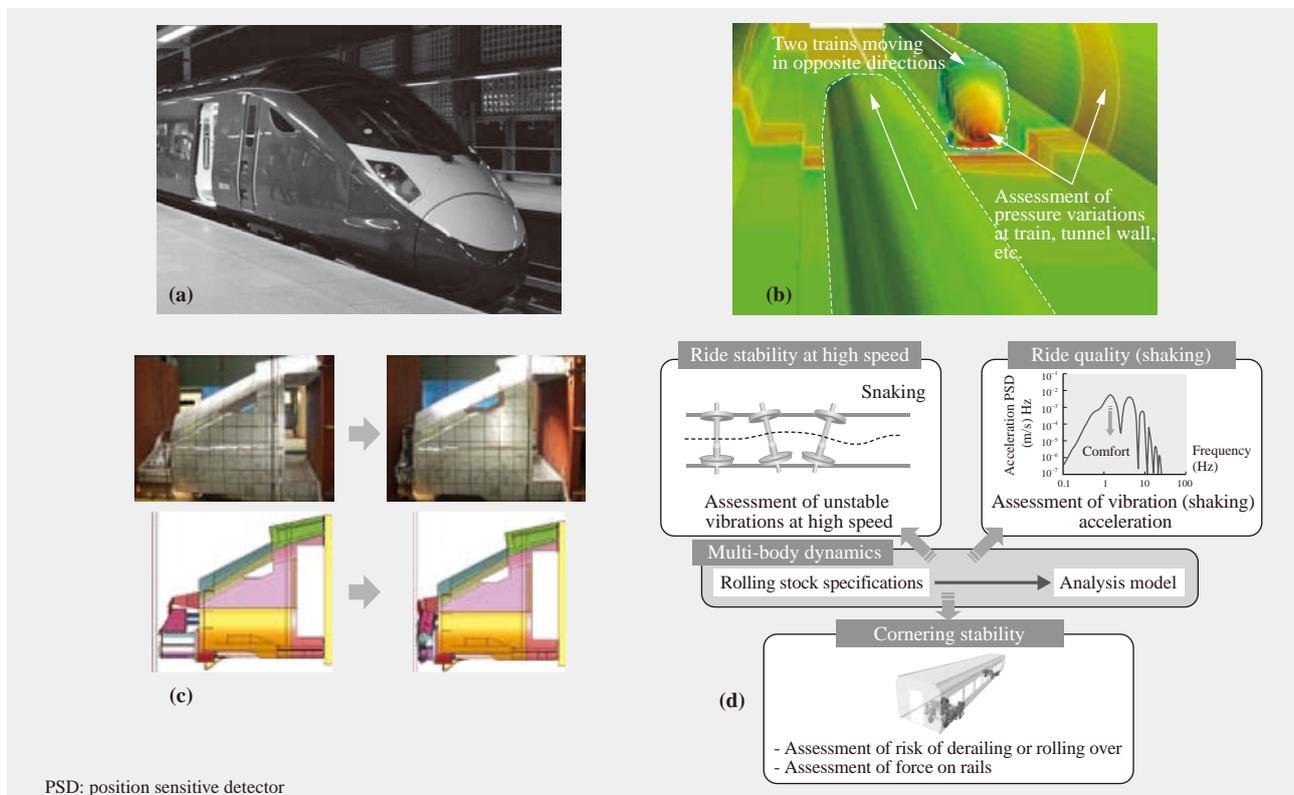


Fig. 1—Example Use of Numerical Simulation for Class 395 High-speed Train for UK Market.

A range of simulation techniques are used for the Class 395 including analysis of the variation in pressure inside and outside trains as they pass through tunnels (b), design of crashworthy structures for the front and rear ends of rolling stocks (c), and design of suspension systems able to provide both ride stability on high-speed lines and stable cornering around sharp curves on conventional lines (d).

This article looks at design case studies involving high-speed trains for the UK, mining dump trucks, and large industrial pumps; describes technologies for quiet operation and dynamic stability control on hydraulic excavators; and discusses microreactors, a new generation of chemical plants with a low impact on the environment.

ANALYSIS-BASED DESIGN TECHNIQUES

High-speed Trains

Hitachi has for some time been working on enhancing analysis techniques which it has used in the development of high-speed trains for the Japanese market. These analysis techniques cover many branches of mechanical and electrical engineering including dynamics, control, vibration and acoustics, structural strength, thermal fluids, and electromagnetic fields. The Class 395 trains that entered commercial service in the UK in December 2009 were the first Hitachi rolling stock to be designed specifically to meet European standards (see Fig. 1). Representative examples of the analysis techniques used include a simulation of the fluid dynamics (pressure fluctuations) of a train passing through a tunnel, crash simulation of crashworthy structures taking account of the non-linear deformation characteristics of aluminum, and simulation of railcar dynamics taking account of track conditions in the UK⁽¹⁾.

Mining Dump Trucks

Hitachi Construction Machinery Co., Ltd. has an active program aimed at producing a series of electrically powered dump trucks for use in mining. In recent years there have been strong demands to improve the ride stability of these electric dump trucks to cope with higher carrying capacities and to improve ride comfort to reduce driver fatigue. To meet these needs, Hitachi is working to develop techniques that can accurately predict how the dump trucks will handle in the wide variety of different conditions in which they are used and make it possible to produce optimum designs for sub-systems such as suspension and driving control without the need for prototyping⁽²⁾ (see Fig. 2).

The dump truck suspension is fitted with struts filled with gas and oil which achieve the desired springiness and damping by the expansion and contraction of this gas and oil and by the resistance to hydraulic fluid passing through an orifice [see Fig. 2 (b) and (c)]. The simulation of dump truck operation consists of two steps. The first models the gas and hydraulic fluid in the struts and the second uses the

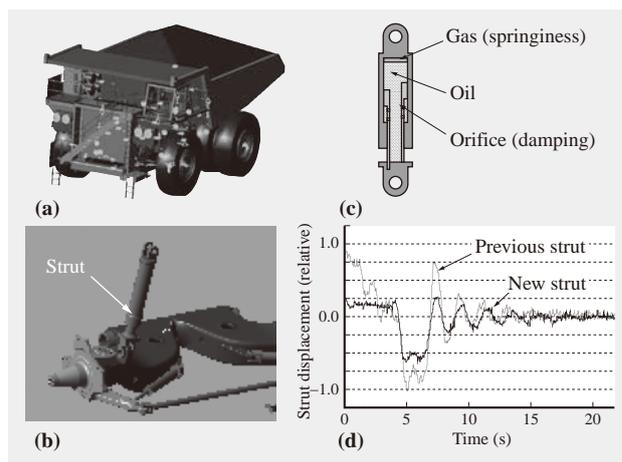


Fig. 2—Example Use of Numerical Simulation for Mining Dump Truck.

Analysis model for entire dump truck (a), analysis model for suspension (b), internal structure of strut (c), and strut displacement during sudden braking to a halt from 12 km/h (d).

strut characteristics obtained from this modeling to perform a mechanical analysis of the entire truck. A new strut design optimizes the quantity of hydraulic fluid and the orifice diameter and succeeded in reducing the level of vibration in the vehicle by about 50% compared to previous models [see Fig. 2 (d)]. In November 2010, Hitachi Construction Machinery released a new dump truck called the EH4000AC II that uses this new strut. Its 220-t capacity places it among the largest dump trucks made in Japan⁽³⁾.

Large Industrial Pumps

Hitachi Plant Technologies, Ltd. is an international supplier of advanced products designed to reduce the burden on the environment⁽⁴⁾.

One of these products is a semi-axial flow pump fabricated from sheet steel including the impeller that is made from welded steel plate [see Fig. 3 (a)]. Switching from a cast impeller to one made by welding steel plate lightens the weight significantly while also reducing the amount of CO₂ emitted during production. Key aspects of the impeller development included the creation of a new method for impeller shape design, the use of proprietary production techniques to achieve an efficiency equal to or better than that of a cast impeller, and the use of coupled analysis of the fluid flow and structure to ensure the reliability of the welds. In dealing with these issues, a high level of performance and reliability was achieved through the use of analysis software originally developed within Hitachi, including cavitation analysis and unsteady flow analysis techniques [see Fig. 3 (b) and (c)].

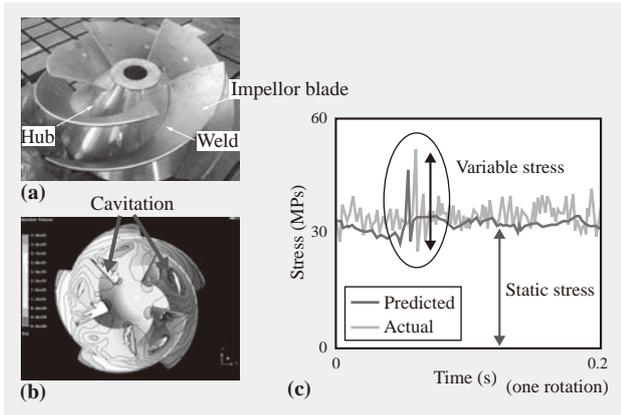


Fig. 3—Example Use of Numerical Simulation for Large Industrial Pump. Photograph of open impellor with welded structure (a), analysis of flow associated with cavitation (b), and comparison of predicted and actual measurements for fluctuation in stress due to cavitation at impellor (c).

TECHNOLOGIES TO REDUCE IMPACT ON ENVIRONMENT AND IMPROVE SAFETY AND COMFORT

Hydraulic Excavators

Environmental requirements such as safety, quieter operation, and restrictions on exhaust emissions have become more stringent in recent years. The ZX-3 Series excavators released by Hitachi Construction Machinery in 2006 not only comply with the tier 3 exhaust emission standards, they also feature a new-generation “clean and

powerful” fuel-efficient engine. Also, improvements to the hydraulic systems provide faster operation. Hitachi Construction Machinery is now working on technical developments aimed at further improving environmental performance and energy efficiency in preparation for the next series of models to go on sale.

One such development is the use of TPA (transfer path analysis) to reduce the noise level in the driver’s cab. Compared to the direct propagation of noise from the hydraulic excavator’s engine and exhaust system through the air to the driver’s cab, the level of noise that originates as vibrations caused by hydraulic pulsations and reaches the cab via the frame is relatively high. To obtain an accurate assessment of this vibration propagation, the TPA method (which is also being used to analyze noise in automobiles) was utilized to develop a new vibration propagation model suitable for a hydraulic excavator (see Fig. 4).

It was confirmed that the overall sound level obtained by TPA using this model agreed with actual measurements with an accuracy of 1 dB [see Fig. 4 (c)]. It was also identified that a characteristic sound peak at 210 Hz caused by hydraulic pulsations was mainly propagating via a clamp located between the hydraulic pump and control valve [see Fig. 4 (d)]. The noise level was then successfully reduced by making improvements based on these findings, including to the control valve mount and hose clamp.

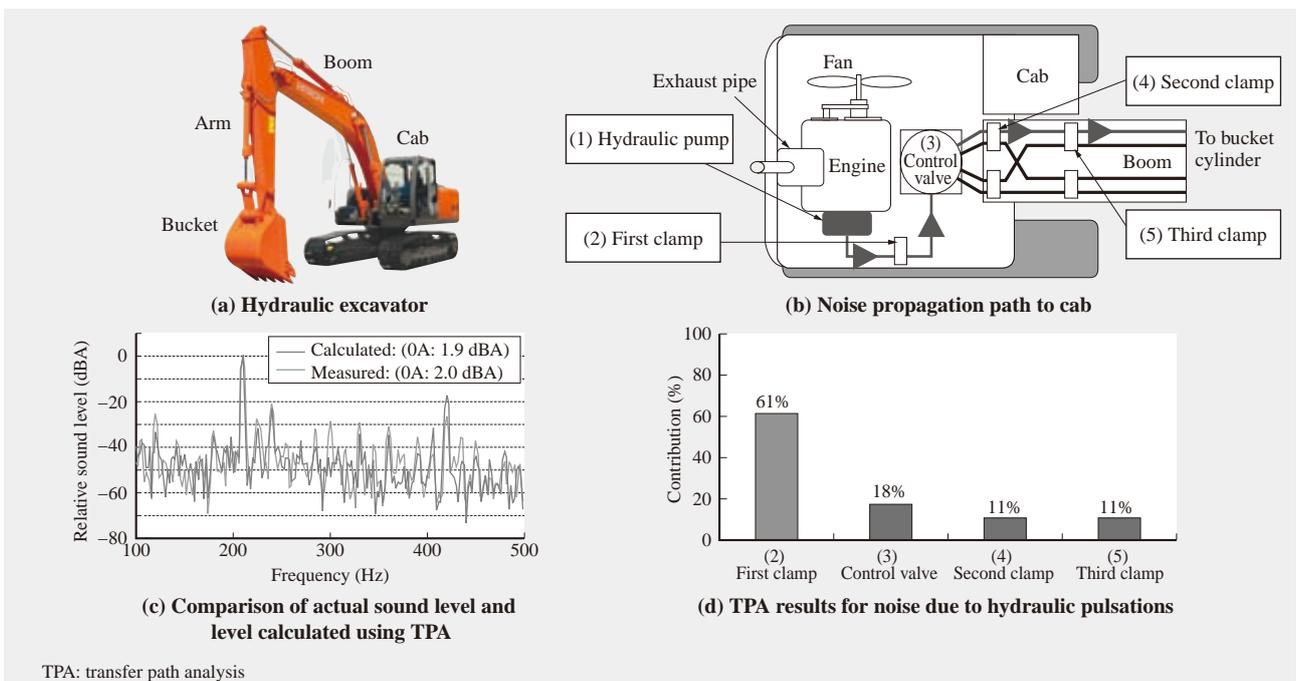


Fig. 4—Use of TPA to Achieve Quiet Operation of Hydraulic Excavators. The TPA technique which has been used for noise analysis in automobiles was applied to a hydraulic excavator.

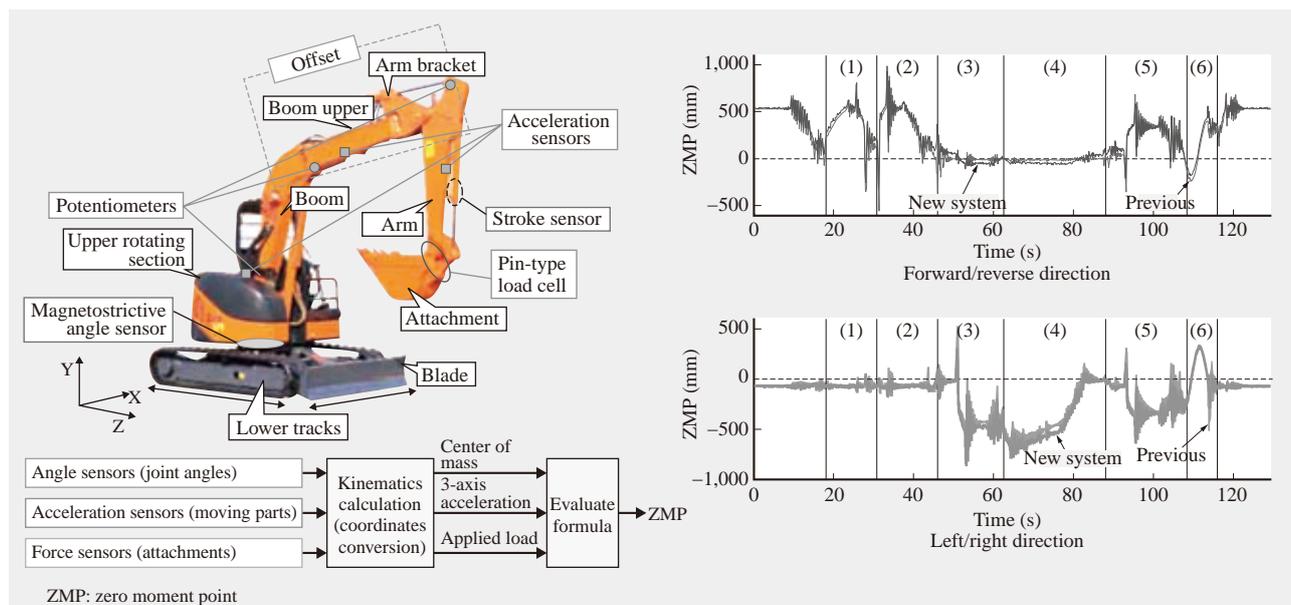


Fig. 5—Newly Developed Dynamic Stability (ZMP) Measurement System. The ZMP indicates the dynamic stability of a system. The hydraulic excavator was modeled as a system of six masses (drive unit, rotating section, boom, arm, attachment, and blade) and the ZMP calculated based on measurement-derived values for the center of mass, acceleration, and external forces applied to each mass.

Hitachi Construction Machinery is also working on use of a dynamic stability measurement system (see Fig. 5) to improve the stability, productivity, and other aspects of hydraulic excavator performance. Hydraulic excavators need to make large movements nimbly and it is important that the large inertia associated with these movements be included in measurements

of dynamic stability. The newly developed dynamic stability measurement system can calculate the ZMP (zero moment point)* for the excavator in realtime based on factors including the position, acceleration,

* Defined as “the point of contact with the ground where the moments due to gravity, inertia, and external forces sum to zero,” this term is widely used in the evaluation of stability for systems such as bipedal robots.

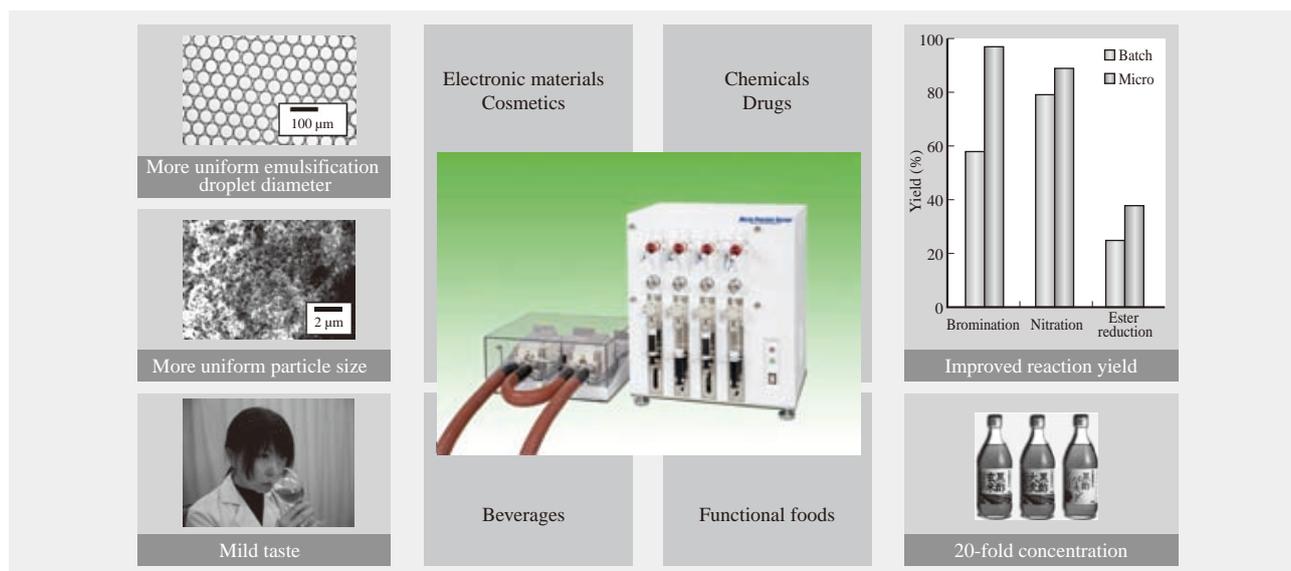


Fig. 6—Laboratory Microreactor, Processes to which it is Suited, and Benefits of Use. The microreactor can be used for processes such as fluid-phase reactions, production of microparticles, and emulsification. For fluid-phase reactions, the benefits demonstrated by the technology include superior reaction yield from bromination, nitration, and ester reduction reactions. For emulsification and nanoparticle production processes, the benefits include more uniform nanoparticle size and droplet diameter for the emulsified liquid.

and external forces applied to each part. The movements of the excavator are controlled based on the result of this calculation to improve stability and ease of operation. Fig. 5 (b) shows an example of the measurement results. Throughout all the movements, the measured values for both the forward/reverse and left/right directions show good agreement with the reference values measured using the previous method. The measurement error is 60 mm or less under static conditions with a peak of 95 mm or less which is small enough relative to the $\pm 1,000$ mm range of variation in the ZMP. In this way, the new system can accurately identify dynamic instabilities that could not be ascertained using the previous static stability estimation method. Hitachi Construction Machinery plans further work including integrating the new method into the control system with the aim of commercializing it in future excavators.

Microreactors

New systems that only impose a small burden on the environment are also required in the field of chemical plants. Microreactors are systems for producing drugs, fine chemicals, cosmetics, functional foods, and other chemical products by mixing feedstocks rapidly and uniformly in narrow flow paths similar in size to a strand of hair. This achieves dramatically better productivity (speed, yield, and quality) than large agitator tank reactors. Microreactors also provide production volume flexibility, being easy to scale up by adding additional units (operating reactors in parallel)⁽⁵⁾.

Fig. 6 shows a laboratory microreactor produced by Hitachi Plant Technologies, Ltd. and its benefits when used for typical processes. Hitachi Plant Technologies also provides comprehensive services including the design and production of microreactors for a range of different chemical processes, use of simulation for process optimization, and microreactor-based plants suitable for mass production.

CONCLUSIONS

This article has looked at design case studies involving high-speed trains for the UK, mining dump trucks, and large industrial pumps; described technologies for quiet operation and dynamic stability control on hydraulic excavators; and discussed microreactors, a new generation of chemical plants with a low impact on the environment.

Production machinery is an important product category for Hitachi because of its contribution to the expansion and development of the Social Innovation

Business. The technologies described in this article achieve innovation in social infrastructure in the global market by improving the performance, reliability, and economics of these products. Hitachi intends to continue developing innovative technologies and working toward objectives like productivity improvement and reducing the burden on the environment.

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ABOUT THE AUTHORS



Tomoji Watanabe

Joined Hitachi, Ltd. in 1984, and now works at the Mechanical Engineering Research Center, Hitachi Research Laboratory. He is currently engaged in the planning of mechanical research and development. Mr. Watanabe is a member of The Japan Society of Mechanical Engineers (JSME) and The Society of Instrument and Control Engineers.



Kazuhiro Umekita

Joined Hitachi, Ltd. in 1987, and now works at the Transport Systems Research Department, Mechanical Engineering Research Center, Hitachi Research Laboratory. He is currently engaged in the research and development of transport systems. Mr. Umekita is a member of the JSME and The Robotics Society of Japan.



Masayuki Kaiho, Dr. Eng.

Joined Hitachi, Ltd. in 1986, and now works at the 1st Department, Mechanical Engineering Research Center, Hitachi Research Laboratory. He is currently engaged in research and development of thermo-fluid products. Dr. Kaiho is a member of the JSME, The Japan Society for Industrial and Applied Mathematics, and The Visualization Society of Japan.