Unique Machines Using Rolling Mill Technology

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Many advanced technologies have been developed and used in the engineering of rolling mills and rolling mill facilities. To produce steel products, mill lines must be controlled by hydraulic systems that operate with micron accuracy and at high speed and under a rolling force of several thousand tons. The rolling mill engineering technologies applied to unique machines are described herein, including a G2000 shock-test machine used for underwater explosion impact testing and a high-speed feeding system using parallel link motion system for transfer press lines for car bodies.

1. Introduction

Many advanced technologies are required in order to design and manufacture rolling mills and rolling mill facilities. Modern rolling mills produce strips with micron accuracy achieved by the use of motors that employ reduction gears and by the hydraulic control of rolling loads of several thousand tons. It is common for a single rolling mill to contain hundreds of thousands of components and have a total weight of over 1 000 tons. The entire rolling line has various kinds of machines, such as a sizing press that reduces the width of red-hot slabs continuously 50 times per minute under a 2 500 ton force, a coil box that coils red-hot strips with a thickness of 80 mm, a high-speed shearing machine that cuts strips flowing at 1 000 m/min. with no loss of speed, and a down coiler that coils the strips at the same speed.

Designing such rolling mills and rolling mill facilities requires not only general machine element technologies but also gear, hydraulic, electric control and many other technologies. Manufacturing also requires technologies in order to handle components of over 100 tons, and for assembly and installation involving complex movements of many components to run as scheduled.

This paper introduces unique machines commercialized by utilizing various Rolling Mills technologies; the G2000 shock-test machines and the high-speed feeding system for transfer press lines for car bodies.

2. Supportive technologies for rolling mills

Rolling mills and rolling mill facilities, particularly steel manufacturing facilities, are huge industrial machines working in harsh environments to roll products under high loads, at high temperatures and at high speeds. We design mills and facilities by using not only general machine design technologies, but also various kinds of know-how backed by many achievements, such as measures to address vibration, corrosion and heat.

In addition, customers using these rolling mill facilities have various kinds of maintenance techniques and equipment technologies. When we receive an order, we supply facilities specifically designed for the customer making full use of our abundant experience.

Although rolling mills and rolling mill facilities are traditional equipment, a great deal of collaboration is involved in the creation of new designs as we must combine our technologies, with our customers' technologies, introduce new technologies, and share ideas. Because of the huge size of the products, we need to design facilities considering not only their functional specifications but also various conditions, such as the processing and assembling of components, construction, transportation, maintenance and the environment. Therefore, we determine the design after thoroughly examining details, including part drawings of each component. Under such circumstances, it can be said that we develop a new product each time we manufacture a rolling mill.

The supportive technologies for rolling mills are considered to be comprehensive design and manufacturing technologies that have both know-how backed by tradition and the flexibility to change the design to mold the products in response to new technologies and situations. These technologies can be applied not only to rolling mills but also to various kinds of special machines, particularly the heavy, long and large machines that have many moving parts and that are to be used in harsh environments.

The Rolling Mills Department has received recognition for these features and has participated in the commercialization of various kinds of machines both inside and outside the company. From out of the products commercialized in this way, two models are introduced in this paper.

3. G2000 shock-test machine

The G2000 shock-test machine was delivered to the Japanese Defense Agency (currently the Japanese Ministry of Defense) in 2001 as a test machine to simulate underwater-bomb impacts to defense ships (**Fig. 1**). Conducting actual explosion tests on heavy equipment is very expensive. The Defense Agency had relied on computational simulations until then and it asked us to develop a machine to mechanically conduct these impact tests.

3.1 Machine specifications

The capacity of a shock-test machine is generally evaluated based on the impact acceleration applied to a test object and the maximum test object weight. The G2000 shock-test machine is one of the world's largest test machines and has the following main specifications:

Maximum test object weight :	4 000 kg
Maximum impact acceleration :	19 600 m/s2 (2 000 G)
Duration of impact :	Approx. 1 ms
Total machine weight :	Approx. 200 000 kg (200 t)

To realize this machine, we worked on designing and manufacturing it with the concerted effort of the Equipment Engineering Department, the Corporate Research and Development, the Rolling Mills Department, the Yokohama No.2 Works and other divisions. The Rolling Mills Department was responsible for the detailed design and manufacturing after the basic concept had been determined and the basic calculations had been completed.

3.2 Basic structure of the shock-test machine

Figure 2 shows an outline of the G2000 shock-test machine.

The basic movements that generate the impact acceleration are given below (**Fig. 3**).

①A test object is fixed on the table. The hydraulic

Fig. 1 Underwater-bomb impact to defense ships

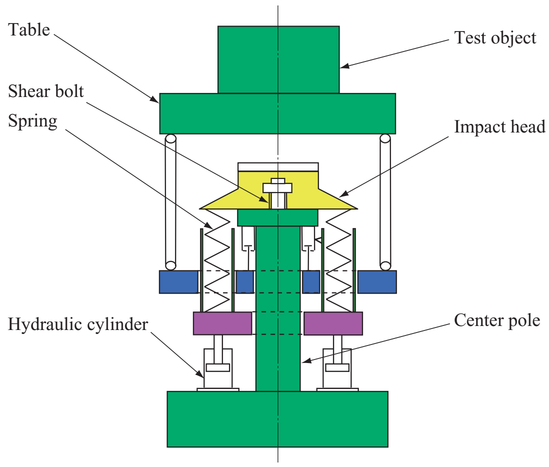

Fig. 2 Outline of G2000 shock-test machine

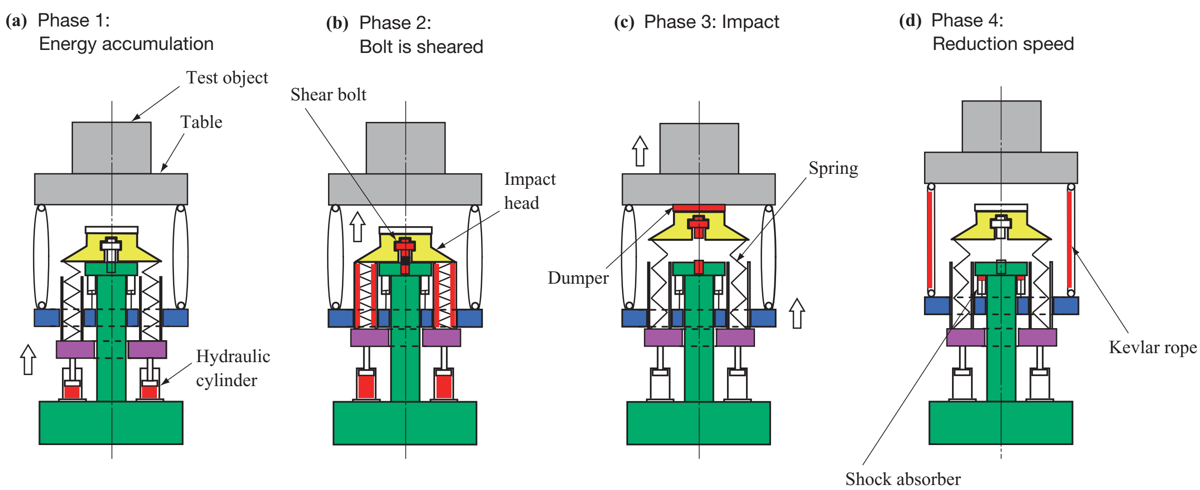

Fig. 3 Mechanism of shock-test machine

cylinder compresses the spring mounted between the center pole and the impact head fixed to the center pole by the shear bolt.

②When the spring compression force exceeds the yield stress of the shear bolt, the bolt is sheared and launches the head.

③The impact head collides with the lower surface of the table and gives an impact force to the table. This impact force is characteristic of the dumper mounted on the upper surface of the impact head, and generates a certain impact waveform.

④After the collision, the speed of the launching table is reduced with a shock absorber via a Kevlar rope, completing the test.

3.3 Technical issues in realizing the test machine

This machine realizes an impact force much larger than the energy generated by a car collision. To develop a mechanism that accumulates such a massive amount of energy in springs and release it , we had to overcome various technical issues.

First, the table on which the test object is loaded must be lightweight and strong to order to achieve an acceleration of 2 000 G. So we adopted a high strength steel plate welded structure. The table receives an excessive force when the head impacts with it. To ensure the soundness of the equipment under such harsh usage conditions, analysis was carried out by the Structure Research Department of the Corporate Research and Development, the welding was examined by the Production Engineering and Development Department of the Production Engineering Center, and the actual welding was conducted by the Aichi Works, a factory that has advanced knowledge regarding the welding of thick plates with shield machines and other equipment. The Rolling Mills Department was in charge of designing the machine so as to achieve a good balance between the specifications required from the analysis and examination results and the actual groove processing and welding. It was very difficult to achieve a design that satisfied both the analyzers who wanted to modify the steel structure as much as possible to reduce the stress and the builders who worried about the difficulty of welding a structure that was too complicated.

To release the energy accumulated in the spring, the shear bolt is required to break in an instant by brittle-fracture with little elongation so as to ensure instantaneous operation. For this reason, we needed to sharpen the notch shape in the fracture part, but there is a limit to the shapes of notches that can be actually processed. In addition, we had to use a bolt as large as M240 to accumulate the vast amount of energy in order to generate 2 000 G in the bolt. However, in order to realize such a bolt, there were many concerns with regard to processing and assembling, as well as to its replacement after being fractured. The Rolling Mills Department prepared a special thread gauge, and proposed and fabricated a special jig for replacing the shear bolt. **Figure 4** shows how the shear bolt is assembled using this jig. The jig is designed to enable both the setting of the shear bolt and the removal of the broken part of the bolt after fracture. It is equipped with a fall-prevention stopper to ensure safety when hoisting the heavy bolt. The shear bolt is a single-use part to be replaced after each test, and ease of replacement was an important issue regarding the operation of the shock-test machine. This jig has enabled safe and smooth changing of shear bolts. **Figure 5** shows the shear bolt removed from this machine after a test.

We also conducted experiments to examine the

Fig. 4 Assembling status of sheared bolt

Fig. 5 Sheared bolt after testing

custom-ordered springs and shock absorbers, the Kevlar rope used for speed reduction, the bushings that slide at high speed and other purchased items, and then reflected the results in the detailed design in each case.

We will never forget that the skills of the rolling-mill-related manufacturing departments contributed greatly to the completion of this large-scale, complicated test machine. The Yokohama No.2 Works was in charge of the final assembly and the comprehensive test run. They finished processing and assembling on schedule with no problems even though they had never manufactured such a machine before. The Construction Department installed 200 tons of components that had been disassembled for transportation on schedule and within one month. These skills realized a high level of construction with no delays, even at the site of the Japanese Defense Agency (currently the Japanese Ministry of Defense), a special environment that differs from ordinary construction sites.

3.4 The G2000 shock-test machine currently

After five years of operation, the G2000 shock-test machine is still working smoothly. In October 2000, it was adopted in the Defense Agency's specification "NDS C 0110E 3.21 high-impact (underwater-bomb impact) testing" as a high-impact testing standard.

I believe that the technologies for stably operating this huge machine under very powerful impacts and vibrations were achieved thanks to revolutionary ideas that were supported by the Rolling Mills Department's know-how regarding design and manufacture. The designing of this unique machine required coordination among many departments and manufacturers. Their opinions were reflected in the design, which was adjusted flexibly in accordance with the situation. I believe this owes much to the Rolling Mills Department's strengths in indent products.

4. High-speed feeding system for transfer press lines for car bodies

High productivity is required from the pressing machines that mold the hoods, door panels and other car body parts. Rough processing, deep drawing, punching, finishing and various other pressing processes are required in order to mold flat steel plates into car body panels with beautiful curves. **Figure 6** shows the pressing processes. Generally, a line is composed of several pressing machines arranged for sequentially pressing. To improve productivity, various machines have been developed, such as a transfer press that integrates this line configuration into one unit.

Today, there are diverse car models and this requires processing of various components on a single line, rather than the mass production of a single component. In this situation, general-purpose tandem press lines have become dominant over transfer presses. This caused a problem in the transfer of workpieces between pressing machines. There were requests for machines to be developed that could transfer the workpieces stably and at a high speed while being compatible with various components.

4.1 Transfer of workpieces in press lines for car bodies

Automation by machines and equipment is important to transfer workpieces between pressing machines safely and stably on a tandem press line with several pressing machines arranged. General-purpose multi-joint robots are generally used to transfer workpieces via vacuum cups for automatic transfer. To handle the workpieces pressed into various shapes, it is necessary to provide grasping tools that are suitable for each workpiece shape and a tool track to create the transfer motion. **Figure 7** shows the transfer motion.

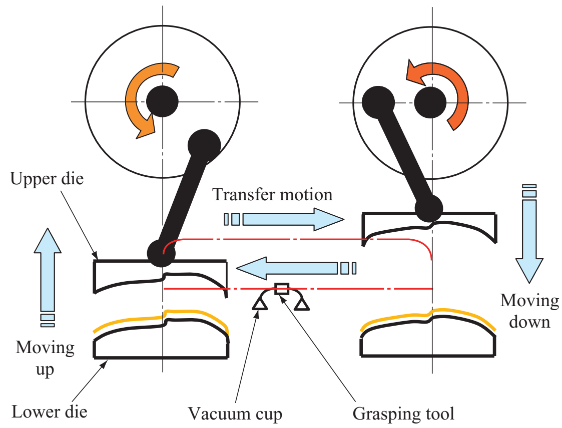

Fig. 7 Transfer motion

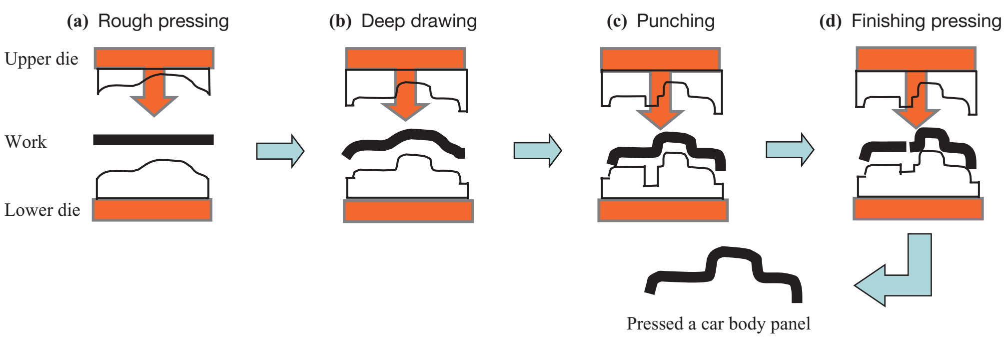

Fig. 6 Pressing process

If this automatic transfer system malfunctions and interferes with the dies, the system may break down and valuable dies may also get damaged. To prevent such a problem, conventional transfer presses use the cam and link mechanism as shown in **Fig. 8** to interlock the movements of transfer systems and dies to prevent interference.

On the other hand, on a press line using multi-joint robots, a robot removes a workpiece after confirming that the upstream process has been completed, and the next pressing machine starts operating after confirming that the workpiece has been set in the downstream process. This reduces productivity. What is more, multi-joint robots are designed for multiple purposes. Large robots must be used to transfer large workpieces, and this makes moving parts heavier and restricts transfer speed. As a substitute for these conventional devices, transfer robots specifically designed for transferring workpieces on press lines have recently received attention. These are the high-speed feeding systems.

4.2 Development of the high-speed feeding system

To transfer car body panels fast and stably, we developed a panel transfer system using a parallel link mechanism. **Figure 9** shows an outline of the system, and **Fig. 10** compares it with a conventional AC servo transfer system.

The parallel link mechanism has actuators that directly connect the end effectors to be controlled with the base. When compared with the serial link mechanism typically employed in multi-joint robots, this mechanism has lighter moving parts and can create faster and more rigid motion systems.

The AC servo transfer system is a high-speed transfer system installed on a transfer press to achieve arbitrary transfer motions by adopting a servomechanism instead of a conventional cam mechanism. However, like the conventional transfer mechanism, it has a servo motor in place of the cam. This results in large moving parts and restricts transfer speed.

In comparison, the newly developed parallel link transfer system has a lightweight and compact design, without having any actuators fitted in its moving parts. Utilizing the characteristics of the parallel link mechanism, this system can average out errors in and play of actuators at workpieces, and it is more rigid than

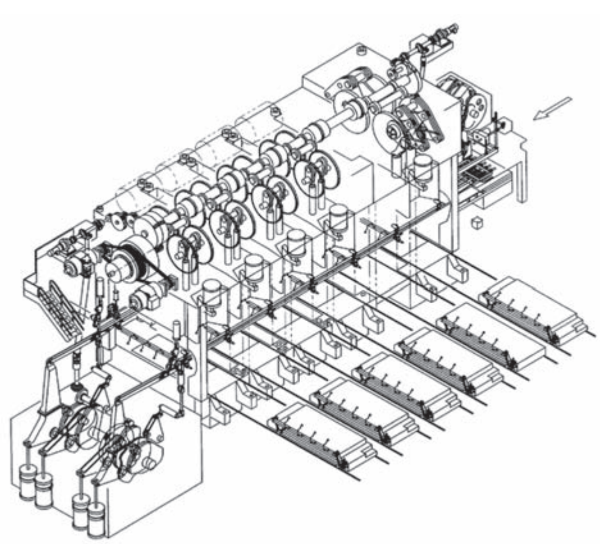

Fig. 8 Feeding system of the transfer press

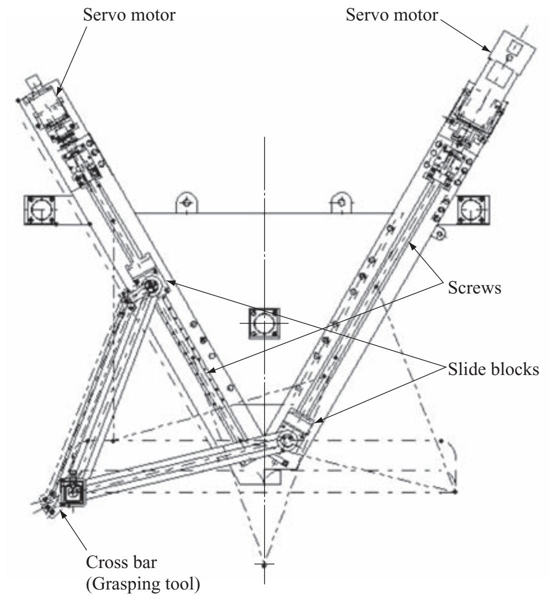

Fig. 9 Outline of high speed feeding system

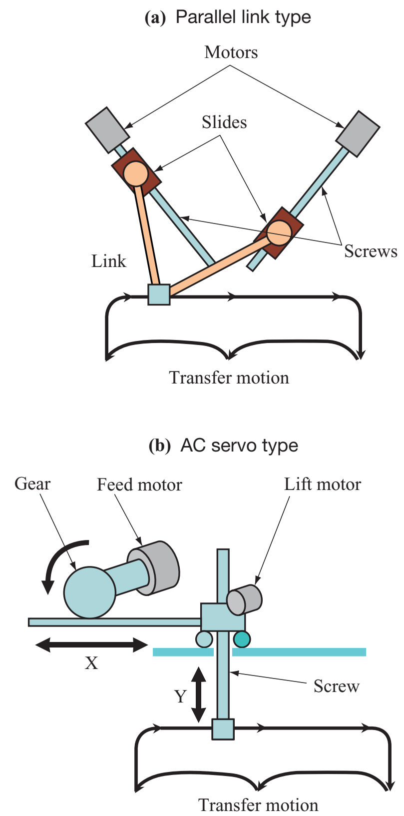

Fig. 10 Feature of feeding system

Fig. 11 High-speed feeding test machine

multi-joint robots.

4.3 Commercialization

When we were developing an idea to adopt the parallel link mechanism for transfer of workpieces for car bodies, we predicted many advantages. However, there were many possible link configurations, and designing the transfer system for commercialization involved repeated trial and error.

For example, when we were determining a transfer distance in designing a new press line, we were caught in a dilemma: between the demand to reduce the distance between pressing machines in order to have transfer efficiency and the demand to provide a certain amount of space available for maintenance of the pressing machines. We considered repeatedly transfer distances that would satisfy both demands and the configuration of the feeding system to be installed within the space. We also developed and examined many parallel link mechanisms: for example by arranging actuators in parallel and devising a transfer method over a longer distance.

As a result, we adopted a structure with actuators arranged in a V shape as shown in **Fig. 9**. The high-speed feeding system test machine is shown in **Fig. 11**. By testing a transfer motion equivalent to that of the actual machine by using this test machine, we succeeded in realizing a transfer speed of 20 SPM (the number of sheets transferred per minute). From the design aspect, we also succeeded in reducing the weight of moving parts by 40%. Tandem press line system 1, where this feeding system is used, has already started operation.

5. Conclusion

This paper has introduced the G2000 shock-test machine and the high-speed feeding system for car bodies that were realized by utilizing our rolling mill and rolling mill facility design and production technologies.

The Rolling Mills Department is now developing various kinds of technologies. This is because rolling mills and rolling mill facilities are an aggregate of all machine technologies. From among them, we are world-leaders in the commercialization of strip casters, continuous hot rolling facilities and other machines.

We will seek further advances, based on traditional rolling mill technologies, to realize products that enable our customers to actualize their goals.